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ЖУРНАЛ ВКЛЮЧЕН В РОССИЙСКИЙ ИНДЕКС НАУЧНОГО ЦИТИРОВАНИЯ

Эндодонтия Today – это научный рецензируемый журнал, включенный в Перечень ВАК рецензируемых научных изданий, в которых должны быть опубликованы основные результаты диссертаций на соискание ученой степени кандидата наук, на соискание ученой степени доктора наук, в соответствии с требованиями приказа Минобрнауки России. Журнал является информационным партнером Стоматологической Ассоциации России.
Журнал Эндодонтия Today является журналом с открытым доступом, что позволяет научному сообществу и широкой общественности получать неограниченный, свободный и немедленный доступ к статьям и свободно использовать контент. В журнале публикуются статьи практикующих врачей-стоматологов и научных сотрудников, подготовленные по материалам оригинальных научных исследований, обзоров научной литературы и клинических случаев в области терапевтической стоматологии и хирургической эндодонтической стоматологии, а также работы смежных стоматологических специальностей. Научная концепция журнала позволяет как врачам-стоматологам, так и врачам общих профилей узнавать о овых и передовых концепциях в лечении корневых каналов и последних достижениях в области эндодонтии.

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Original Research

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Features of pathological mechanisms of tooth damage in workers of chemical industries

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Abstract

INTRODUCTION. Under conditions of increasing exposure to chemical factors that predispose individuals to the development of pathology, the processes of hard-tooth-tissue destruction undergo modification not only in terms of their kinetics but also through the direct incorporation of exogenous chemical agents. These circumstances inevitably affect the macro- and microelement composition of enamel, as well as dentin and cementum in cases of disease progression. Obtaining reliable information on elemental composition is crucial for choosing appropriate treatment strategies and substantiating preventive measures.

AIM. To perform X-ray fluorescence analysis of teeth from employees of chemical enterprises, assessing qualitative and quantitative changes in elemental composition associated with pathological processes.

MATERIALS AND METHODS. The dental status of 100 workers and engineering personnel involved in the production of biologically active substances, paint-and-coating materials, and metal products, all of whom had direct contact with inorganic and organic reagents, was assessed. The control group included teeth from 50 individuals working at the same enterprises but not exposed to occupational hazards. The chemical composition of tooth hard-tissue samples was determined using an M4 TORNADO (Bruker) X-ray fluorescence spectrometer. The MultiPoint mode was used. The software provides the content of each element relative to the total amount of detected elements, considering the entire spectrum as 100%. A relatively constant Ca/P ratio served as an additional reference point for discussing deviations from normal values.

RESULTS. The identified diseases in the affected zones were accompanied by atypical accumulations of trace elements detected via XRF spectra. In several employees of a metallurgical plant, high titanium content – up to 1.14 wt% of total elemental content – was found in areas of dental erosion. Titanium levels in adjacent intact enamel were significantly reduced, although trace amounts were still present. In patients with long-term employment at a paint, coating, and anti-corrosion materials enterprise, potassium content in deep carious lesions reached 12.64%, and most individuals also showed substantial levels of zinc, barium, iron, sulfur, chlorine, manganese, and copper. Among workers of an agrobiological enterprise without hot workshops or industrial dust – due to multistage air purification and sterilization – caries prevailed. In employees of a chemical-pharmaceutical production facility, no cases of caries were detected; only non-inflammatory conditions such as increased tooth wear and wedge-shaped defects were diagnosed.

CONCLUSIONS. XRF analysis demonstrated that enamel demineralization processes in workers of chemical industries are accompanied by qualitative and quantitative changes in trace-element profiles within pathological zones. Environmental exposure results in the isomorphic and isoinic incorporation of elements into apatite structures of hard tooth tissues and disrupts the natural kinetics of mineralization and demineralization. The intensity of trace-element accumulation in tooth tissues is directly related to the degree of industrial air purification. Treatment and prevention of dental disorders in these workers must account for industry-specific occupational factors.

Keywords: chemical industries, harmful occupational factors, X-ray fluorescence analysis, Ca/P ratio, occupational dental erosion, tooth mineral structure

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Особенности механизмов патологии зубов у сотрудников химических предприятий

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Резюме

ВВЕДЕНИЕ. В условиях усиления влияния химического фактора, предрасполагающего к возникновению патологии, происходит модификация процессов деструкции твердых тканей зубов и в плане изменения их кинетики, и прямого включения в них экзогенных химических агентов. Эти обстоятельства не могут не влиять на макро- и микроэлементный состав не только эмали, но и дентина, и цемента в случае усугубления заболевания. Получение достоверной информации по составу элементов имеет существенное значение для выбора правильной тактики лечения и обоснования профилактических мер.

ЦЕЛЬ. Провести рентгенофлуоресцентный анализ твердых тканей зубов сотрудников химических предприятий, с оценкой качественных и количественных изменений элементного состава, сопровождающих развитие патологии.

МАТЕРИАЛЫ И МЕТОДЫ. Был определен стоматологический статус 100 рабочих и инженерно-технических работников, занятых в производстве биологически активных веществ, лакокрасочных материалов, металлопродукции, имевших непосредственный контакт с неорганическими и органическими реагентами. Контрольную группу составили зубы 50 человек, работавших на этих предприятиях в условиях отсутствия профессиональных вредностей. Химический состав образцов твердых тканей зуба определяли на рентгенофлуоресцентном спектрометре M4 TORNADO (Bruker). В ходе работы использовали режим MultiPoint. Программа показывает содержание данного элемента относительно суммы всех определяемых элементов, принимая весь полученный спектр за 100%. Ориентиром для обсуждения наблюдаемых отклонений содержания элементов от нормы служила, в том числе, относительно постоянная величина индекса Ca/P.

РЕЗУЛЬТАТЫ. Обнаруженные заболевания в зонах поражения зубов сопровождаются нетипичными накоплениями микроэлементов, которые зарегистрированы спектрами РФА. У ряда сотрудников металлургического завода, в области эрозии зубов отмечено высокое содержание титана, до 1,14 % по массе от общего содержания элементов. В составе интактной эмали, расположенной рядом с эрозией, содержание титана резко снижено, но все же он присутствует. У пациентов, длительное время проработавших на предприятии, производящем лакокрасочные и антикоррозионные материалы, содержание калия в зоне глубокого кариеса составило до 12,64 %, а также у большинства пациентов показано довольно существенное присутствие цинка, бария, железа, серы, хлора, марганца, меди. У обследованных работников агробиологического предприятия, на котором отсутствуют горячие цеха и в явном виде промышленная пыль, поскольку воздух в промзоне подвергается многоступенчатой очистке и стерилизации, в большей степени преобладает кариес. Среди обследованного персонала химико-фармацевтического производства практически не выявлено случаев кариеса, диагностированы заболевания невоспалительного характера, в основном повышенная стираемость и клиновидные дефекты зубов.

ВЫВОДЫ. Методом РФА установлено, что у сотрудников химических производств процессы деминерализации эмали зубов сопровождаются качественным и количественным изменением номенклатуры микроэлементов в зоне патологии. Воздействие элементов из окружающей среды состоит в их изоморфном и изоинном внедрении в апатитные структуры зубов и нарушении естественной кинетики процессов минерализации и деминерализации. Интенсивность накопления микроэлементов в твердых тканях зубов непосредственно связана со степенью очистки промышленного воздуха. Терапия и профилактика стоматологических проблем должна учитывать специфику производственной деятельности работников предприятий.

Ключевые слова: химические предприятия, вредный фактор, рентгенофлуоресцентный анализ, индекс Ca/P, профессиональная эрозия зубов, минеральная структура зуба

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INTRODUCTION

In numerous publications of recent years, the chemical, biochemical, and physical aspects of various dental diseases have been comprehensively addressed under both *in vitro* and *in vivo* conditions. These studies describe fundamentally different mechanisms of hard dental tissue destruction occurring as a result of microbial activity (dental caries) as well as widely prevalent non-carious dental disorders that are non-inflammatory in nature, primarily including dental erosion, wedge-shaped defects, and increased tooth wear [1–5].

An increased research focus has been placed on the clinical manifestations of dental diseases among workers exposed to hazardous occupational conditions, particularly those employed in chemical industries [6; 7], as they are subject to a significantly higher risk. It is evident that under conditions of enhanced chemical exposure predisposing to the development of pathology, the processes of hard dental tissue destruction are modified not only in terms of their kinetics but also through the direct involvement of exogenous chemical agents. These factors inevitably affect the macro- and microelemental composition not only of enamel but also of dentin and cementum in cases of disease progression.

Obtaining reliable information on elemental composition is of critical importance for the selection of appropriate therapeutic strategies and for substantiating preventive measures aimed at reducing the risk of dental damage among personnel involved in chemical raw material processing, organic or inorganic synthesis, or related analytical activities.

As has been repeatedly demonstrated [2; 4], the acquisition of accurate and statistically significant data on elemental content in hard dental tissues is optimally achieved using modern X-ray fluorescence spectrometers designed for direct analysis of solid surfaces. One of the key advantages of X-ray fluorescence analysis (XRF) is that the analyzed samples do not require complex sample preparation.

AIM

To perform X-ray fluorescence analysis of the hard dental tissues of employees of chemical enterprises, with an assessment of qualitative and quantitative changes in elemental composition accompanying the development of pathology.

MATERIALS AND METHODS

The study was conducted at the Departments of Therapeutic Dentistry and Endodontics, as well as General and Bioorganic Chemistry of the Russian University of Medicine (Ministry of Health of the Russian Federation), and in the laboratories of the N.S. Kurnakov Institute of General and Inorganic Chemistry of the Russian Academy of Sciences.

The dental status of 100 workers and engineering-technical personnel involved in the production of biologically active substances, paints and coatings, and metal products, who had direct contact with inorganic and organic reagents, was assessed. The control group consisted of teeth obtained from 50 individuals employed at the same enterprises under conditions without occupational hazards.

Teeth subjected to X-ray fluorescence analysis were, in all cases, extracted for periodontal or orthodontic indications. Only intact teeth without signs of prior dental treatment were used. The samples were cleaned of soft tissues, disinfected, and stored in distilled water at 4°C.

The chemical composition of hard dental tissue samples was determined using an M4 TORNADO X-ray fluorescence spectrometer (Bruker), a micro-XRF analyzer designed for non-destructive qualitative and quantitative material analysis. The method is based on the interaction of elements present in the sample with high-energy X-ray radiation, resulting in the emission of detectable secondary X-ray radiation (X-ray fluorescence) characteristic of each atomic species. The operating unit of the instrument is a rhodium fine-focus X-ray tube (maximum excitation voltage 50 kV, power 30 W, current 600 μA). Measurements were performed in the Multi-Point mode, allowing analysis at several points within a selected area of the enamel surface.

During the analysis, the X-ray beam was directed at a predetermined point on the sample surface, and elemental composition was determined for a spot with a diameter of 20 μm. The computer integrated into the instrument processed the data using specialized software and provided measurement results for the selected point as an average value over 100 pulses, presented as a spectrum of detected elements. The resulting spectrum was subsequently converted into a table of mass percentage ratios of the constituent elements in the analyzed area. The software reports the content of each element relative to the total sum of all detected elements, considering the entire spectrum as 100%. As is well known, X-ray fluorescence analysis does not allow sufficiently accurate determination of elements from the first two periods of the Periodic Table or sodium; however, this limitation did not impede the achievement of the study objectives.

The instrument was calibrated using a standard sample of calcium dihydrogen phosphate, $Ca(H_2PO_4)_2$, with respect to calcium and phosphorus content. The measurement accuracy was 0.01%. Statistical analysis of the obtained data was performed using a personal computer and the software package *Statistica 9.0*.

In discussing deviations of elemental content from normal values, reference was made, among other parameters, to the relatively constant Ca/P ratio. According to the literature, this ratio for enamel resistant to acid exposure ranges from 1.6 to 2.1 by mass. In the present study, the Ca/P ratio for enamel samples of healthy teeth from the control group ranged from 1.9 to 2.2.

RESULTS

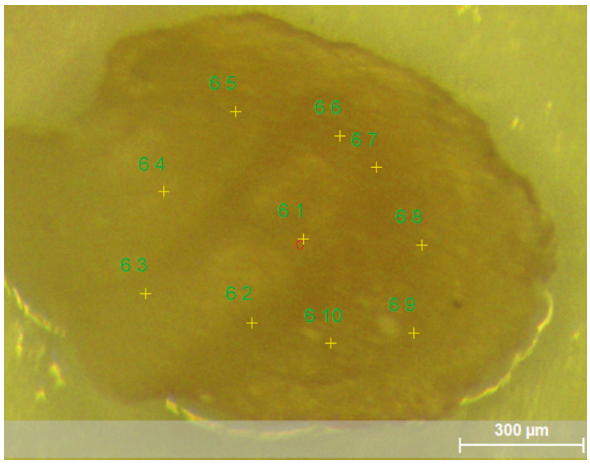
The detected diseases in the affected areas were accompanied by atypical accumulations of trace elements, as evidenced by X-ray fluorescence (XRF) spectra. Without addressing the pathways by which these elements enter the hard dental tissues (potentially via industrial air), which constitutes the subject of a separate investigation, it can be stated that an association was observed

between elevated concentrations of specific elements or groups of elements and the type of dental pathology.

For example, in a number of employees of a metallurgical plant that utilizes zinc-, aluminum-, and other nonferrous metal-containing alloys in its core operations, a high titanium content was detected in areas of dental erosion, reaching up to 1.14 wt% of the total elemental content registered in the spectrum. These observations were made in patients whose oral cavities contained no metallic restorations or prosthetic structures. As an illustration, Fig. 1 presents a fragment of one such tooth (Patient No. 1), together with the corresponding X-ray fluorescence spectrum and the numerical values of the relative elemental contents at the analyzed points.

Similarly elevated titanium concentrations were identified in erosion zones of teeth in a number of other patients from this enterprise. In Patient No. 2, multiple cervical non-carious lesions were diagnosed, including concurrent erosions and wedge-shaped defects, with a titanium mass fraction of 1.06%.

Of particular interest is the observation that in the intact enamel adjacent to the erosion (Patient No. 1), the titanium content was markedly reduced, yet still detectable, as evidenced by the data presented in Fig. 2.



Mass percent (%)

Spectrum	P	S	Cl	K	Ca	Ti	Fe	Zn
6 10	5.50	0.26	0.40	0.96	91.67	0.62	0.22	0.37
6 9	5.61	0.13	0.27	0.85	91.09	1.59	0.15	0.32
6 8	5.84	0.15	0.47	0.65	90.54	1.93	0.05	0.36
6 7	6.54	0.17	0.46	0.69	89.89	1.84	0.20	0.22
6 6	6.11	0.21	0.38	1.07	89.52	2.06	0.22	0.44
6 5	6.86	0.28	0.50	0.72	89.56	1.63	0.13	0.31
6 4	6.74	0.11	0.24	0.51	90.91	0.98	0.13	0.38
6 3	6.09	0.16	0.33	0.52	92.17	0.12	0.31	0.29
6 2	6.26	0.15	0.30	0.73	91.96	0.04	0.23	0.33
6 1	6.49	0.29	0.48	0.58	91.19	0.57	0.12	0.28
Mean value:	6.21	0.19	0.38	0.73	90.85	1.14	0.18	0.33
Sigma:	0.46	0.06	0.09	0.18	0.96	0.76	0.07	0.06
Sigma mean:	0.15	0.02	0.03	0.06	0.30	0.24	0.02	0.02

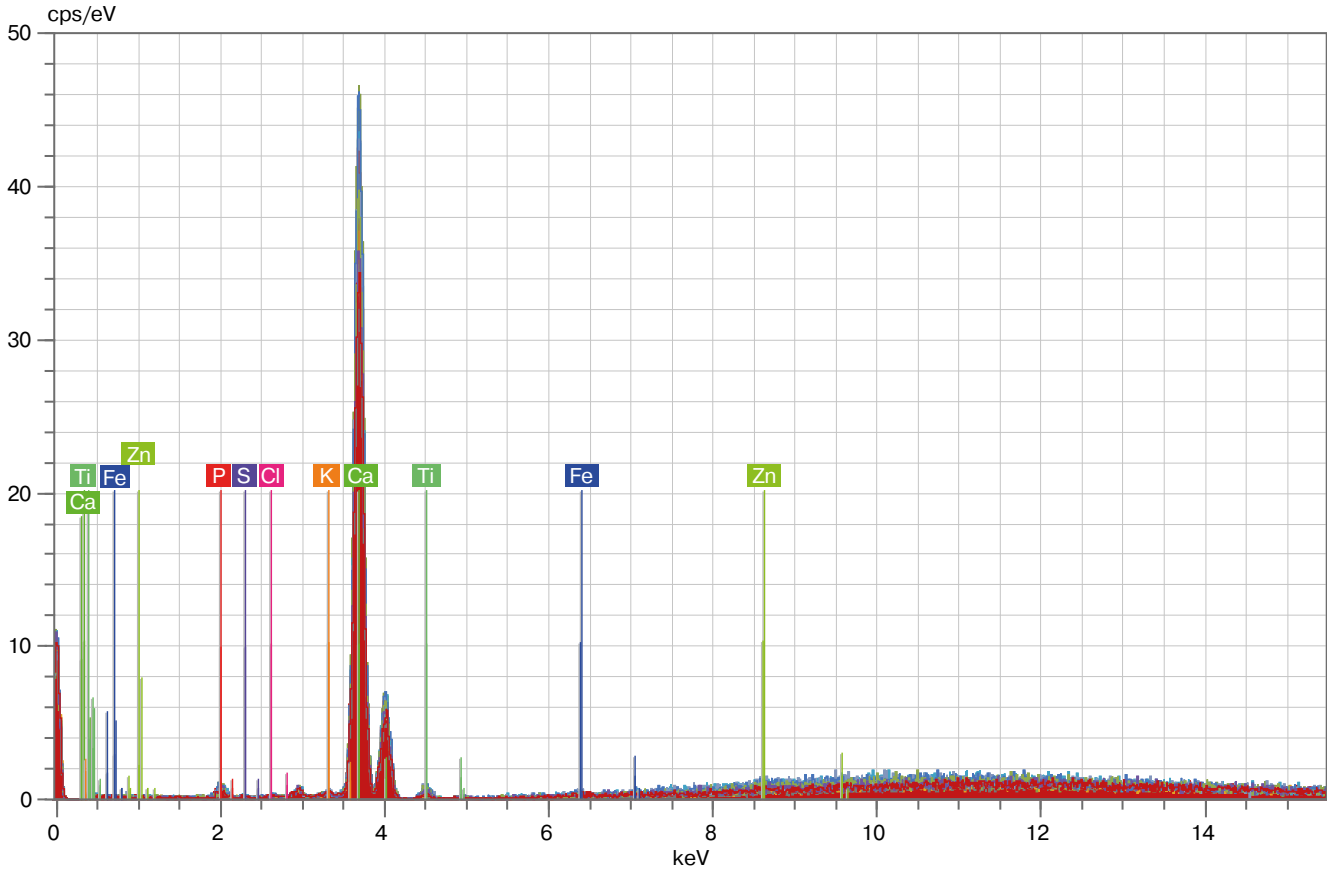
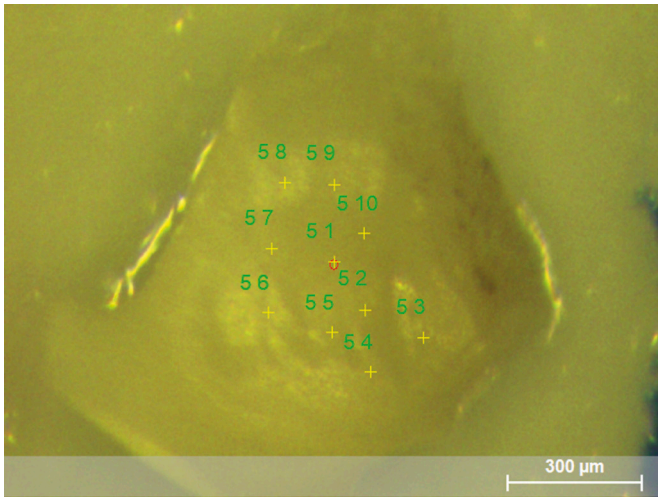


Fig. 1. Data on the analysis of the tooth erosion site of patient No. 1 (XRF, MultiPoint mode)

Рис. 1. Данные по анализу участка эрозии зуба пациентки № 1, (РФА, режим MultiPoint)

Notably, a high potassium content, reaching up to 1.86% in the affected areas, was observed; in some cases, though not consistently, this was associated with elevated titanium levels. Data reported by researchers from different laboratories regarding potassium content in healthy enamel are contradictory, although potassium is consistently regarded as a trace element. Our previous results obtained using laser mass spectrometry [8] demonstrated that the potassium mass fraction in intact enamel does not exceed 0.1% and is usually considerably lower.

In Patient No. 3, who had been employed for an extended period at an enterprise producing paints, coatings, and anticorrosive materials, the potassium content in the area of deep caries reached 12.64%, as shown in Fig. 3. In the same region, a substantial presence of zinc, barium, iron, sulfur, chlorine, manganese, and copper was also detected. Manganese accompanied by a similar spectrum of associated trace elements was identified in another employee of the same enterprise, who presented not with caries but with dental erosion.



Spectrum	Mass percent (%) P	Ca	Ti	Zn	Sr
5 10	8.30	90.86	0.26	0.13	0.46
5 9	7.73	91.73	0.16	0.13	0.25
5 8	8.19	91.14	0.26	0.10	0.31
5 7	7.81	91.42	0.31	0.14	0.32
5 6	8.08	91.44	0.06	0.10	0.31
5 5	8.39	90.91	0.25	0.10	0.35
5 4	8.36	90.94	0.20	0.11	0.39
5 3	8.30	90.67	0.52	0.13	0.38
5 2	8.79	90.45	0.30	0.15	0.32
5 1	8.03	91.29	0.27	0.12	0.29
Mean value:	8.20	91.09	0.26	0.12	0.34
Sigma:	0.31	0.39	0.12	0.02	0.06
Sigma mean:	0.10	0.12	0.04	0.01	0.02

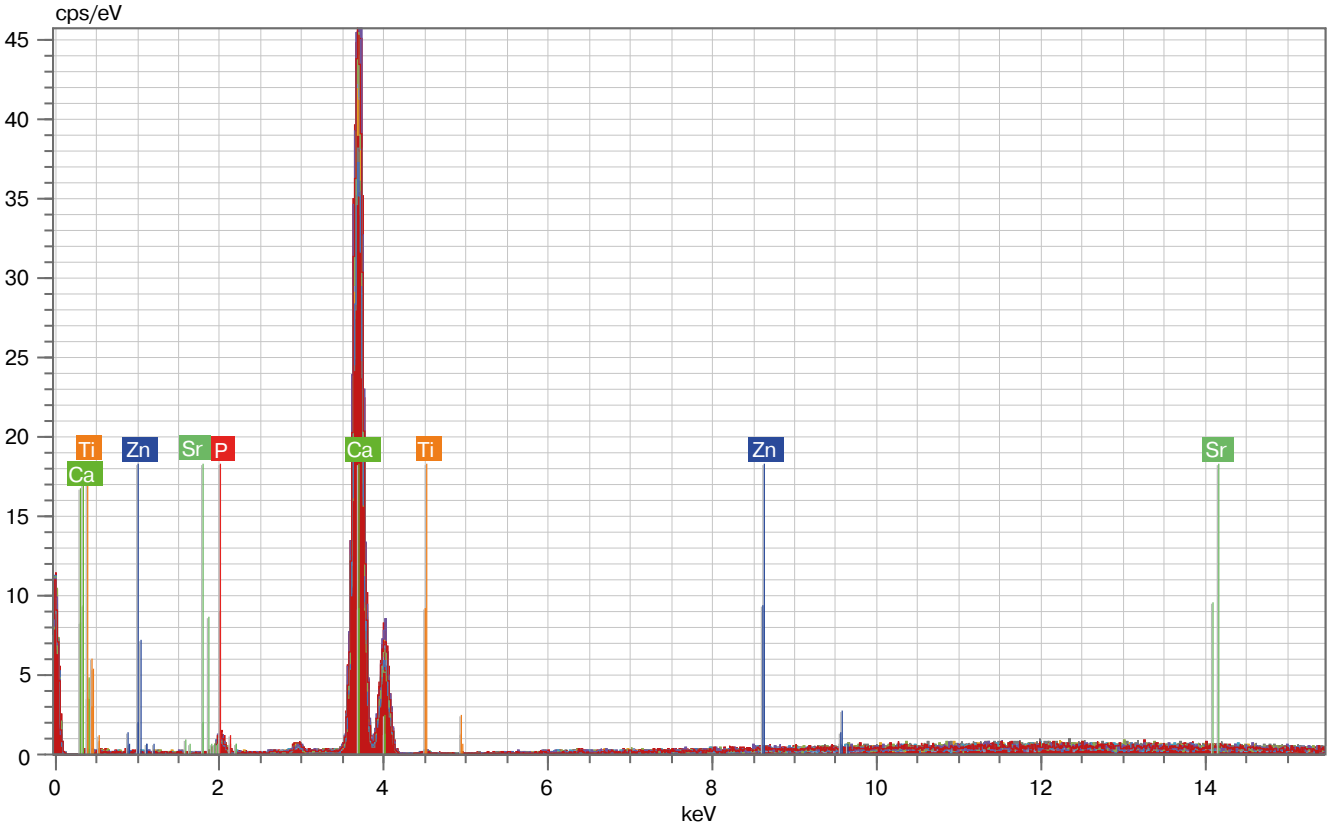
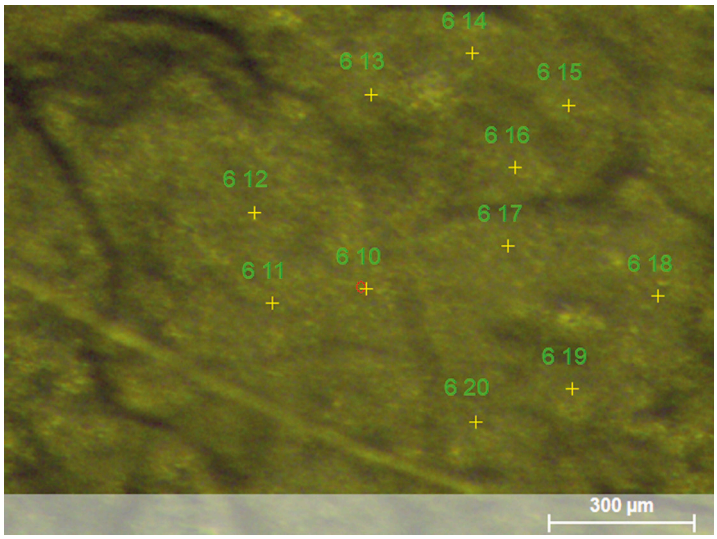


Fig. 2. Data on the analysis of an intact enamel area near the erosion of tooth in patient No. 1, (XRF, MultiPoint mode)

Рис. 2. Данные по анализу участка интактной эмали рядом с эрозией зуба пациентки № 1, (РФА, режим MultiPoint)



Mass percent (%)

Spectrum	P	S	Cl	K	Ca	Ti	Mn	Fe	Cu	Zn	Sr	Ba
6 20	4.07	1.36	1.89	11.86	75.61	0.01	0.25	0.85	0.43	2.22	0.56	0.88
6 19	3.91	1.16	1.93	12.06	76.61	0.00	0.25	0.77	0.45	1.68	0.37	0.80
6 18	3.99	1.42	1.95	9.96	78.92	0.00	0.25	0.74	0.39	1.55	0.37	0.45
6 17	4.21	1.57	2.19	11.52	74.23	0.00	0.23	0.72	0.35	1.75	0.75	2.49
6 16	4.57	1.57	2.18	12.55	74.50	0.00	0.31	0.71	0.50	1.70	0.53	0.88
6 15	5.05	1.73	2.65	14.27	71.71	0.00	0.33	0.93	0.47	1.75	0.44	0.67
6 14	5.69	1.97	3.80	18.52	65.10	0.00	0.36	1.03	0.57	2.19	0.49	0.28
6 13	4.97	1.77	2.52	12.61	73.61	0.00	0.34	0.82	0.48	2.09	0.49	0.28
6 12	4.46	1.53	2.12	13.58	74.33	0.00	0.21	0.75	0.41	1.85	0.43	0.33
6 11	4.43	1.41	2.02	11.28	76.78	0.00	0.28	0.83	0.43	1.87	0.37	0.30
6 10	4.40	1.24	1.81	10.83	77.82	0.00	0.26	0.70	0.41	1.73	0.28	0.54
Mean value:	4.52	1.52	2.28	12.64	74.47	0.00	0.28	0.80	0.44	1.85	0.46	0.72
Sigma:	0.53	0.24	0.57	2.29	3.72	0.00	0.05	0.10	0.06	0.22	0.12	0.63
Sigma mean:	0.16	0.07	0.17	0.69	1.12	0.00	0.01	0.03	0.02	0.07	0.04	0.19

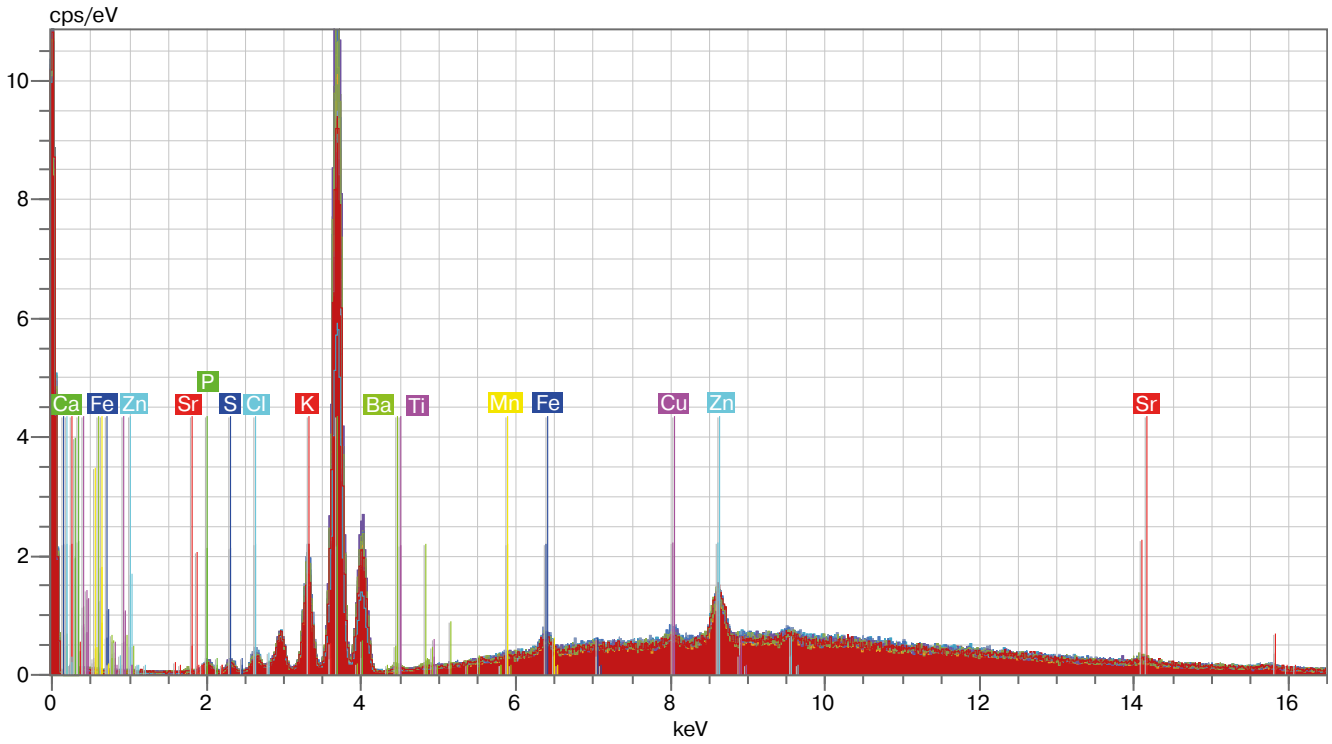
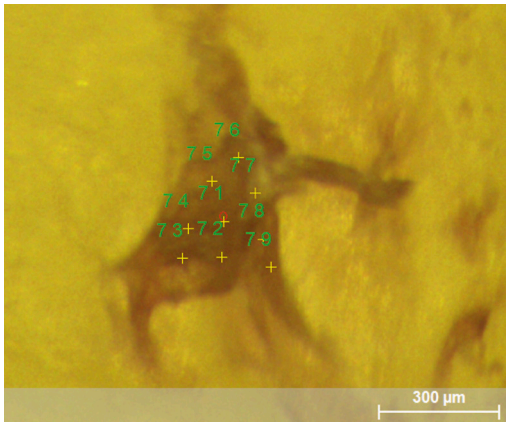


Fig. 3. Data on the analysis of the deep caries area of tooth No. 3, (XRF, MultiPoint mode)

Рис. 3. Данные по анализу участка глубокого кариеса зуба пациента № 3, (РФА, режим MultiPoint)

The nature of predominant negative changes in the oral cavity among the patient sample appears to be, to some extent, specific to each enterprise engaged in chemical production. Among the workers examined at an agrobiological facility – where there are no hot workshops and industrial dust is not present due to multistage air purification and sterilization in the production area – dental caries was the most prevalent condition. For example, Patient No. 4 exhibited pronounced light-brown pigmentation, with the corresponding spectral data presented in Fig. 4. The production processes at this enterprise involve various biological objects, nutrient media, and pharmacologically active compounds, which may explain the presence of a wide range of elements in the inflammatory focus, including chlorine, zinc, strontium, potassium, titanium, barium, iron, and sulfur.

By contrast, a more technologically advanced facility is the chemical-pharmaceutical plant operating under GMP requirements, which has implemented technical and technological solutions to purify workshop air and create clean zones where the accumulation of production dust, solvent vapors, and other volatile substances is minimized. Among the personnel examined at this facility, no cases of dental caries were detected; only non-inflammatory conditions were diagnosed, primarily increased tooth wear and wedge-shaped defects. Moreover, as shown in Fig. 5, Patient No. 5, employed at this enterprise, exhibited a relatively limited spectrum of detectable trace elements at low concentrations (iron, nickel, zinc), while the content of other elements was, apparently, below the instrument's detection threshold.



Mass percent (%)

Spectrum	P	S	Cl	K	Ca	Ti	Fe	Zn	Sr	Ba
7 9	3.13	0.90	0.84	1.75	91.99	0.01	0.48	0.51	0.19	0.20
7 8	3.20	0.73	0.80	1.70	92.12	0.10	0.51	0.49	0.15	0.20
7 7	3.75	0.65	0.68	1.51	91.95	0.17	0.44	0.43	0.16	0.27
7 6	3.64	0.47	0.59	1.38	92.76	0.15	0.35	0.42	0.13	0.11
7 5	3.47	0.59	0.65	1.35	92.71	0.15	0.26	0.49	0.14	0.17
7 4	1.31	1.01	1.10	2.23	92.36	0.11	0.50	0.74	0.29	0.36
7 3	1.06	1.37	1.46	2.82	90.59	0.31	0.79	0.78	0.28	0.53
7 2	1.36	1.28	1.57	2.91	89.57	0.98	0.81	0.80	0.27	0.46
7 1	1.74	1.28	1.42	2.74	89.33	0.90	0.65	0.76	0.33	0.85
Mean value:	2.52	0.92	1.01	2.04	91.49	0.32	0.53	0.60	0.21	0.35
Sigma:	1.12	0.33	0.38	0.64	1.32	0.36	0.19	0.16	0.08	0.23
Sigma mean:	0.37	0.11	0.13	0.21	0.44	0.12	0.06	0.05	0.03	0.08

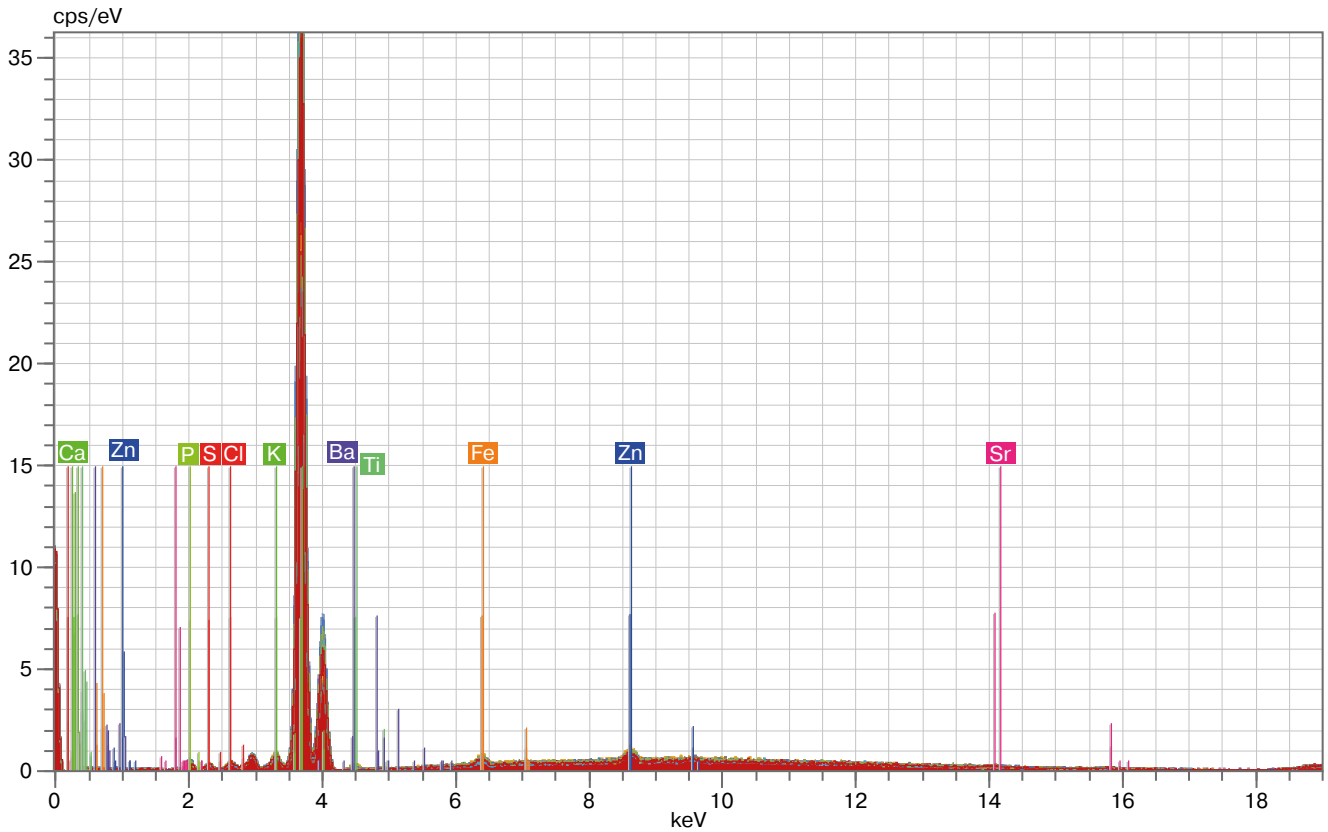
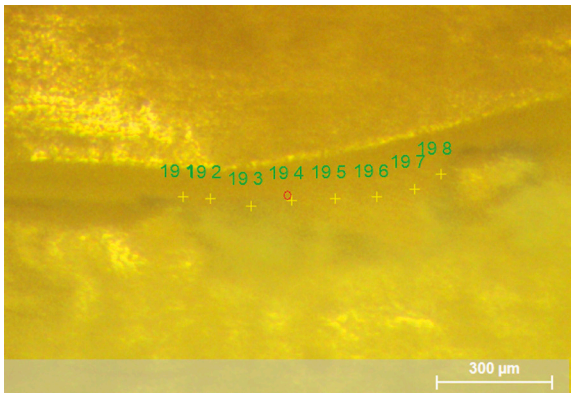


Fig. 4. Data on the analysis of the caries site of the pigmented tooth of patient No. 4, (XRF, MultiPoint mode)

Рис. 4. Данные по анализу участка кариеса пигментированного зуба пациента № 4, (РФА, режим MultiPoint)



Spectrum	Mass percent (%) P	Ca	Fe	Ni	Zn
19 8	7.44	91.85	0.13	0.18	0.39
19 7	7.06	92.47	0.09	0.12	0.27
19 6	8.01	91.72	0.04	0.08	0.15
19 5	9.15	90.45	0.08	0.11	0.21
19 4	7.91	91.61	0.07	0.11	0.31
19 3	7.83	91.65	0.10	0.10	0.33
19 2	9.00	90.52	0.12	0.09	0.27
19 1	7.99	91.54	0.12	0.06	0.29
Mean value:	8.05	91.48	0.09	0.10	0.28
Sigma:	0.71	0.68	0.03	0.03	0.07
Sigma mean:	0.25	0.24	0.01	0.01	0.03

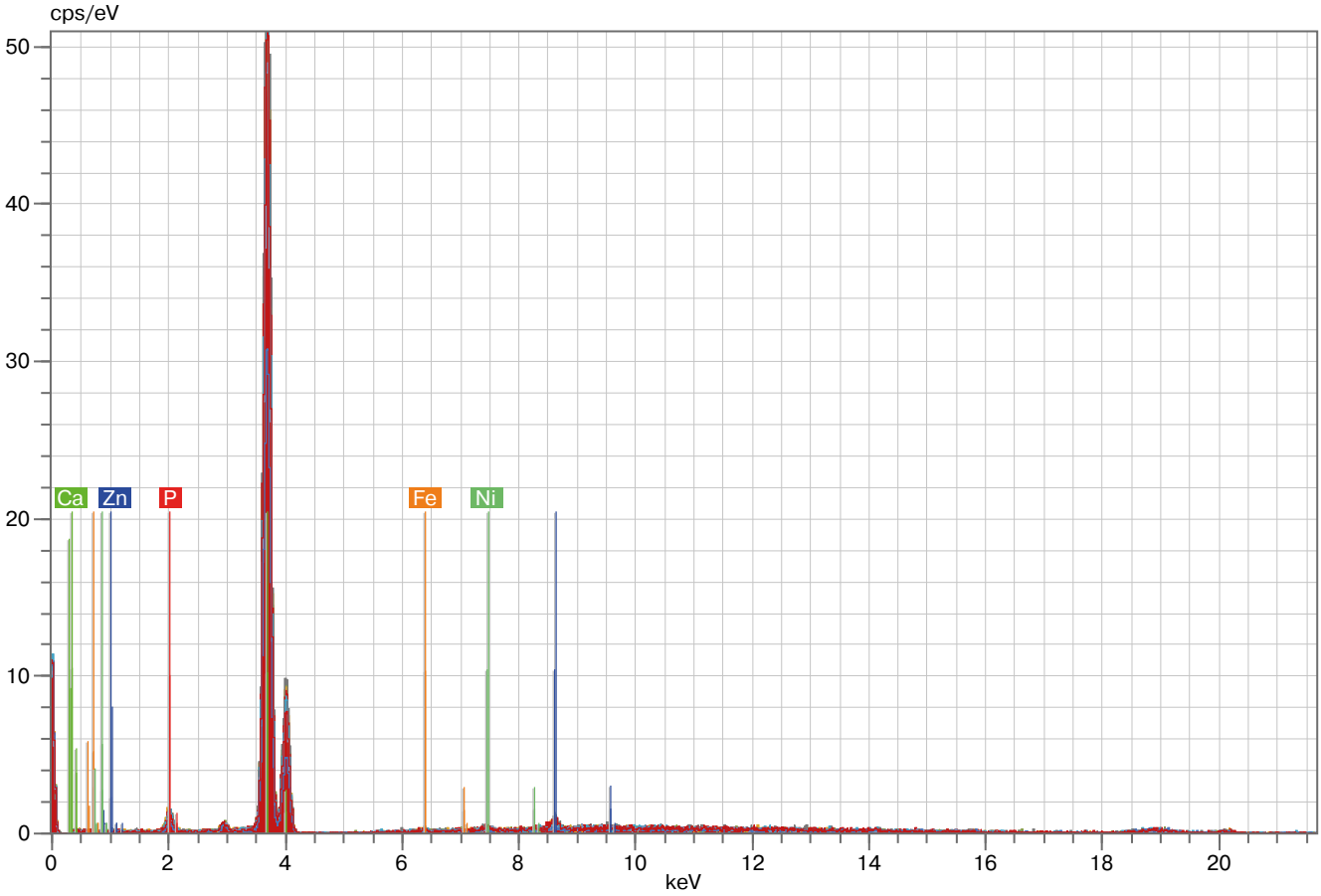


Fig. 5. Data on the analysis of the wedge-shaped tooth defect in patient No. 5 (XRF, MultiPoint mode)

Рис. 5. Данные по анализу участка клиновидного дефекта зуба пациента № 5, (РФА, режим MultiPoint)

DISCUSSION

The findings obtained in this study logically integrate into the broader body of knowledge generated by numerous investigations aimed at identifying the characteristics of dental disease progression in workers involved in chemical production [9–12]. Harmful occupational factors shift the dental status of individuals toward pathology, with exogenous intoxication clearly affecting the macro- and microelement composition not only in the lesion area but also in adjacent regions where clinical signs of disease are absent, yet the elemental composition of the tooth surface already differs from normal both qualitatively and quantitatively.

The elevated titanium content observed in erosion zones of teeth among several employees of a metallurgical enterprise is of particular concern for occupational health services, which would likely identify the source of this trace element exposure. Titanium itself is known to be one of the most biocompatible metals, widely used in medicine, including orthopedic and dental implants. However, first, the examined patients had no metallic restorations in the oral cavity, and second, titanium in the hard dental tissues was present in oxidized forms rather than as the pure metal. Whereas titanium was once considered biologically inert, recent studies increasingly highlight its potential toxicity: tita-

nium particles and ions can accumulate in tissues and induce inflammatory responses [13].

Regarding the concurrent elevation of potassium and titanium in the pathological zones, such an association requires further investigation, as these elements perform distinct biological functions and are not directly linked in biochemical pathways. It should be noted that among employees of the metallurgical plant, non-carious lesions predominated, and the Ca/P ratio, exceeding the normal range and reaching 3.27, indicates a canonical pattern of enamel demineralization characterized by more rapid dephosphorylation relative to decalcification. Notably, XRF spectra from intact enamel adjacent to erosion returned the Ca/P ratio to 2.19, effectively restoring it too normal.

In workers at the enterprise producing paints and anticorrosive materials, the elemental composition within carious lesions – including essential elements – exhibited considerable diversity and significant quantitative deviations from normal, particularly for iron, sulfur, chlorine, zinc, and barium. The presence of these elements, incorporated as cations and anions into the lesion, suggests their direct or indirect involvement in mineralization processes, whereby their isomorphic or isoelectronic integration into apatite-like structures alters the usual kinetics of the opposing demineralization process. While classical caries progression typically reduces the Ca/P ratio from the normal range of 1.9–2.1 [14], in this patient group it increased up to 3.24, indicating intensified dephosphorylation relative to decalcification. This effect may be linked to the simultaneous presence in the lesion and saliva of salts comprising cations of strong bases (strontium, potassium, barium) and anions of weak acids (sulfides, sulfites), whose hydrolysis produces an alkaline environment that reduces the concentration of hydronium ions responsible for calcium substitution in hydroxyapatite [15–17].

At the agrobiological enterprise, the number of caries cases among examined workers was more than twice that of recorded increased tooth wear, potentially reflecting variations in work across different production areas. XRF spectra from carious lesions demonstrated not only a wide range of trace elements, as in previous examples, but also similar deviations of the Ca/P ratio above normal, reaching 5.92 in one patient. In contrast, spectra from intact enamel adjacent to the lesion reduced this ratio to 2.98.

For the subset of patients at the same enterprise exhibiting increased tooth wear, XRF spectra revealed no deviations from normal. The Ca/P ratio ranged from 2.07 to 2.46, a slight elevation consistent with observations for non-inflammatory hard tissue lesions [18].

Among employees of the chemical-pharmaceutical enterprise, all deviations from normal dental status were non-inflammatory. Erosive lesions and wedge-shaped defects occurred with roughly equal frequency. Detected trace elements showed only sporadic and minor quantitative deviations and were typical in type. In nearly all cases, the macroelement Ca/P ratio was slightly elevated, reflecting standard enamel demineralization processes in the absence of microbial involvement.

CONCLUSION

1. X-ray fluorescence analysis (XRF) demonstrated that, in employees of chemical production facilities, enamel demineralization is accompanied by both qualitative and quantitative changes in the microelement composition within pathological zones. In nearly all cases, the Ca/P ratio was increased, in some instances reaching 3.27, indicating a canonical pattern of enamel demineralization characterized by more rapid dephosphorylation relative to decalcification.

2. Environmental elements exert their effect through isomorphic and isoelectronic incorporation into the apatite structures of hard dental tissues, disrupting the natural kinetics of mineralization and demineralization. The detection of iron, sulfur, chlorine, zinc, and barium, incorporated as cations and anions into inflammatory foci, indicates their direct or indirect involvement in the mineralization process.

3. The intensity of microelement accumulation in hard dental tissues is directly related to the degree of industrial air purification from toxic chemical agents. For example, in erosion zones of teeth from metallurgical plant employees, titanium content reached as high as 1.14%.

4. Therapy and preventive strategies for dental disorders should take into account the specific occupational exposures of employees working in chemical production facilities.

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Original Research

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White spot lesions in orthodontics: A comprehensive review of prevalence, etiology, risk factors, and management strategies

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Abstract

AIM. White spot lesions (WSLs) are initial carious formations marked by the demineralization of enamel, commonly seen in individuals with fixed orthodontic appliances. This study aims to compile and analyze existing research on the prevalence, causes, risk factors, prevention, and treatment of WSLs in orthodontic patients.

MATERIALS AND METHODS. A comprehensive literature review was performed using the PubMed, Embase, and Cochrane Library databases. The review included studies published in English that involved human subjects and focused on WSLs in orthodontic contexts.

RESULTS. The occurrence of WSLs in orthodontic patients ranges significantly (8–97%), influenced by diagnostic techniques and patient demographics. Key factors include inadequate oral hygiene, high sugar intake, decreased saliva production, and the design of fixed appliances. Effective preventive and treatment methods include fluoride-based solutions, casein phosphopeptide-amorphous calcium phosphate (CPP-ACP), and resin infiltration.

CONCLUSIONS. Timely detection and tailored preventive measures are essential to lessen the frequency and effects of WSLs. Future studies should aim to enhance minimally invasive treatments and assess the long-term results of preventive measures.

Keywords: white spot lesions, dental caries, tooth demineralization, tooth remineralization, orthodontics, risk factors

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Белые пятна эмали при ортодонтическом лечении: комплексный обзор распространенности, этиологии, факторов риска и стратегий ведения

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Резюме

ЦЕЛЬ. Белые пятна эмали (white spot lesions, WSLs) представляют собой начальные кариозные поражения, характеризующиеся деминерализацией эмали, и часто выявляются у пациентов с несъемной ортодонтической аппаратурой. Целью данного исследования является обобщение и анализ существующих научных данных о распространенности, причинах, факторах риска, профилактике и методах лечения WSLs у ортодонтических пациентов.

МАТЕРИАЛЫ И МЕТОДЫ. Проведен комплексный обзор литературы с использованием баз данных PubMed, Embase и Cochrane Library. В обзор включены исследования, опубликованные на английском языке, выполненные с участием людей и посвященные проблеме белых пятен эмали в контексте ортодонтического лечения.

РЕЗУЛЬТАТЫ. Частота возникновения WSLs у ортодонтических пациентов варьирует в широких пределах (8–97 %), что обусловлено применяемыми диагностическими методами и демографическими характеристиками пациентов. Ключевыми факторами риска являются неудовлетворительная гигиена полости рта, высокое потребление сахара, снижение слюноотделения и конструктивные особенности несъемных ортодонтических аппаратов. Эффективные профилактические и лечебные подходы вклю-

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чают использование фторсодержащих средств, казеинфосфопептида – аморфного фосфата кальция (CPP-ACP), а также методику инфильтрации смолами.
ВЫВОДЫ. Своевременное выявление и индивидуализированные профилактические мероприятия имеют ключевое значение для снижения частоты и выраженности белых пятен эмали. Перспективные исследования должны быть направлены на совершенствование минимально инвазивных методов лечения и оценку долгосрочной эффективности профилактических стратегий.

Ключевые слова: белые пятна эмали, кариес зубов, деминерализация зубов, реминерализация зубов, ортодонтия, факторы риска

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INTRODUCTION

White spot lesions (WSLs) are a common symptom encountered during orthodontic treatment. Chalky, demineralised spots on the tooth surface could end up in persistent cosmetic and functional problems if not adequately treated. Orthodontic experts need to understand the prevalence, origins, risk variables, prevention, and treatment of WSLs in order to deliver the most effective treatment for patients [1]. Orthodontic therapy, typically utilising fixed tools such as braces, is usually carried out in order to fix dental misalignments. However, these fixed appliances may create conditions conductive to the formation of WSLs. Contributing factors comprise insufficient dental hygiene, continuous contact with fermentable carbohydrates, as well as changes in the oral microbiota, all of that result in enamel demineralisation and the emergence of WSLs [2]. The consequences of WSLs reach beyond apparent cosmetic problems. Regardless of their chalky, opaque appearance causing distress to patients, particularly if involving the front teeth, these lesions reflect the initial phase of enamel demineralisation and could progress to cavitated carious lesions if not handled properly [3]. Upon the onset of cavitation, affected teeth might need restorative treatment, hence increasing both the medical effort and the financial burden of medical treatment. Besides physical harm, white spot lesions may significantly decrease patient satisfaction with orthodontic treatment, especially if the desired ideal smile is not attained post-brace removal. This discontent could impact the perceived effectiveness of orthodontic treatment, irrespective of the attainment of functional goals. Furthermore, visible WSLs can lead to psychosocial issues, such as decreased self-confidence, embarrassment, or reluctance to smile, especially among teenagers and young adults. These effects collectively compromise the overall quality of life, making WSL prevention and management a priority not only for maintaining oral health but also for ensuring positive emotional and aesthetic outcomes [4; 5]. Given these far-reaching implications, it is essential that clinicians adopt proactive strategies to detect, prevent, and treat WSLs throughout the course of orthodontic treatment. However, a comprehensive and up-to-date synthesis of the existing literature is crucial for providing evidence-based recommendations and guiding clinical practice.

By synthesizing the findings from relevant studies, this review will provide an overview of the current knowledge and identify gaps that require further investigation. The findings of this review can help orthodontic practitioners implement effective preventive and management strategies to minimize the occurrence and impact of white spot lesions during and after orthodontic treatment.

MATERIALS AND METHODS

Search strategy

A comprehensive literature search was conducted using electronic databases, including PubMed, Embase, and Cochrane Library. The search terms included variations of “white spot lesions”, “orthodontics”, “prevalence”, “etiology”, “risk factors”, “prevention”, and “management”. The search was limited to articles published in English and conducted on human subjects. The search was conducted up until the date of this review.

Study selection

The initial search yielded a large number of articles. The inclusion criteria were defined as studies that focused on WSLs in orthodontic patients, provided information on prevalence, etiology, risk factors, prevention, or management, and had a clear study design (e.g., randomized controlled trials, cohort studies, case-control studies). Review articles and case reports were excluded, but their reference lists were checked for relevant articles. Two independent reviewers screened the titles and abstracts of the identified articles, followed by full-text review of the selected studies.

Data extraction and synthesis

data from the selected studies were extracted using a standardized form. The extracted information included study characteristics, patient demographics, sample size, study design, diagnostic methods, prevalence rates, etiological factors, risk factors, preventive measures, and management strategies. The findings were synthesized qualitatively due to the heterogeneity of the study designs and outcome measures.

Quality assessment

The methodological quality of the selected studies was assessed to ensure the reliability and validity of the findings included in this review. Appropriate quality appraisal tools were applied based on the design of each study. Each study was independently reviewed by two authors, and any disagreements were resolved through discussion or consultation with a third reviewer. Studies were rated as low, moderate, or high quality based on their overall risk of bias. The results of the quality assessment were used to guide data interpretation, with greater emphasis placed on high-quality studies during evidence synthesis.

After a comprehensive search of electronic databases using appropriate keywords and MeSH terms, initially, a total of 191 articles were identified. After removing duplicates, the titles and abstracts of 86 articles were screened for relevance. Following this screening process, 88 articles were selected for full-text assessment. These articles underwent a detailed evaluation based on predefined inclusion and exclusion criteria. During the full-text assessment, 60 articles were excluded due to reasons such as irrelevant study design, inappropriate population, and inadequate outcome measures. Consequently, a total of 28 articles were included in this review. The selected papers were thoroughly reviewed for data extraction, study characteristics, methodology, and outcomes addressing the prevalence, origin, risk variables, prevention, and therapeutic management of white spot lesions in orthodontics.

RESULTS AND DISCUSSION

Prevalence of white spot lesions

Incidence rates

The prevalence of WSLs in orthodontic patients ranges from 8 to 97% [6–9]. The variation can be linked to variations in sample characteristics, diagnostic techniques, and follow-up duration.

Patient demographics

Numerous patient characteristics, such as age, gender, and socioeconomic standing, have been acknowledged as key determinants impacting the prevalence of WSLs. Adolescents and young adults are particularly susceptible because to an increased requirement for orthodontic interventions, irregular oral hygiene practices, and a high consumption of sugary or acidic food items. In this demographic, compliance with oral hygiene habits can often be inconsistent, resulting in an increased possibility of plaque accumulation and enamel demineralisation. In addition, individuals from less privileged socioeconomic backgrounds can face obstacles in obtaining dental treatment and preventative education, leaving them more vulnerable to the formation of WSLs. Research suggests that males might show a somewhat higher prevalence, possibly linked to less rigorous oral hygiene practices [10].

Factors influencing prevalence

Several significant variables impact the differing prevalence of WSLs. Oral hygiene practices are crucial ineffective plaque management around brackets and wires substantially heightens the risk of enamel demineralisation. Dietary practices, especially the regular intake of fermentable carbohydrates and acidic beverages, supply an ideal environment for acidogenic bacteria, hence accelerating lesion growth. The length of orthodontic treatment is essential; longer treatment durations correspond with a greater incidence of WSLs due to extended contact with plaque-retentive instruments. The kind of orthodontic appliance increases risk; fixed equipment provides more difficulties for oral hygiene management than removable alternatives such as clear aligners, which have been linked to a reduced occurrence of WSLs (Table 1) [11; 12].

Etiology of white spot lesions

WSLs are the earliest visible manifestation of enamel demineralization and result from a multifactorial etiology involving biological, behavioural, and iatrogenic factors. Understanding these causative pathways is essential for effective prevention and management in orthodontic patients (Table 2).

Table 1. Risk factors associated with white spot lesions in orthodontics

Таблица 1. Факторы риска, связанные с появлением белых пятен в ортодонтии

Risk Factors	Description
Poor oral hygiene	Inadequate plaque control and lack of proper oral hygiene practices
Prolonged orthodontic treatment duration	Longer treatment duration increases the risk of WSL development
Fixed orthodontic appliances	Brackets and bands provide niches for plaque accumulation and make oral hygiene maintenance challenging
Inadequate oral hygiene during treatment	Insufficient plaque control during orthodontic treatment
High caries activity	Individuals with a history of frequent dental caries are more susceptible to WSLs
Low socioeconomic status	Socioeconomic factors can influence oral hygiene habits and dietary habits
Reduced salivary flow and buffering capacity	Decreased saliva flow and lower buffering capacity contribute to WSL formation

Table 2. Etiological factors contributing to the development of white spot lesions

Таблица 2. Этиологические факторы, способствующие развитию белых пятнистых поражений

Research Question	Etiological Factors
What are the etiological factors for WSLs?	Poor oral hygiene, high sugar intake, acidic environment, poor mineralization, compromised saliva flow
What are the risk factors for WSLs in orthodontics?	Poor oral hygiene, prolonged orthodontic treatment, use of fixed appliances, inadequate brushing technique
What are the microbiological factors for WSLs?	Streptococcus mutans, Lactobacillus species, biofilm formation, plaque accumulation
What are the dietary factors for WSLs?	High sugar intake, frequent consumption of acidic foods and beverages, low calcium intake

Plaque accumulation and poor oral hygiene

the most significant etiological factor for WSL development is the accumulation of dental plaque due to inadequate oral hygiene. Plaque forms a biofilm that adheres to the tooth surface, particularly around orthodontic brackets and at the gingival margins [13]. In the presence of fermentable carbohydrates, this biofilm becomes a reservoir for acidogenic bacteria that lower the local pH, resulting in the dissolution of hydroxyapatite crystals in enamel [14]. Areas that are difficult to clean such as interproximal surfaces and bracket peripheries are especially susceptible to demineralization. Without timely plaque removal, these early lesions can progress rapidly into more advanced enamel damage.

Microbial factors

Specific bacterial species have been directly implicated in the formation of WSLs. Streptococcus mutans and Lactobacillus spp. are the primary acidogenic and aciduric bacteria responsible for producing lactic acid from carbohydrate metabolism, initiating demineralization of enamel [15; 16]. These organisms thrive in the anaerobic microenvironment beneath plaque biofilms, particularly in orthodontic patients where appliance components create protected niches for colonization. A higher count of S. mutans has been positively correlated with increased lesion severity, emphasizing the importance of microbial control through hygiene reinforcement and chemotherapeutic agents.

Salivary factors

Saliva's buffering ability, mechanical cleansing activity, and delivery of calcium and phosphate ions make it a natural defensive mechanism against demineralization. These preventive benefits are undermined by a decreased salivary flow rate, which can occur in xerostomia, systemic disease, or drug side effects [17]. Additionally, saliva's ability to act as a buffer aid in counteracting the acids that plaque bacteria create. Demineralization is preferred over remineralization when salivary pH shifts toward acidic levels. Therefore, patients who have changed salivary quantity or quality are more likely to develop WSL, particularly if they are receiving orthodontic treatment for an extended period of time.

Nutritional factors

The etiology of WSLs is significantly influenced by diet. Regular intake of fermentable carbohydrates, particularly sucrose and glucose, encourages cariogenic bacteria to produce acid, which causes the oral cavity's pH to drop repeatedly [18]. Frequent consumption of acidic beverages, such as fruit juices, sports drinks, and soft drinks, further worsens enamel erosion and reduces the ability for remineralization. Adolescent orthodontic patients are especially at risk for unhealthy eating habits and snacking. The risk of enamel demineralization can be increased by consuming insufficient amounts of remineralizing minerals as calcium, phosphate, and vitamin D.

Orthodontic treatment-related factors

orthodontic appliances themselves contribute to the etiology of WSLs by altering the oral microenvironment. Fixed components such as brackets, bands, and ligatures create plaque-retentive sites that hinder effective oral hygiene [19]. The rough surfaces of these appliances favor biofilm formation and reduce the mechanical cleaning efficiency of brushing. Furthermore, prolonged treatment duration increases the exposure time of enamel to cariogenic challenges. Excessive orthodontic forces can also lead to localized inflammation and difficulty in maintaining oral hygiene, indirectly promoting lesion formation. Innovations in appliance design and adhesive technology aim to mitigate these risks but do not eliminate them entirely [20].

Risk factors associated with white spot lesions

A complex interaction of biological, behavioural, and treatment-related factors leads to WSLs. Early detection of at-risk persons and the use of individualized preventative measures depend on an understanding of these risk factors (Table 3).

Table 3. Risk factors associated with the formation and progression of white spot lesions

Таблица 3. Факторы риска, связанные с образованием и прогрессированием белых пятнистых поражений

Research Question	Risk Factors
What are the risk factors for the formation of WSLs in orthodontics?	Age, poor oral hygiene, high plaque accumulation, prolonged orthodontic treatment, inadequate fluoride exposure, compromised saliva flow
What are the risk factors for the progression of WSLs in orthodontics?	Poor oral hygiene, persistent plaque accumulation, inadequate brushing technique, acidic environment, compromised enamel
What are the patient-related risk factors for WSLs?	Age, poor oral hygiene, high sugar intake, previous history of dental caries, compromised saliva flow
What are the appliance-related risk factors for WSLs?	Type of orthodontic appliance, prolonged orthodontic treatment, inadequate oral hygiene, poor bracket placement, improper bonding materials, friction from orthodontic wires

Patient-related factors

The following patient-related factors have a major impact on the likelihood of developing WSL:

Poor Oral Hygiene Habits: The most significant risk factor for the development of WSL continues to be inadequate plaque control. Patients who neglect proper brushing and interdental hygiene let plaque to build up over time, especially around brackets and gingival margins, which causes localized demineralization of enamel [21].

Previous History of WSLs or Dental Caries: Future lesion development is strongly predicted by a past history of caries or white spot lesions. This could point to underlying microbiological or behavioural issues like high levels of Streptococcus mutans or a propensity for sugar consumption [22].

High Caries Activity: WSLs are more likely to occur in patients with persistently high caries activity, which is frequently indicated by recent restorations or untreated lesions. Frequent exposure to fermentable carbs, insufficient fluoride exposure, and compromised remineralization capacity are the most typical causes of this [23].

Low Socioeconomic Status: A higher incidence of WSL is closely linked to socioeconomic factors, such as poor eating habits, a lack of oral health education, and restricted access to dental treatment. Research indicates that children from lower socioeconomic origins are more likely to have delayed dental visits and poor oral hygiene [24].

Systemic Conditions Affecting Saliva: Additional determining elements in the formation of WSL include saliva and fluoride. Both exert considerable favourable effects on minimising mineral loss, either by eliminating fermentable substrates and acids, as seen with saliva, or by promoting mineral precipitation onto teeth, as observed with fluoride [25].

Orthodontic treatment-related factors

the mechanics and duration of orthodontic treatment itself can contribute significantly to WSL development:

Use of Fixed Orthodontic Appliances: Conditions such as xerostomia, diabetes mellitus, or medication-induced hyposalivation can impair the natural protective effects of saliva, including buffering capacity and mineral exchange. Reduced salivary flow creates a favourable environment for plaque retention and enamel demineralization Fixed appliances, such as brackets, bands, and wires, create retentive sites that favor plaque accumulation and impede mechanical plaque removal. These components also complicate access to critical areas during brushing, increasing the risk of enamel demineralization [26].

Inadequate Oral Hygiene During Treatment: Many patients experience a decline in oral hygiene compliance after appliance placement. If not consistently reinforced by the orthodontic team, this can lead to rapid plaque accumulation and increased WSL risk, especially in the early stages of treatment [27].

Longer Orthodontic Treatment Duration: Extended treatment times are directly correlated with higher WSL incidence. Prolonged exposure to plaque-retentive appliances gives demineralization more time to progress, particularly in patients with suboptimal hygiene practices [28].

Poor Bracket Placement: Improperly positioned brackets, especially those placed too close to the gingival margin, can exacerbate plaque accumulation in areas that are difficult to clean. This increases the likelihood of lesion formation in those regions [29].

Insufficient Orthodontic Force Control: Excessive or improperly distributed orthodontic forces may lead to areas of gingival inflammation or enamel microfractures, compromising oral hygiene maintenance and increasing lesion susceptibility. Gentle, controlled force application is essential to minimize iatrogenic effects [30].

Prevention of white spot lesions

oral Hygiene Education and Maintenance: Patient education on proper oral hygiene practices, including toothbrushing techniques, interdental cleaning, and the use of adjunctive oral hygiene aids, is crucial in preventing WSLs. Regular monitoring and reinforcement of oral hygiene practices throughout the orthodontic treatment period are essential [31].

Fluoride Use: It has been demonstrated that topical fluoride application through mouthwash, toothpaste, or professional fluoride treatments is useful in preventing WSLs. Additional protection can be obtained by using fluoride varnishes or gels and using toothpaste with a high fluoride content [32].

Remineralization Strategies: Early enamel lesions can be remineralized and additional demineralization can be avoided with the use of remineralizing agents, such as casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) pastes and fluoride-releasing resin materials [15].

Antimicrobial Agents: Antimicrobial products, including mouthwashes or varnishes containing chlorhexidine, can lessen the amount of germs in the oral cavity and stop WSLs from developing. However, because of the possibility of adverse consequences, its long-term usage should be closely monitored [33].

Diet Modification: Dietary changes that lessen the acid assault on the enamel and lower the likelihood of WSL development include cutting back on fermentable carbohydrates and acidic beverages. For general dental health, it is also advantageous to promote a well-balanced diet high in vitamins and minerals [34] (Table 4).

Table 4. Preventive measures effective in reducing the incidence of white spot lesions

Таблица 4. Профилактические меры, эффективные для снижения частоты появления белых пятен

Research Question	Preventive Measures
What preventive measures are effective against WSLs?	Regular and effective oral hygiene practices, adequate fluoride exposure, low sugar and acid intake, remineralizing agents
What are the effective oral hygiene practices for WSLs?	Proper brushing techniques, use of fluoride toothpaste and mouthwash, interdental cleaning, regular dental check-ups
What are the dietary modifications to prevent WSLs?	Limiting sugar and acidic food and beverage consumption, increasing calcium intake, balanced diet
What are the preventive measures for specific patient groups?	Tailored oral hygiene instructions, use of antimicrobial agents, additional fluoride supplementation, saliva substitutes

Management of white spot lesions

Non-invasive treatment options

wSLs can be treated non-invasively to enhance appearance, encourage enamel remineralization, and limit the progression of the lesion without compromising tooth structure. These methods are becoming more and more popular since they are conservative and work particularly well for early, non-cavitated lesions.

Topical Fluoride Applications: Enamel remineralization is greatly aided by high-concentration fluoride products, including as mouthwashes, gels, and varnishes containing 5% sodium fluoride. Fluoride ions help hydroxyapatite change into fluorapatite, a mineral phase that is more resistant to acid. During orthodontic treatment, these treatments fortify the enamel and lessen the vulnerability to demineralization, particularly in high-risk individuals. Over time, consistent use at home or in the workplace can dramatically lower the depth and activity of WSLs. Furthermore, when used sporadically throughout orthodontic treatment, fluoride varnishes have demonstrated effectiveness in avoiding the development of new lesions [35].

Casein Phosphopeptide-Amorphous Calcium Phosphate (CPP-ACP): CPP-ACP formulations, available in pastes and sugar-free chewing gums, serve as a reservoir for calcium and phosphate ions, the building blocks of enamel. These agents help stabilize ion concentrations at the enamel surface, facilitating natural remineralization processes. CPP-ACP is particularly beneficial in patients with salivary deficiencies or poor dietary habits. When used in conjunction with fluoride, its synergistic effect enhances the formation of fluorapatite and leads to faster regression of visible WSLs. Its non-invasive nature and ease of application make it a valuable adjunct in orthodontic patients who are prone to plaque accumulation around brackets [36].

Resin Infiltration: Resin infiltration, a microinvasive technique primarily using low-viscosity light-curing resins (e.g., Icon®), aims to arrest WSL progression and simultaneously mask the chalky white appearance. By infiltrating the microporosities in the enamel, the resin alters the lesion's optical properties, significantly improving aesthetics. This technique is ideal for post-orthodontic WSLs and is particularly effective for anterior teeth where aesthetics are paramount. Clinical studies have shown that resin infiltration can achieve long-term colors stability and reduce the need for more aggressive restorative interventions [37].

Microabrasion: Enamel microabrasion combines the mechanical action of abrasive particles with mild acidic agents (typically hydrochloric acid-pumice slurry) to remove a superficial enamel layer. This technique is indicated for superficial WSLs confined to the outermost enamel and is often used in conjunction with polishing to achieve a uniform surface lustre. Microabrasion can produce immediate aesthetic results, especially for shallow lesions or localized opacities. However, it is best reserved for cases where lesion depth is minimal and should be performed conservatively to avoid unnecessary enamel loss [38].

Invasive treatment options

for WSLs that do not respond adequately to non-invasive treatments or have progressed to irreversible enamel damage or cavitation, invasive restorative approaches become necessary. These options aim to restore both function and aesthetics, particularly when lesions compromise enamel integrity or patient expectations are high.

Composite Resin Restorations: Direct composite resin restorations are often indicated when WSLs have progressed to cavitated lesions or when enamel breakdown is evident. This conservative approach involves the removal of affected enamel and the placement of tooth-coloured resin materials, allowing immediate restoration of form, function, and aesthetics. Composite resins offer the advantage of minimal tooth preparation and high polishability, making them a favourable option for anterior teeth. They are also relatively cost-effective and can be completed in a single visit. Long-term success depends on proper isolation, bonding technique, and patient oral hygiene [39].

Porcelain Veneers or Ceramic Crowns: In cases where WSLs are extensive, deeply etched, or aesthetically disfiguring especially in the anterior aesthetic zone more comprehensive coverage may be required. Porcelain veneers offer a minimally invasive yet highly aesthetic solution by masking the underlying white opacities and restoring a natural appearance. They are bonded to the facial surfaces of teeth and can be customized for colors, shape, and translucency. In situations involving significant enamel loss, multiple surfaces, or when structural support is compromised, full-coverage ceramic crowns may be more appropriate. While these options are more invasive and costly, they provide long-lasting aesthetic outcomes and improved resistance to staining and wear [35].

Aesthetic Considerations

When WSLs persist despite preventive and non-invasive treatments, aesthetic management becomes an important aspect of patient satisfaction, especially in cases involving anterior teeth. The visual impact of these lesions can be significant, particularly in adolescents and young adults, affecting self-confidence and overall perception of orthodontic treatment outcomes.

Bleaching: Professional dental bleaching using hydrogen peroxide or carbamide peroxide-based agents can reduce the optical difference between WSLs and adjacent sound enamel. Although bleaching does not remove the lesions, it lightens the surrounding enamel, thereby masking the white opacity and improving the overall appearance. However, bleaching should be approached with caution in active lesions, as it may cause transient sensitivity or further dehydration of the enamel if not properly indicated [40].

Orthodontic Treatment Planning: Strategic planning during orthodontic therapy can help minimize the visual prominence of WSLs. For example, placing brackets in a way that avoids known areas of demineralization or using customized appliance systems can reduce plaque retention and make oral hygiene maintenance easier. Additionally, treatment techniques such as staged bonding or using self-ligating brackets may contribute to better enamel preservation. In patients with pre-existing WSLs, clinicians may also consider short-term aesthetic interventions post-treatment, such as resin infiltration or conservative restorations, as part of the finishing phase to enhance the final smile aesthetics [41].

Future directions and research recommendations

WSLs in orthodontic patients have been better understood and managed, however there are still a number of unexplored areas that require further research.

Development of novel remineralizing agents

future research ought to concentrate on creating and assessing next-generation remineralizing agents that surpass fluoride and CPP-ACP. Because of their higher enamel penetration and biomimetic qualities, delivery technologies based on nanotechnology, including as peptide-based remineralizers, nano-hydroxyapatite, and bioactive glass, present promising substitutes. To evaluate their effectiveness and long-term safety in orthodontic populations, longitudinal clinical trials are required.

Personalized risk assessment models

there is a need for the development of individualized WSL risk prediction tools using artificial intelligence (AI), machine learning, and salivary diagnostics. Incorporating patient-specific factors such as genetics, salivary flow, microbiome profiles, and dietary habits into predictive models could enable orthodontists to implement tailored prevention strategies early in the treatment process.

Standardization of diagnostic criteria

currently, variations in diagnostic tools and criteria across studies hinder the comparability of WSL prevalence and treatment outcomes. Future studies should prioritize the adoption of standardized, validated assessment methods such as the International Caries Detection and Assessment System (ICDAS), quantitative light-induced fluorescence (QLF), or digital image analysis to ensure consistency in WSL detection and grading.

Long-term outcome studies

most studies assessing preventive and therapeutic strategies for WSLs are of short duration and lack follow-up. Well-designed longitudinal clinical trials are necessary to evaluate the durability, aesthetic stability, and relapse rates of various treatment modalities, including resin infiltration and bleaching.

Integration of preventive protocols into orthodontic practice

more research is needed to evaluate the clinical and cost-effectiveness of implementing structured preventive protocols such as fluoride varnish programs, diet counselling, and patient education apps within orthodontic care. Studies should assess patient compliance, satisfaction, and behavior modification outcomes to inform practical, evidence-based guidelines.

Multidisciplinary collaboration

future initiatives should encourage collaboration among orthodontists, preventive dentists, material scientists, and digital health specialists to advance the clinical management of WSLs. Integrating emerging technologies such as smart brackets, antimicrobial coatings, and salivary biomarker testing into orthodontic workflow may open new avenues for prevention and early intervention.

CONCLUSION

This review synthesized current evidence on WSLs in orthodontic patients, addressing their prevalence, etiology, risk factors, prevention, and management. WSLs are a frequent complication of fixed orthodontic treatment, with contributing factors including poor oral hygiene, high sugar intake, acidic oral environment, and reduced salivary protection. Risk factors such as prolonged treatment duration, inadequate fluoride exposure, and appliance design further increase susceptibility. Patient-related elements, including age, caries history, and dietary habits, also play a significant role. Preventive strategies emphasized regular oral hygiene, fluoride use, dietary adjustments, and remineralizing agents, with tailored approaches recommended for high-risk individuals. Management options for existing lesions include microabrasion, resin infiltration, remineralization therapies, and aesthetic restorations, aimed at improving both enamel integrity and appearance.

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А. Кхарче – внесла существенный вклад в разработку концепции и дизайна статьи, подготовила первоначальный текст статьи и/или выполнила его критическое редактирование с точки зрения значимого интеллектуального содержания.

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С. Дешмукх – участвовала в подготовке текста статьи и/или его критическом пересмотре с точки зрения значимого интеллектуального содержания, утвердила версию статьи для публикации.

А. Матхур – участвовала в сборе, анализе и интерпретации данных для статьи, утвердила версию статьи для публикации.

Original Research

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Distribution of dental caries in primary schoolchildren in Al-Samawah City

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Abstract

INTRODUCTION. Dental caries is teeth decay due to bacteria. One of the most preventable of oral health problems and the most prevalent ongoing health issue in primary school children, it is also the most anticipated chronic disorder in children around the globe. Bad oral health influences the quality of life of children.

AIM. The aim of this study was to establish the prevalence rate of dental carries and the potential demographical variables among the major pupils in the primary school in the Al-Samawah City.

MATERIALS AND METHODS. This survey study conducted between February and June 2025 and, carried out in Al-Muthanna province in four schools (2 public + 2 private) randomly drawn from a list of all primary schools in the governorate. This study used a total sample of 100, 5 schools was also used in random selection of 25 children in each school who were taken to the dentists by the research personnel, to determine the prevalence on Dental caries and other relevant information on the demographical characteristic and sociodemographic status was obtained through a structured questionnaire that was set aside to carrying it out. The data analyses were conducted using the Statistical Package for Social Sciences (SPSS) version-23.

RESULTS. Overall, the results of this study revealed the highest no. of dental caries was in children of private school (48), while the non-dental caries children prevalence highest in public school with no (10). However, numbering of decay teeth according to type of school illustrated of the following [the no. of children that not have dental caries in public school were highest (10), while the no. of children that have (1-4) teeth decay were highest in public school also with no (29). In contrast to that, the private school children illustrated highest no. of dental caries in (4-10) and in more than 10 teeth with numbering (16 and 5, respectively). In term of cleaning status of children, the college or institutional education level of father showed highest percentage in public and private school (39.13% and 63.64%, respectively). On the other hand, the highest percentage of tooth brush children in public school was in intermediate economic level family (67.39%), while the highest percentage of tooth brushing children in private school were in good economic level family (65.91%). Overall, study findings indicated that it was found that a higher no. of dental caries was related to that of a children, mothers and fathers with secondary as well as, college or institutional education level.

CONCLUSIONS. The study is useful in giving me ideas on the distribution patterns and causes of caries as well as influences of the sociodemographics on dental caries in adolescent schoolchildren. According to this research, in general, a wide range of prevalence of dental caries among primary schoolchildren was present in the Al-Muthanna province. But the difference in the prevalence rates is seen in respect of sampling technique, sample size related to the factors associated with this province like economic conditions of the family, education level of mother and father and youngsters brushing their teeth. Nevertheless, the findings depicted that the highest no. of dental caries was observed in kids of a private school. In addition, more decay teeth were linked with a child whose parents had secondary and as well as college or institutional education level.

Keywords: dental decay, schoolchildren, Al-Muthanna province, prevalence, public school

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Особенности распределения кариеса зубов среди детей младшего школьного возраста в г. Эс-Самава

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Резюме

ВВЕДЕНИЕ. Кариес зубов представляет собой разрушение твердых тканей зуба, обусловленное деятельностью бактерий. Он является одной из наиболее предотвратимых стоматологических проблем и одновременно наиболее распространенным хроническим заболеванием среди детей младшего

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школьного возраста. Во всем мире кариес рассматривается как одно из наиболее ожидаемых хронических расстройств детского возраста. Плохое состояние полости рта существенно влияет на качество жизни детей.
ЦЕЛЬ. Целью данного исследования было определить уровень распространенности кариеса зубов и возможные демографические факторы среди учащихся начальных школ города Эс-Самава.
МАТЕРИАЛЫ И МЕТОДЫ. Настоящее обследовательское исследование проводилось в период с февраля по июнь 2025 г. в провинции Аль-Мутанна. В исследование были включены четыре школы (2 государственные и 2 частные), случайным образом отобранные из общего списка начальных школ губернаторства. Общий объем выборки составил 100 детей. В каждой школе методом случайного отбора было включено по 25 учащихся, которые были осмотрены стоматологами исследовательской группы для определения распространенности кариеса. Дополнительная информация о демографических и социально-экономических характеристиках собиралась с использованием структурированной анкеты. Статистическая обработка данных проводилась с использованием пакета программ Statistical Package for Social Sciences (SPSS), версия 23.
РЕЗУЛЬТАТЫ. В целом результаты исследования показали, что наибольшее число случаев кариеса выявлено у детей частных школ (48), тогда как наибольшая распространенность отсутствия кариеса наблюдалась среди учащихся государственных школ (10). Анализ количества пораженных зубов в зависимости от типа школы показал, что наибольшее число детей без кариеса было в государственных школах (10), а также максимальное количество детей с поражением 114 зубов также отмечено в государственных школах (29). В то же время среди учащихся частных школ наибольшее число случаев кариеса приходилось на группы с поражением 4-10 зубов и более 10 зубов (16 и 5 соответственно). С точки зрения гигиенического статуса, наибольший процент отцов с высшим или институциональным уровнем образования был выявлен как в государственных, так и в частных школах (39,13 и 63,64 % соответственно). Кроме того, наибольший процент детей, регулярно использующих зубную щетку, в государственных школах наблюдался в семьях со средним уровнем дохода (67,39 %), тогда как в частных школах – в семьях с высоким экономическим уровнем (65,91 %). В целом результаты исследования показали, что большее число кариозных поражений ассоциировано с детьми, а также с уровнем образования матерей и отцов, имеющих среднее и высшее (колледжное или институциональное) образование.
ВЫВОДЫ. Проведенное исследование позволяет получить представление о закономерностях распределения кариеса и факторах, влияющих на его развитие, а также о роли социально-демографических показателей в формировании стоматологического статуса школьников. В провинции Аль-Мутанна выявлен широкий диапазон распространенности кариеса среди учащихся начальных школ. Различия в показателях распространенности связаны с методикой отбора, объемом выборки и факторами, характерными для данной провинции, такими как экономическое положение семьи, уровень образования родителей и гигиенические навыки детей. При этом установлено, что наибольшее число кариозных поражений наблюдалось у детей частных школ. Кроме того, большее количество пораженных зубов отмечалось у детей, родители которых имели среднее и высшее (колледжное или институциональное) образование.

Ключевые слова: кариес зубов, школьники, провинция Аль-Мутанна, распространенность, государственная школа

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INTRODUCTION

Dental caries or tooth decay Worldwide, it is one of the most common chronic diseases encountered by people, that is, there is no age limit to encounter the disease. The condition occurs as a result of long and complicated interaction that involves acid producing bacteria and the presence of fermentable carbohydrates in a combination of several host factors such as teeth and saliva [1; 2]. Very alarming especially in children because dental caries weakens even the treated tooth structures yet it promotes the growth and development of the afflicted child. Pain during chewing may cause child to have poor nutritional status hence missing school. Dental caries is also on the rise in the developing countries due to many factors including consumption of cariogenic foodstuffs, poor oral care, socio economic, health, age, accessibility to health provision and other lifestyle issues [3].

Severe untreated caries can potentially impair children's growth due to poor oral intake and weight loss. Additionally, affected children have been found to gain weight rapidly after receiving proper dental care [4]. Additionally, aesthetic appearance is a significant factor that affects the self-esteem and social interactions of children [5]. Dental interventions and preventive remedies can be employed to mitigate the adverse effects of dental caries on children and enhance their overall quality of life [6]. The (D) Index indicated that the overall prevalence of dental caries was 76.4%. In a study conducted in Saudi Arabia in 2025, the prevalence of dental caries was 86.4%, 82.4%, 70%, and 50% for the ages of 8, 7, 6, and 12 years, respectively [4].

Mahmood et al. conducted an additional study that demonstrated that a serum Vitamin D level of 15 ng/mL or higher and a normal body mass index (BMI) are associated with a lower caries index in children [7].

At the age of 12, dental caries was prevalent at 32.6%. At the age of 12, females exhibited a greater incidence of caries than males at both ages. In Himachal Pradesh, India, children attending government schools exhibited a higher incidence of dental caries than those attending private schools [8].

According to the research developed by Al-Akwa and Al-Maweri, 2018, about 67.6 percent of children were affected by dental caries in Yamen and children living in urban districts recorded higher average scores than the ones living in rural districts [9].

Kareem and his colleagues demonstrated in their research that the prevalence rate of dental caries in Karbala city was 95.60% [10].

AIM AND METHODS

This survey study carried out in Al-Muthanna province from February to June 2025; in following four schools randomly drawn from a list of all primary schools in the governorate included (Ahrar Al-Iraq Elementary School for Boys and Amina bint Wahb for girls) these are attended public school. While, the other two schools included (Uruk Girls School and Al-Kindi Boys School) are private. The 100-sample included in this study were randomly selected and examined by dentists as well as, all demographical characteristic such as "the child's age and gender, level of education for mother and father of children, the economic status of the family, cleaning children's teeth and number of decayed teeth" and other information are recorded by questioner designated for this purpose. However, from each school 25 children selected. The age ranged is 12 years for all selected children and sex of children included are (50 male + 50 female).

Statistical analysis

The data that was collected was analysed using the Statistical Package for Social Sciences (SPSS) version 23 (SPSS, An IBM Company). The descriptive analysis was conducted by computing frequency distributions and percentages for the research variables, including the level of education, the economic status of the family, the number of decayed teeth, and the dental cleaning of children.

RESULTS

The purpose of this study was to determine the prevalence and risk factors for caries among children in Samawa City. A total of 100 suitable schoolchildren (25 from each school), aged 12 years, were involved. Females accounted for 50 children, while 50 children were male.

Distribution of cleaning children's teeth according to type of school

The distribution of cleaning status of children teeth are recorded in (Fig. 1) were the tooth brushing level in public school children higher than in private school (46 vs. 45). On the other hand, the level of non-tooth brushing children in private school were higher than in public (6 vs. 3).

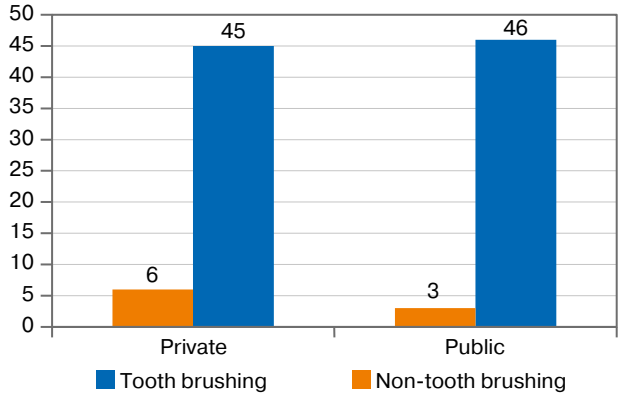

Fig. 1. Distribution of tooth brushing for children according to type of school

Рис. 1. Распределение частоты чистки зубов у детей в зависимости от типа школы

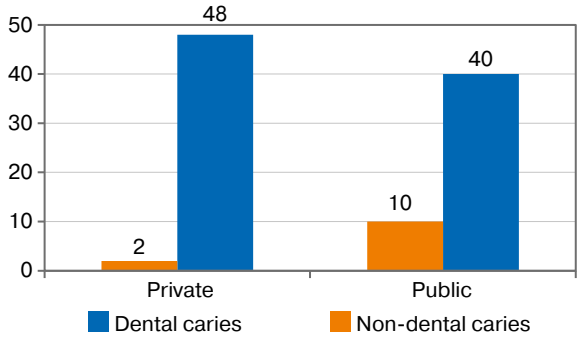

Fig. 2. Distribution of participants according to presence of dental caries or non

Рис. 2. Распределение участников в зависимости от наличия или отсутствия кариеса зубов

Distribution of participants according to presence of dental caries or non

Figure 2 depicts the distribution of dental caries in primary children based on school type, with (48 vs. 40) representing the distribution levels of dental caries for children in private and public schools, respectively. The frequency of non-dental caries among children was as follows (10 vs. 2 in public and private schools, respectively).

Prevalence of decay teeth according to type of school

The prevalence of decay teeth of children in public school children as following [10 children not have dental caries, 29 children have dental caries in number (1-4) of teeth, 11 children have dental caries in numbering of (4-10) of teeth, as well as the number of children these have dental caries in more than 10 of teeth were 1].

Conversely, the prevalence of dental caries among private school students was as follows: 3 children had no dental decay, 27 children had decay affecting 4 to 10 teeth, 16 children had decay in 4 to 10 teeth, and 5 children had decay in more than 10 teeth, as seen in Fig. 3.

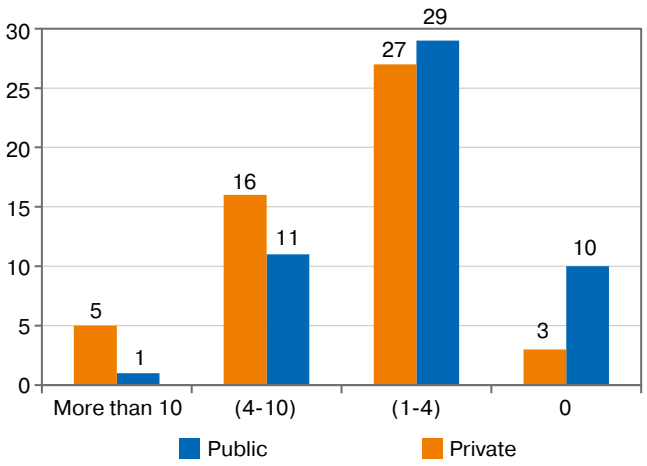

Fig. 3. Numbering of decay teeth according to type of school

Рис. 3. Количество кариозных зубов в зависимости от типа школы

On the other hand, in private school the highest prevalence rate of tooth brushing were in college educational level of children (63.64%), while lowest percentage was in paternal postgraduate (9.09%). However, the percent of non-tooth brushing children was equally distributed in primary and secondary educational level in percentage were (33.33%), respectively. While, in college level was (33.34%). Meanwhile, the lowest percentage was in postgraduate father (0.00%) as in the (Fig. 4).

Distribution of cleaning status according to mother educational level

The Fig. 4 showed the cleaning status distribution according to educational level of father; were the highest percentage of tooth brushing in public school in children these have secondary father education level (39.13%), while the lowest percentage was in postgraduate father (0.00%). In contrast, the percentage of non-tooth brushing children were equally distributed in primary and college father education in percentage (50.00%).

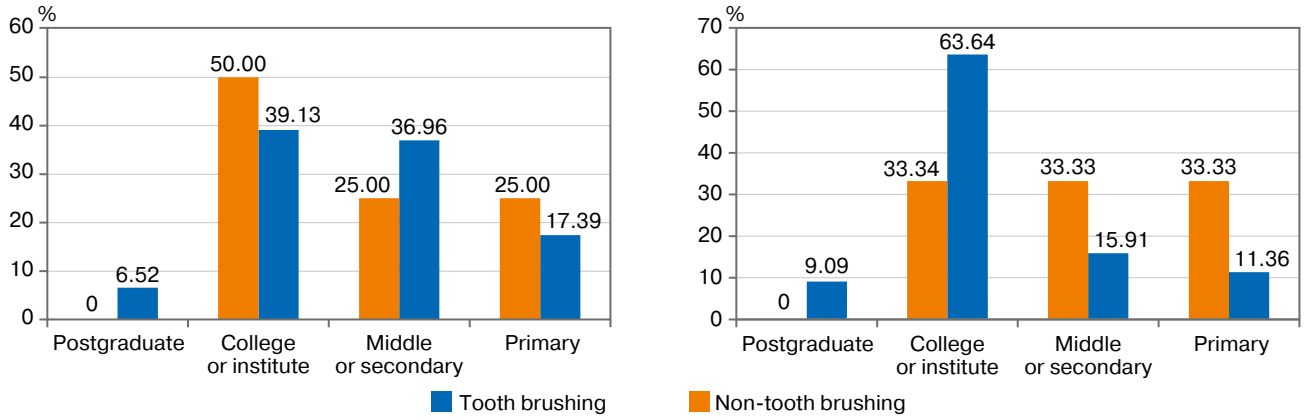

Fig. 4. Cleaning status distribution according to paternal educational level in public school (*A*) and in private school (*B*)

Рис. 4. Распределение гигиенического статуса детей в государственных школах (*A*) и в частных школах (*B*) в зависимости от уровня образования отцов

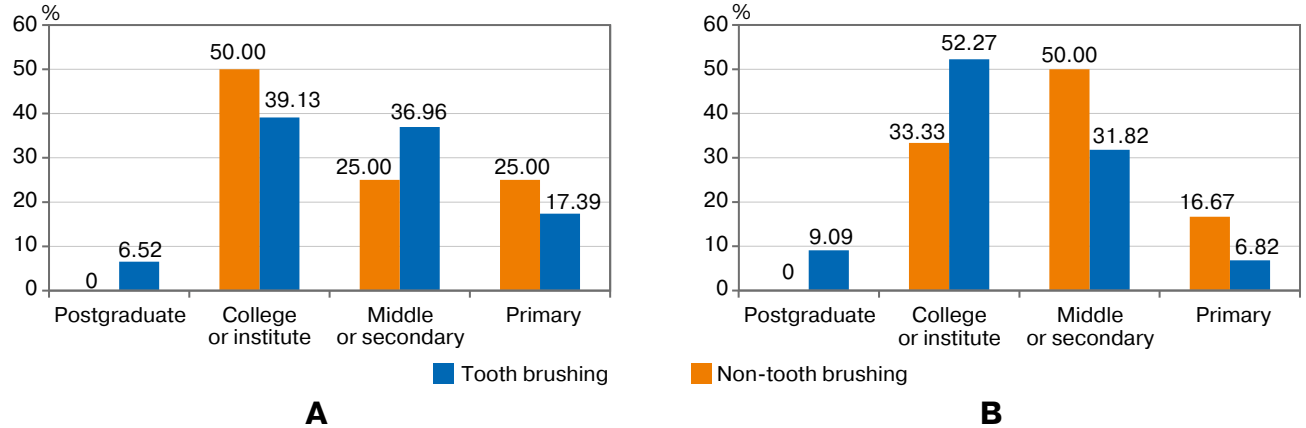

Fig. 5. Distribution of cleaning status in public school (*A*) and in private school (*B*) according to maternal educational level

Рис. 5. Распределение гигиенического статуса детей в государственных школах (*A*) и в частных школах (*B*) в зависимости от уровня образования матерей

As well as, equally distributed in secondary and postgraduate father of children in percent (0.00%). On the other hand, in private school, the highest prevalence rate of tooth brushing were in college educational level of children (52.27%), while lowest percentage was in primary father (6.82%). However, the percent of non-tooth brushing children was highest in college or instituted father level (33.33%). While, the lowest percentage level was in postgraduate father (0.00%) as in (Fig. 5).

Distribution of cleaning status of children according to father educational level

The Table 1 revealed the cleaning status distribution according to paternal educational level; were the highest percentage of tooth brushing in public school in children these have college or institute father education level (39.13%), while the lowest percentage was in postgraduate father (6.52%). In contrast, the lowest percentage of non-tooth brushing children in postgraduate educational father level (0.00%). While, the highest percentage was in college or institutional education level with percentage (50.00%).

On the other hand, in private school the highest prevalence rate of tooth brushing were in college educational level of children (63.64%), while lowest percentage was in paternal postgraduate (9.09%). However, the percent of non-tooth brushing children was equally distributed in primary and secondary educational level in percentage were (33.33%), respectively. While, in college level was (33.34%). Meanwhile, the lowest percentage was in postgraduate father (0.00%).

Distribution of cleaning status according to mother educational level

The Table 2 showed the cleaning status distribution according to educational level of mother; were the highest percentage of tooth brushing in public school in children these have secondary mother educational level (39.13%), while the lowest percentage was in postgraduate mother education (0.00%). In contrast, the percentage of non-tooth brushing children were equally distributed in primary and college mother education in percentage (50.00%). As well as, equally distributed in secondary and postgraduate mother of children in percent (0.00%).

On the other hand, in private school, the highest prevalence rate of tooth brushing were in college educational level of children (52.27%), while lowest percentage was in primary mother (6.82%). However, the percent of non-tooth brushing children was highest in college or instituted mother level (33.33%). While, the lowest percentage level was in postgraduate maternal level (0.00%).

Prevalence Dental caries according to school type and paternal educational level

The Table 3 showed the numbering of decay teeth according to educational status of father. In public school, the highest percentage of children that not have dental decay were in these have primary father education level (60.00%), while the lowest percentage was in secondary and postgraduate father (0.00%). In contrast, the percentage of children these have (1-4) decay

Table 1. Cleaning status distribution according to paternal educational level (%)

Таблица 1. Распределение гигиенического статуса детей в зависимости от уровня образования отцов, %

Educational status of father	Public		Private	
	Tooth brushing	Non-tooth brushing	Tooth brushing	Non-tooth brushing
Primary	17.39	25.00	11.36	33.33
Middle or secondary	36.96	25.00	15.91	33.33
College or institute	39.13	50.00	63.64	33.34
Postgraduate	6.52	0.00	9.09	0.00
Total	100.00	100.00	100.00	100.00

Table 2. Distribution of cleaning status according to maternal educational level (%)

Таблица 2. Распределение гигиенического статуса детей в зависимости от уровня образования матерей, %

Educational level of mother	Public		Private	
	Tooth brushing	Non-tooth brushing	Tooth brushing	Non-tooth brushing
Primary	26.09	50.00	6.82	16.67
Middle or secondary	39.13	0.00	31.82	50.00
College or institute	34.78	50.00	52.27	33.33
Postgraduate	0.00	0.00	9.09	0.00
Total	100.00	100.00	100.00	100.00

teeth were highest distributed in the college father education in percentage (44.83%), while, lowest in primary father of children (13.79%). However, the children that have secondary father education have highest percentage level of dental caries (63.64%) with range (4-10), while the lowest percentage was in postgraduates' father of children. Furthermore, all children not have dental caries more than 10 as in table below.

On the other hand, in private school, the children that have college father education have highest prevalence rate of non-dental caries (66.67%), followed by postgraduates' father of children with percentage (33.33%). The children that have college education have teeth caries in (1-4) teeth with highest percentage (53.85%), likewise, the highest percentage of dental decay in (4-10) teeth were in college father education. Lastly, the highest percentage of dental decay in more than 10 teeth was in college or institutional father educational level (80.00%) as in the table above.

Numbering of Dental caries according to type of school and maternal educational

The Table 4 showed the numbering of decay teeth according to educational status of mother. In public school, the highest percentage of children that not have dental decay were in these have primary father education level (50.00%), while the lowest percentage was in postgraduate father (0.00%). In contrast, the percentage of children these have (1-4) decay teeth were highest distributed in the secondary mother education in percentage (44.83%), while, lowest in postgraduates' mother of children (00.00%). However, the children that have college mother education have highest percentage level of dental caries (45.45%) with range (4-10), while the lowest percentage was in postgraduates' mother of children (0.00%). Furthermore, all children not have dental caries more than 10 as in table below.

On the other hand, in private school, the children that have college mother education have highest prevalence rate in of non-dental caries (100.00%). The children that have college education of mother have dental caries in (1-4) teeth with highest percentage (50.00%), likewise, the highest percentage of dental decay in (4-10) teeth were in college or institutional mother education (47.37%). Lastly, the highest percentage of dental decay in more than 10 teeth was in secondary or middle mother educational level (60.00%) as in the table above.

Distribution of cleaning status according to school type in relation to socioeconomic level of family

The Table 5 illustrated the cleaning status distribution according to socioeconomic level of family; were in public school the highest percentage of tooth brushing seen in family of intermediate economic level with percentage level (67.39%), while the non-tooth brushing children showed equally distribution (50.00%) in intermediate and good economic level family. In another side, in private school; the highest percentage of tooth brushing children seen in family that have good economic status (65.91%). However, the family of middle economic level had highest percentage (66.66%) of non-tooth brushing children as shown in table below.

Table 3. Numbering of decay teeth according to paternal educational level (%)

Таблица 3. Количество кариозных зубов в зависимости от уровня образования отцов, %

Educational level of father	Public				Private			
	No. of decay teeth							
	0	1-4	4-10	>10	0	1-4	4-10	>10
Primary	60.00	13.79	18.18	0.00	0.00	15.38	18.75	0.00
Middle or secondary	0.00	37.93	63.64	0.00	0.00	19.23	18.75	20.00
College or institute	40.00	44.83	18.18	0.00	66.67	53.85	56.25	80.00
Postgraduate	0.00	3.45	0.00	0.00	33.33	11.54	6.25	0.00
Total	100.00	100.00	100.00	0.00	100.00	100.00	100.00	100.00

Table 4. Numbering of decay teeth according to maternal educational level (%)

Таблица 4. Количество кариозных зубов в зависимости от уровня образования матерей, %

Educational level of mother	Public				Private			
	No. of decay teeth							
	0	1-4	4-10	>10	0	1-4	4-10	>10
Primary	50.00	24.14	27.27	0.00	0.00	10.71	5.26	0.00
Middle or secondary	10.00	44.83	27.27	0.00	0.00	28.57	42.11	60.00
College or institute	40.00	31.03	45.46	0.00	100.00	50.00	47.37	40.00
Postgraduate	0.00	0.00	0.00	0.00	0.00	10.72	5.26	0.00
Total	100.00	100.00	100.00	0.00	100.00	100.00	100.00	100.00

Table 5. Distribution of cleaning status according to socioeconomic level of family (%)

Таблица 5. Распределение гигиенического статуса детей в зависимости от социально-экономического уровня семьи, %

Socioeconomic level of family	Public		Private	
	Tooth brushing	Non-tooth brushing	Tooth brushing	Non-tooth brushing
Weak	0.00	0.00	0.00	0.00
Intermediate	67.39	50.00	34.09	66.66
Good	32.61	50.00	65.91	33.34
Total	100.00	100.00	100.00	100.00

Table 6. Numbering of decay teeth according to socioeconomic level of family (%)

Таблица 6. Количество кариозных зубов в зависимости от социально-экономического уровня семьи, %

Socioeconomic level of family	Public				Private			
	No. of decay teeth				No. of decay teeth			
	0	1-4	4-10	>10	0	1-4	4-10	>10
Weak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Middle	63.64	68.97	54.55	0.00	0.00	39.29	40.00	25.00
Good	36.36	31.03	45.45	0.00	100.00	60.07	60.00	75.00
Total	100.00	100.00	100.00	0.00	100.00	100.00	100.00	100.00

Dental caries prevalence in relation to the socioeconomic status of the family

The prevalence of decay teeth of children in public school children as following [the intermediate socioeconomic level of family showed highest percentage of children that not have dental caries with level (63.64%), also, the highest percentage of children that have (1-4) dental caries were in middle family level (68.97%), likewise, the children that have (4-10) teeth decay have highest level of percentage in middle family socioeconomic level (54.55%), whereas, the public school children not have and teeth decay in more than 10 of teeth].

On the other hand, in private school; [the (100.00%) of children not have dental caries in good socioeconomic level family, (60.07%) of children have dental caries in number (1-4) of teeth, (60.00%) of children have dental caries in numbering of (4-10) of teeth, as well as the percentage of children these have dental caries in more than 10 of teeth were (75.00%), respectively in good socioeconomic level of family] as shown in the (Table 6).

DISCUSSION

Globally, dental caries persists as a significant chronic problem, impacting 60–90% of school-aged children and virtually all adults [11]. The frequency of caries in this research was correlated with the kind of school, household socioeconomic position, and parental education levels. Furthermore, the tooth brushing findings of this study are inconsistent with those of Ridho and Sofyan, who asserted that low parental income adversely affects the maintenance of oral health services for their children. Conversely, higher parental income and education correlate with a reduced incidence of caries in children. Notably, this study observed the highest prevalence of dental caries in private schools [12].

Karki et al. reported a significant incidence of dental caries among schoolchildren, attributing it to the low frequency of teeth brushing and other contributing factors [13].

Furthermore, children enrolled in public schools, whose parents possessed only primary education or less, along with those from low socioeconomic status (SES) backgrounds, demonstrated the highest incidence of dental caries in the study conducted by Alshayeb and Dashash [14]. Additionally, it was shown that children who did not engage in regular tooth brushing, failed to utilise dental floss or mouthwash, sought dental care solely when necessary, and lacked parental oversight, all contributed to the prevalence of caries, corroborating the findings of this study [15].

In an alternative context, Alhaffar et al. reported that the caries prevalence among 12-year-olds reached 86% by 2019 [16]. Nonetheless, it corresponds with the 2023 research conducted by Mesrabi et al., which reported a caries prevalence of 90.4% among children aged 10–13 years in Damascus [17], among comparable rates in Iran (89.9%) [18] and Saudi Arabia (91.3%) [19].

The result of such variation in prevalence in this study is probably because of the differences in sample size, demographic factor, dietary habits, which can explain the differences in the results as compared to other studies done in Iraq like study by Baghdady and Ghose in Baghdad [20].

In certain tables of this study, the prevalence of dental caries was higher among children from families with reduced socioeconomic status (SES). This finding is consistent with the findings of the study conducted by Alshayeb and Dashash in 2025 [14]. Nevertheless, the findings of this investigation fail to align with those of Alshayeb and Dashash, who demonstrated that the

prevalence of cavities was substantially higher in children attending public schools than in private schools.

Similarly, additional studies have shown a greater frequency of caries in children from better socioeconomic status households, perhaps because to increased sugar intake and frequent snacking [21; 22]. Ghandour, however, identified no statistically significant disparity in caries frequency between socioeconomic categories [23]. These results contradict research associating poor socioeconomic status with heightened caries risk [24; 25].

The occupation of mother presents a complex effect on the oral health and caries levels of the children. That can be explained by the fact that there might be less supervision and irregular family routine, and that can negatively influence the diet, oral care [26–32].

CONCLUSION

The dental caries prevalence among the schoolchildren of the age group 12 years in this study revealed that there is a variation in terms of prevalence between the public and private school students of Al-Samawah City. Over about sampling techniques, amount of sample relative to associated factors in this province; in general, these outcomes portrayed that highest prevalence no of dental caries was in Children of non-government school. Additionally, more decaying teeth have been found to relate to a child whose parents possess secondary and in addition, college or institutional education qualification. That, the present findings indicated the most significant importance of dental caries prevention and dental caries treatment amongst the school children.

RECOMMENDATIONS

The low prevalence of caries among kids should be maintained by creating more awareness and introducing effective measures of oral health care to enhance the dental health of the school kids in Samawa city further. The authors of this study suggest that the nutritional status of school children should be studied with greater sample size and greater dispersion of the schools in this province, and regional distribution of dental caries should also be studied since they may have substantial influence not only on the gingival health but also, on the development of a good nutritional school program, moreover, it is suggested to develop study surveys that can be undertaken after every five years that can monitor dental caries and effectiveness of such a program. All in all, the regular visit to the dentist, dental floss, and the brush to reduce the incidences of dental caries in children.

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Original Research

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Gender differences in dental caries intensity in young and preschool children living in Moscow

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Abstract

INTRODUCTION. Early childhood caries (ECC) is one of the most pressing and unresolved problems in modern pediatric dentistry. The incidence and severity of this pathology show no trend toward decline worldwide. Some researchers note gender differences in caries incidence rates, while other studies deny a link between caries rates and gender. It is believed that the primary mechanisms underlying the genetic influence on the higher prevalence and severity of dental caries in females compared to males lie in the sex chromosomes, demonstrating sex-linked inheritance patterns. Delayed dental development in boys is due to the fact that males have larger teeth, which requires a longer development time. The causes of sexual dimorphism in dental development are associated with differential activity of genes that control dental tissue histogenesis.

AIM. To study the index of dental caries intensity and its structural components in children aged 1 to 5 years living in Moscow, depending on age and gender.

MATERIALS AND METHODS. A survey of children aged 1 to 5 years in Moscow was conducted. All children were categorized by age and gender. The average dental caries incidence was calculated for each age group and by gender. The results were analyzed statistically.

RESULTS. An analysis of dental caries incidence in young and preschool-aged children showed that this indicator increases with age. Statistically significant differences in caries incidence were found between age groups ($H = 27.83$; $df = 4$; $p < 0.001$). Statistically significant differences were found separately for boys and girls ($p < 0.001$ and $p = 0.0002$, respectively). A comparison of caries incidence in different age groups using the nonparametric Mann-Whitney test showed that caries incidence was higher in girls than in boys ($p = 0.000003$). At 1 and 5 years of age, the caries intensity in boys and girls differs statistically significantly ($p = 0.000003$ and $p = 0.002$, respectively), while for ages 2 to 4, the differences are statistically insignificant ($p = 0.123$, $p = 0.103$, and $p = 0.730$, respectively, for ages 2, 3, and 4).

In the caries intensity index, the "*k*" indicator (caries) predominates across all age groups, and this indicator is higher in girls than in boys.

CONCLUSIONS. Dental caries occurs in all age groups and in both sexes. At all ages, the "*k*" component – caries of primary teeth – predominates in the intensity index structure. The dental caries intensity index is higher in girls than in boys at all ages. Statistically significant differences in the intensity index are observed between girls and boys at 1 and 5 years of age. Statistically significant differences in the caries intensity index are observed as children age.

Keywords: caries intensity index, gender differences, early childhood caries, dental caries

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Гендерные различия показателя интенсивности кариеса зубов у детей раннего и дошкольного возраста, проживающих в г. Москве

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Резюме

ВВЕДЕНИЕ. Ранний детский кариес (РДК) – одна из насущных и нерешенных проблем современной детской стоматологии. Показатели индекса интенсивности и тяжести данной патологии не имеют тенденции к снижению во всем мире.

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Ряд исследователей отмечают гендерные различия в показателях интенсивности кариеса, другие исследования отрицают взаимосвязь показателей кариеса и пола. Предполагается, что основные механизмы генетического влияния на более высокие показатели распространенности и интенсивности кариеса зубов у лиц женского пола по сравнению с мужчинами лежат в половых хромосомах, демонстрируя сцепленные с полом способы наследования. Запаздывание развития зубов у мальчиков связано с тем, что размер зубов у лиц мужского пола больше, это требует более длительного времени развития. Причины полового диморфизма развития зубов связаны с различной активностью генов, контролирующих гистогенез тканей зуба.

ЦЕЛЬ. Изучить индекс интенсивности кариеса зубов и его структурные компоненты у детей в возрасте от 1 года до 5 лет, проживающих в г. Москве в зависимости от возраста и пола.

МАТЕРИАЛЫ И МЕТОДЫ. Было проведено обследование детского населения в возрасте от 1 года до 5 лет в г. Москве. Все обследуемые дети были распределены по возрасту и полу. Была рассчитана средняя интенсивность кариеса зубов для каждой возрастной группы и с разделением по полу. Полученные результаты обработаны статистически.

РЕЗУЛЬТАТЫ. Анализ интенсивности кариеса зубов у детей раннего и дошкольного возраста показал, что данный показатель увеличивается по мере взросления детей. Выявлены статистически значимые различия показателя интенсивности кариеса между возрастными группами ($H = 27{,}83$; $df = 4$; $p < 0{,}001$). Статистически значимые различия выявлены отдельно в группе мальчиков и девочек ($p < 0{,}001$ и $p = 0{,}0002$ соответственно). Анализ сравнения показателя интенсивности кариеса в различных-возрастных группах с использованием непараметрического критерия Манна-Уитни показал, что интенсивность кариеса у девочек выше, чем у мальчиков ($p = 0{,}000003$). В 1 год и 5 лет интенсивность кариеса у мальчиков и девочек статистически значимо различается ($p = 0{,}000003$ и $p = 0{,}002$ соответственно), а в возрасте от 2 до 4 лет различия статистически незначимые ($p = 0{,}123$, $p = 0{,}103$, $p = 0{,}730$ соответственно для 2-х, 3-х и 4-х лет).

В структуре индекса интенсивности кариеса во все возрастные периоды преобладает показатель «*k*» – кариес и данный показатель выше у девочек, чем у мальчиков.

ВЫВОДЫ. Кариес зубов встречается во всех возрастных группах и у лиц обоего пола. Во все возрастные периоды в структуре индекса интенсивности преобладает компонент «*k*» – кариес временных зубов. Показатель индекса интенсивности кариеса зубов во все возрастные периоды выше у девочек, чем у мальчиков. Статистически значимые отличается индекс интенсивности у девочек и мальчиков в возрасте 1 года и 5 лет. Статистически значимые отличия показателя индекса интенсивности кариеса наблюдаются по мере взросления детей.

Ключевые слова: индекс интенсивности кариеса, гендерные различия, ранний детский кариес, кариес зубов.

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INTRODUCTION

Early childhood caries (ECC) remains one of the most urgent and unresolved problems in contemporary pediatric dentistry. The indices of intensity and severity of this pathology remain high and show no tendency to decrease, not only in Russia but worldwide[1] [1; 2].

The American Academy of Pediatric Dentistry introduced the term early childhood caries (ECC) to describe carious lesions and their complications in children aged 6 to 71 months. Owing to the high prevalence and severity of ECC, the World Health Organization[2] proposed the age of 3 years as a new reference age for epidemiological surveys. Nevertheless, caries is detected at even earlier stages, shortly after the eruption of primary teeth[3] [3–6].

Some investigators report gender differences in caries prevalence and intensity, whereas other studies deny any association between caries indicators and sex [7–10]. Overall, research addressing sex-related differences in caries prevalence and severity remains limited and contradictory.

An assessment of the dental status of children in the United Kingdom revealed no gender differences in caries prevalence among children aged 5 and 8 years. However, at the ages of 12 and 15 years, girls demonstrated higher DMFT values compared with boys (1.28, 95% CI: 1.10–1.49 and IRR: 1.16, 95% CI: 1.00–1.35, respectively) [11].

A study conducted in the Northern Appalachians investigating caries prevalence according to sex identified the following trends. In children aged 1–5 years,

[1] American Academy of Pediatric Dentistry (AAPD). Denition of early childhood caries (ECC). American Academy of Pediatric Dentistry. 2008.

[2] World Health Organization et al. WHO expert consultation on public health intervention against early childhood caries: report of a meeting, Bangkok, Thailand, 26–28 January 2016. World Health Organization, 2017.No. WHO/NMH/PND/17.1.

[3] American Academy of Pediatric Dentistry. Policy on early childhood caries (ECC): Classifications, consequences, and preventive strategies. The Reference Manual of Pediatric Dentistry. Chicago, Ill.: American Academy of Pediatric Dentistry; 2020, pp. 79–81.

no significant sex-related differences were observed. In the 6–11-year age group, caries prevalence in girls was 1.5 times lower than in boys ($p < 0.001$). In adolescents aged 12–17 years, caries indicators in girls became comparable to those in boys [12].

M. Ferraro and A.R. Vieira from the University of Pittsburgh suggest that the main genetic mechanisms underlying the higher caries prevalence in females compared with males are associated with sex chromosomes and demonstrate sex-linked inheritance patterns. The amelogenin gene (AMELX) is located on the short arm of the X chromosome (Xp22.31–p22.1). This gene and its protein product contribute to enamel formation. Amelogenin constitutes approximately 90% of the enamel matrix. Mutations in the AMELX gene result in X-linked amelogenesis imperfecta. A deficiency of the amelogenin gene or reduced amelogenin expression may impair enamel matrix formation and, consequently, increase susceptibility to caries.

In males, the AMELY gene is located on the Y chromosome (locus Yp11.2). AMELY expresses a greater amount of amelogenin, which contributes to higher tooth strength and lower susceptibility to caries [13; 14].

Sexual dimorphism, including that of the dentofacial system, persists throughout life. Girls generally exhibit earlier development than boys. Mineralization, eruption, and root formation of teeth occur earlier in girls than in boys. However, the timing of tooth germ initiation does not differ between sexes.

It has been hypothesized that delayed dental development in boys is associated with larger tooth size, which requires a longer developmental period. The causes of sexual dimorphism in dental development are related to differential activity of genes controlling dental tissue histogenesis. According to skeletal maturity and eruption criteria, girls on average advance ahead of boys.

Modern genetic and molecular biological data indicate that genes responsible for tooth growth and size are located on both the X and Y chromosomes; however, the Y chromosome exerts a more pronounced influence on tooth dimensions. It is assumed that Y-linked genes stimulate amelogenesis and dentinogenesis. Consequently, enamel and dentin thickness in the tooth crown is greater in males than in females [10].

The X chromosome exerts a less pronounced effect on enamel deposition. Earlier eruption, weaker mineralization, and a thinner layer of hard dental tissues in girls are considered risk factors for caries development [10].

A key tool for monitoring dental caries is the caries intensity index, which reflects the degree of hard tissue involvement in each child or within a population. Most epidemiological studies calculate caries intensity using the dmft/DMFT indices developed by Klein, Palmer, and Knutson in 1938 and later adapted by the World Health Organization for national dental epidemiological surveys worldwide[4] [15].

Currently, several indices and caries assessment systems with higher sensitivity to caries and its complications have been developed, taking multiple factors into account: the Significant Caries Index (SiC); the International Caries Detection and Assessment System (ICDAS I and II); the Filled/Sound Teeth index (FS-T); the pufa/PUFA index; and the Caries Assessment Spectrum and Treatment (CAST) index.

However, none of these systems can be considered ideal. All indices require validation of their reliability for clinical and experimental research.

Thus, the DMFT/dmft index may be regarded as a practical screening tool for large-scale studies, particularly in early childhood and preschool populations [16–18].

AIM

To investigate the dental caries intensity index and its structural components in children aged 1 to 5 years living in Moscow, with respect to age and sex.

MATERIALS AND METHODS

To achieve the stated objective, a survey of the pediatric population aged 1 to 5 years residing in Moscow was conducted. The study was performed in accordance with the Order of the Ministry of Health of the Russian Federation dated April 14, 2025, No. 211n, "On Approval of the Procedure for Preventive Medical Examinations of Minors, the Registration Form No. 030-PO/u 'Preventive Medical Examination Record of a Minor', the Rules for Its Completion, as well as the Statistical Reporting Form No. 030-PO/o 'Data on Preventive Medical Examinations of Minors' and the Procedure for Its Completion".

The examination was carried out after obtaining written informed voluntary consent for medical intervention from parents or legal guardians in accordance with Article 20 of the Federal Law of the Russian Federation No. 323-FZ dated November 21, 2011, "On the Fundamentals of Health Protection of Citizens in the Russian Federation" (as amended and effective from January 11, 2023)[5].

A total of 1,440 children were examined, including 686 boys (47.6%) and 754 girls (52.4%). The age distribution was as follows: 284 children aged 1 year (19.7%), 289 aged 2 years (20.1%), 290 aged 3 years (20.1%), 289 aged 4 years (20.1%), and 288 aged 5 years (20.0%). All participants were stratified by age and sex.

To assess the degree of hard tissue involvement in individual children and at the population level, the caries intensity index (*dmft*) was determined. The mean caries intensity was calculated for each age group with additional stratification by sex. The group mean *dmft* was obtained by summing individual *dmft* scores and dividing by the number of examined children in each group.

[4] World Health Organization et al. WHO expert consultation on public health intervention against early childhood caries: report of a meeting, Bangkok, Thailand, 26–28 January 2016. World Health Organization. 2017; WHO/NMH/PND/17.1

[5] Federal Law of November 21, 2011 N 323-FL (as amended on July 24, 2023) "On the fundamentals of protecting the health of citizens in the Russian Federation" (as amended and supplemented, entered into force on July 13, 2022). Available at: https://www.consultant.ru/document/cons_doc_LAW_121895/ (accessed: 03.07.2025).

Statistical analysis was performed using the *R* programming language for statistical computing (version 4.2.2). Comparative analysis of caries intensity between two independent groups was conducted using the nonparametric Mann–Whitney U test. When more than two groups were compared, the nonparametric Kruskal–Wallis test was applied. Statistical significance was assessed at an alpha level of 0.05, and results were considered significant at $p < 0.05$.

RESULTS

The caries intensity index according to age and sex is presented in Table 1.

The analysis of the mean caries intensity index demonstrated that at the age of 1 year it was 1.46±0.14 (0.58±0.14 in boys and 2.22±0.22 in girls); at 2 years, 1.55±0.16 (1.23±0.20 in boys and 1.88±0.26 in girls); at 3 years, 1.41±0.13 (1.15±0.19 in boys and 1.64±0.19 in girls); at 4 years, 1.63±0.16 (1.61±0.23 in boys and 1.65±0.22 in girls); and at 5 years, 2.24±0.17 (1.63±0.19 in boys and 2.88±0.27 in girls). Overall, caries intensity increased with age. A slight decrease in caries intensity was observed at 3 years compared with 2 years of age.

Between 12 and 35 months, active tooth eruption and formation of the primary dentition occur. After eruption, final (tertiary) mineralization of hard dental tissues continues for several years. Consequently, insufficiently mineralized teeth are more susceptible to the carious process.

Analysis of the structure of the caries intensity index revealed that in all age groups the dominant component was **“d” (decayed teeth)**, and this parameter was consistently higher in girls than in boys. At 1 year, the “*d*” component was 0.32±0.11 in boys and 1.64±0.21 in girls; at 2 years, 0.64±0.13 and 1.32±0.22, respectively; at 3 years, 0.72±0.14 and 1.15±0.15; at 4 years, 1.25±0.20 and 1.35±0.18; and at 5 years, 1.26±0.16 and 2.19±0.23. An age-related increase in this component of the caries intensity index was observed.

The **“f” (filled teeth)** and **“m” (missing teeth)** components were markedly lower than the “*d*” component. The “*f*” component of the index was as follows: at 1 year, 0.23±0.09 in boys and 0.45±0.11 in girls; at 2 years, 0.26±0.08 and 0.52±0.13; at 3 years, 0.28±0.06 and 0.38±0.08; at 4 years, 0.25±0.07 and 0.25±0.09; and at 5 years, 0.20±0.07 and 0.46±0.11, respectively. In all age groups, the “*f*” component was higher in girls than in boys.

The **“m” component (missing teeth)** was: at 1 year, 0.03±0.03 in boys and 0.05±0.04 in girls; at 2 years, 0.19±0.07 and 0.07±0.04; at 3 years, 0.15±0.05 and 0.10±0.04; at 4 years, 0.12±0.07 and 0.05±0.03; and at 5 years, 0.16±0.06 and 0.22±0.06, respectively.

Table 2 presents the results of the nonparametric Mann–Whitney U test used to compare caries intensity between boys and girls across different age groups.

Comparative analysis of caries intensity across age groups using the nonparametric Mann–Whitney U test demonstrated that caries intensity was significantly higher in girls than in boys ($p = 0.000003$). At the ages of 1 and 5 years, caries intensity differed significantly between boys and girls ($p = 0.000003$ and $p = 0.002$, respectively), whereas no statistically significant differences were observed between 2 and 4 years of age ($p = 0.123$, $p = 0.103$, and $p = 0.730$ for ages 2, 3, and 4 years, respectively).

Table 1. Intensity of dental caries in children aged 1–5 years

Таблица 1. Показатель индекса интенсивности кариеса зубов у детей в возрасте 1–5 лет

Age	Total	Caries intensity (Mean±SD)			
		k	***p***	***y***	***kpy***
1 year	284	1.03±0.13	0.35±0.07	0.04±0.02	1.46±0.14
Boys	132	0.32±0.11	0.23±0.09	0.03±0.03	0.58±0.14
Girls	152	1.64±0.21	0.45±0.11	0.05±0.04	2.22±0.22
2 years	289	0.98±0.13	0.39±0.08	0.13±0.04	1.55±0.16
Boys	146	0.64±0.13	0.26±0.08	0.19±0.07	1.23±0.2
Girls	143	1.32±0.22	0.52±0.13	0.07±0.04	1.88±0.26
3 years	290	0.96±0.1	0.33±0.05	0.12±0.03	1.41±0.13
Boys	131	0.72±0.14	0.28±0.06	0.15±0.05	1.15±0.19
Girls	159	1.15±0.15	0.38±0.08	0.1±0.04	1.64±0.19
4 years	289	1.3±0.14	0.25±0.06	0.08±0.03	1.63±0.16
Boys	129	1.25±0.2	0.25±0.07	0.12±0.07	1.61±0.23
Girls	160	1.35±0.18	0.25±0.09	0.05±0.03	1.65±0.22
5 years	288	1.72±0.14	0.33±0.07	0.19±0.04	2.24±0.17
Boys	148	1.26±0.16	0.2±0.07	0.16±0.06	1.63±0.19
Girls	140	2.19±0.23	0.46±0.11	0.22±0.06	2.88±0.27
Total examined	1440	1.2±0.06	0.33±0.03	0.11±0.02	1.66±0.07
Boys	686	0.84±0.07	0.24±0.03	0.13±0.03	1.25±0.09
Girls	754	1.52±0.09	0.41±0.05	0.1±0.02	2.03±0.1

The mean caries intensity in girls was 2.03 (SD 2.87), compared with 1.25 (SD 2.28) in boys ($p = 0.000003$). However, between 2 and 4 years of age, sex-related differences were not statistically significant. At 2 years, the mean value was 1.88 (SD 3.07) in girls and 1.23 (SD 2.43) in boys; at 3 years, 1.64 (SD 2.40) and 1.15 (SD 2.14), respectively; and at 4 years, 1.65 (SD 2.82) and 1.61 (SD 2.62), respectively ($p = 0.123$, $p = 0.103$, and $p = 0.730$ for ages 2, 3, and 4 years, respectively).

In contrast, statistically significant differences were observed at 1 and 5 years of age. At 1 year, girls had a mean caries intensity of 2.22 (SD 2.72) compared with 0.58 (SD 1.55) in boys ($p < 0.000001$). At 5 years, the corresponding values were 2.88 (SD 3.18) in girls and 1.63 (SD 2.36) in boys ($p = 0.002$).

The nonparametric Kruskal–Wallis test was applied to compare ECC intensity among more than two age groups with stratification by sex.

Table 3 presents the results of the Kruskal–Wallis test for comparisons of ECC intensity across different age groups stratified by sex.

Statistically significant differences in caries intensity were detected between age groups ($H = 27.83$; $df = 4$; $p < 0.001$). An age-related upward trend in caries intensity was observed: the mean value was 1.46 at the age of 1 year and increased to 2.24 by the age of 5 years.

Statistically significant differences were also identified separately in boys and girls ($p < 0.001$ and $p = 0.0002$, respectively).

Table 2. Comparison of the caries intensity index in boys and girls in different age groups using the nonparametric Mann-Whitney test

Таблица 2. Сравнение показателя интенсивности кариеса у мальчиков и девочек в различных возрастных группах с использованием непараметрического критерия Манна-Уитни

Factor		Sample size	Mean	SD	Sum of ranks	*U*	|*z*|	*p*
Total group	M	686	1.25	2.28	457325.0	221684	4.67	0.000003
	F	754	2.03	2.87	580195.0			
1 year	M	132	0.58	1.55	15468	6690	4.84	0.000001
	F	152	2.22	2.72	25002			
2 years	M	146	1.23	2.43	20075.5	9344.5	1.54	0.123
	F	143	1.88	3.07	21829.5			
3 years	M	131	1.15	2.14	17903	9257	1.63	0.103
	F	159	1.64	2.40	24292			
4 years	M	129	1.61	2.62	18949	10076	0.34	0.730
	F	160	1.65	2.82	22956			
5 years	M	148	1.63	2.36	19187	8161	3.11	0.002
	F	140	2.88	3.18	22429			

Table 3. Comparison of the intensity index of the RDC with division by gender and age using the nonparametric Kruskal-Wallis test

Таблица 3. Сравнение показателя интенсивности РДК с разделением по полу и возрасту с использованием непараметрического критерия Краскела-Уоллиса

Factor		Sample size	Mean	SD	*H*	df	*p*
Age group (years) N = 1440	1 year	284	1.46	2.40	27.83	4	<0.001
	2 years	289	1.55	2.78			
	3 years	290	1.41	2.29			
	4 years	289	1.63	2.73			
	5 years	288	2.24	2.85			
Male	1 year	132	0.58	1.55	31.81	4	<0.001
	2 years	146	1.23	2.43			
	3 years	131	1.15	2.14			
	4 years	129	1.61	2.62			
	5 years	148	1.63	2.36			
Female	1 year	152	2.22	2.72	21.78	4	0.0002
	2 years	143	1.88	3.07			
	3 years	159	1.64	2.40			
	4 years	160	1.65	2.82			
	5 years	140	2.88	3.18			

In boys, the increase in caries intensity was most pronounced between 1 and 2 years of age (0.58 and 1.23, respectively). In subsequent years, the dynamics were less marked: by 3 years the index slightly decreased (1.15), and by 4–5 years the intensity stabilized (1.61 and 1.63, respectively).

In girls, a relatively high caries intensity was already observed at 1 year of age (mean 2.22). Smaller tooth dimensions and earlier eruption compared with boys may contribute to increased susceptibility to caries. By the ages of 3–4 years, the intensity stabilized (1.64 and 1.65, respectively), while at 5 years it increased to 2.88, exceeding the corresponding value in boys of the same age.

Overall, statistically significant differences in the caries intensity index ($p < 0.001$) were found across age groups both in the total sample and after stratification by sex. With increasing age, a consistent tendency toward higher mean caries intensity was observed, rising from 1.46 at 1 year to 2.24 at 5 years.

Among boys, statistically significant differences in caries intensity across age groups were confirmed ($H = 31.81$; $df = 4$; $p < 0.001$). The most pronounced increase occurred between 1 and 2 years (0.58 to 1.23), followed by a slight decrease at 3 years (1.15) and subsequent stabilization at 4–5 years (1.61 and 1.63).

In the group of girls, statistically significant differences in caries intensity across age categories were also observed ($H = 21.78$; $df = 4$; $p = 0.0002$). At 1 year, the mean caries intensity was already high (2.22). By 3–4 years, the values stabilized (1.64 and 1.65), and at 5 years the index increased to 2.88, exceeding the corresponding value in boys of the same age.

DISCUSSION

The aim of this study was to investigate the dental caries intensity index and its structural components in children aged 1 to 5 years living in Moscow, with respect to age and sex.

The present investigation demonstrated that dental caries occurs in children at all examined ages. Comparison of caries intensity across age groups using the nonparametric Mann–Whitney U test revealed that, on average, caries intensity in girls was higher than in boys.

Analysis of the structure of the caries intensity index showed that in all age periods the dominant component was **“d” (decayed teeth)**, and this parameter was consistently higher in girls than in boys.

Statistically significant differences in caries intensity between girls and boys were observed at the ages of 1 and 5 years ($p < 0.000001$ and $p = 0.002$ for ages 1 and 5, respectively). In contrast, between 2 and 4 years of age, sex-related differences in the caries intensity index were not statistically significant (at 2 years $p = 0.123$; at 3 years $p = 0.103$; at 4 years $p = 0.730$).

Application of the nonparametric Kruskal–Wallis test to compare early childhood caries intensity across multiple age groups demonstrated statistically significant differences both in the total sample and after stratification by sex ($p < 0.001$). As children aged, a clear tendency toward an increase in the caries intensity index was observed.

CONCLUSION

1. Dental caries is present in all age groups and in children of both sexes.

2. In all age periods, the **“d” (decayed primary teeth)** component predominates in the structure of the caries intensity index.

3. The caries intensity index is higher in girls than in boys across all age groups.

4. Statistically significant differences in caries intensity between girls and boys are observed at the ages of 1 and 5 years.

5. Statistically significant changes in the caries intensity index are observed with increasing age.

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A cross-sectional investigation was carried out to evaluate the beliefs and awareness of parents of children on preventive dentistry

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Abstract

INTRODUCTION. The branch of dentistry known as preventive dentistry focuses on treatments and lifestyle choices that assist individuals in preventing the onset or progression of oral disease. It involves both patient-performed dental care at home and professional dental staff-performed dental care and education in an office or clinic. Fluoride is frequently used to avoid and eradicate dental cavities, new unfavorable media coverage and worries regarding careless fluoride usage contributed to a change in parental attitudes. The benefit of fluoride and possible natural or herbal substitutes, this study investigates parental knowledge, preferences, and attitudes toward preventive interventions.

MATERIALS AND METHODS. A survey study was the design of our investigation. Parents of children ages 6 to 14 whom brought their children to the Dijlah University Department of Pediatric Dentistry for examination or treatment were given a 9-questions survey form as part of the study, 300 parents participated in the study. Numbers and percentages were used to record the data.

RESULTS. 155 (51.6%) of the parents said they would prefer natural alternatives to fluorinated varnish if they were given a choice to use natural herbal components instead. There was a statistically significant correlation found between the parents' educational level and their observations on the effects of fluoride ($p < 0.05$). Just 19 parents (6.3%) who were university graduates believed fluoride had negative consequences, in contrast to 59 (19.6%) of parents who were primary graduates believed fluoride had negative consequences.

CONCLUSIONS. some parents continue to avoid using fluoride products, and parents lack adequate attitudes and thoughtful regarding oral and dental health prevention measures. Therefore, parents need to be aware of fluoride consumption and its impact on children's health.

Keywords: preventive dentistry, fluoride varnish, knowledge, dental caries

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Убеждения и осведомленность родителей детей в области профилактической стоматологии: поперечное исследование

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Резюме

ВВЕДЕНИЕ. В стоматологии существует отдельная отрасль – профилактическая стоматология, которая сосредоточена на методах лечения и образе жизни, способствующих предотвращению возникновения или прогрессирования заболеваний полости рта. Она включает как уход за зубами, выполняемый пациентом дома, так и профессиональный уход и образовательную работу, проводимые стоматологическим персоналом в клинике. Фтор широко используется для профилактики и устранения кариеса, однако появление неблагоприятной информации в СМИ и опасений по поводу неправильного

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применения фтора привело к изменению отношения родителей. Учитывая пользу фтора и возможные натуральные или травяные альтернативы, настоящее исследование направлено на изучение знаний, предпочтений и отношения родителей к профилактическим мерам.
МАТЕРИАЛЫ И МЕТОДЫ. Дизайн исследования представлял собой опросное исследование. Родителям детей в возрасте от 6 до 14 лет, приведших своих детей на осмотр или лечение в кафедру детской стоматологии Университета Диджлах, была предложена анкета из 9 вопросов. В исследовании приняли участие 300 родителей. Для анализа данных использовались показатели количества и процентов.
РЕЗУЛЬТАТЫ. 155 родителей (51,6 %) заявили, что предпочли бы использовать натуральные альтернативы фторсодержащему лаку, если бы была возможность применять компоненты на основе трав. Была выявлена статистически значимая связь между уровнем образования родителей и их оценкой воздействия фтора (p <0,05). Только 19 родителей (6,3 %), имеющих высшее образование, считали, что фтор имеет негативные последствия, тогда как среди родителей с начальными школами таких было 59 человек (19,6 %).
ВЫВОДЫ. Некоторые родители продолжают избегать использования фторсодержащих продуктов, а также демонстрируют недостаточный уровень знаний и осознанности в вопросах профилактики заболеваний полости рта. Следовательно, необходимо повышать информированность родителей о применении фтора и его влиянии на здоровье детей.

Ключевые слова: профилактическая стоматология, фторсодержащий лак, знания, кариес зубов

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INTRODUCTION

Caries in early childhood is a serious disorder that affects young children's teeth [1]. Reducing the spread of cariogenic bacteria, particularly Streptococcus mutants, in children is important for its prevention [2; 3]. Mothers are the most frequent source of Streptococcus mutans colonization in their infants due to salivary bacterial transmission [4]. Carious lesions are one of the most common causes of beginning tooth loss [5]. Dental caries is more common as a result of dietary changes, poor oral hygiene, and consumption of sugar-rich foods [6]. Early detection and treatment are possible for the majority of problems with oral health [7]. The oral health of their children is greatly influenced by the decisions their parents make regarding their personal health.

In the early stages, caries is preventable and reversible, but if treatment is not received, it can worsen and eventually destroy the tooth [8]. Fluoride prevents cavities in tooth enamel by decreasing demineralization and promoting remineralization. The most popular protective substance for the prevention and treatment of dental cavities is fluoride [9; 10]. [(9, 10)]

Fluoride was added to milk, salt, and toothpaste after it was discovered that fluoride in water prevented dental cavities. Additionally, using toothpaste that has been fluoridated decreases the risk of dental decay.

Administering toothpaste with a fluoride content of 850 ppm-1150 ppm for children under 6 years old and up to 5000 ppm for adults and older has been shown to be an effective self-administered topical treatment for dental decay prevention [11].

Professional fluoride applications, include fluoride-containing mouthwashes, fluoride gel, varnish, and restorative materials toothpaste, are useful in lowering dental cavities, a social health issue [12; 13].

Caries can be effectively reduced by brushing teeth twice a day using fluoride toothpaste in the proper dosage as instructed by the dentist. Patients at high risk of dental caries can also avoid the development of caries by receiving fluoride treatments from their dentist [12; 13].

Regular dental checkups assist parents in learning about their child's oral health, including the development of tooth decay or malocclusions [14].

Numerous studies have recommended that children receive dental exams before being 12 months old [15–17]. The age of a child through his or her first dental appointment is a predictor of that child's future oral health [16–18].

Because fluoride-related information is unclear, some people believe that natural or herbal substances can be used in place of fluoride to avoid or treat dental cavities [19].

AIM

The purpose of the current study was to analyze parents' attitudes and levels of understanding on preventative dentistry.

MATERIALS AND METHODS

The study comprised 300 parents of children between the ages of 6 and 14 years who came for an examination or treatment between 10.10.2023 and 30.02.2024 at the Department of Pediatric and Preventive Dentistry of Dijlah University.

During the questionnaire interview, each participant was asked to sign a formal ethical consent form. The Dijlah University Faculty of Dentistry's Ethical Committee created and approved the informed ethical consent form.

There were nine questions in all on the questionnaire. The first three questions asked about the parent and child's sociodemographic information, including gender, age and education.

Questions 4–6 discussed the parents' viewpoints, behaviors, attitudes and level of product fluoridation knowledge and 7–9 questioned about their views regarding alternative natural products and fluoride treatments given to children throughout the six weeks prior to a year (Table 1).

Table 1. Responses of Participants towards Preventive Oral Health

Таблица 1. Отношение участников к профилактическому уходу за полостью рта

Questions	Responses (*n*)	Percentages (%)
1. What is the suggested time (in minutes) for someone to brush their teeth?	5	34.6
	7	26.0
	2	39.4
2. How frequently do you change your child's toothbrush?	Once a month	30.4
	Once in 6 months	52.3
	Once a year	17.3
3. When should kids learn how to brush their teeth, in years?	2–3	15.4
	5–6	62.4
	6–7	22.2
4. What fluoride knowledge do you have?	Knew Nothing About Fluoride	64.0
	Reduces Dental Cavities	14.0
	Beneficial to teeth	22.0
5. Who would you prefer to apply protection products containing fluoride?	Dentist	39.0
	Pedodontics	61.0
6. Where may one find information on fluoride?	Dentists	47.6
	Internet or social media	32.6
	Family	19.6
7. For your kids, would you prefer toothpaste with fluoride?	no	50.6
	yes	14.0
	No answer	35.3
8. Allow treatments applied to them at school?	There was no prophylactic fluoride gel application at our school	49.6
	Allow	12.0
	Not allow	38.3
9. Choosing a herbal alternative or fluoride varnish as protective treatment	Fluoride varnish	48.3
	Herbal alternative	51.6

RESULTS

A total of 300 parents, 195 females (65%) and 105 (35%) males participated in the study. Table 2 shows that 77 (25.6%) of the parents had completed their primary education, 84 (28.6%) had completed their secondary education, 72 (24.7%) had completed their high school education, and 67 (22%) had graduated from university.

Table 2. Distribution of parents' according educational level

Таблица 2. Распределение родителей в зависимости от уровня образования

Patient education level	Frequency (*n*)	Percentages (%)
Primary education	77	25.6
Secondary education	84	28.6
high education	72	24.7
Graduated from university	67	22.0

52.3% of research participants said they would change their toothbrushes once in 6 months, and 62.4% almost said their kids should learn to clean their teeth by the time they are 5–6 years old.

Of the parents, 64% (194) said they knew nothing about fluoride, 14% (42) said it reduces dental cavities, and 22% (66) said it is beneficial to teeth.

117 parents (39%) said they would prefer the dentist to apply a fluoride product to their children, compared to 183 parents (61%) who said they would prefer the pedodontist.

Parents reported that dentists were the primary source of information regarding fluoride 143 (47.6%), followed by the internet and social media 98 (32.6%)

Asking parents if they choose toothpaste with fluoride when selecting toothpaste for their children resulted in 50.6% (152) saying they did not, and 14% (42) saying they did and 106(35.3%) have no answer.

149 (49.6%) of the parents express that fluoride varnish was not handle at school, while 36 (12%) of the parents said they permitted their children to administer it there, and 115 (38.3%) not allow.

(51.6 %) of the parent choosing a herbal or natural alternative while (48.3%) choose fluoride protective treatment.

There was a statistically significant correlation ($p < 0.05$) found between the parents' educational level and their comments on the effects of fluoride. Just 19 (6.3%) graduates' parents of universities believed fluoride was harmful for them. While, 48 (16%) of parents with a university education and 18 (6%) of parents with a primary school education found fluoride application prevents caries formation.

The level of education of the parents and their selection for natural or herbal alternatives to fluorinated varnish for their kids was found to be statistically significant ($p < 0.05$), 51.6% ($n = 155$) of the parents described that they would prefer natural or herbal alternatives in place of fluorinated varnish.

Table 3. Parents' educational level and their opinion on the effects of fluoride

Таблица 3. Уровень образования родителей и их мнение о влиянии фторида

Education level	Effect of fluoride				Total number	P < 0.05
	Yes		No			
	n	%	*n*	%		
Primary	18	6	59	19.6	77	Chi = 51.37
Secondary	17	5.6	67	22.3	84	
High	25	8.3	47	15.6	72	Critical value = 7.8
University	48	16	19	6.3	67	d*f* = 3
Total	108	36	192	64	300	

Table 4. Parents' educational level their selection for natural or herbal alternatives to fluorinated varnish

Таблица 4. Уровень образования родителей и их выбор натуральных или травяных альтернатив фторсодержащему лаку

Education level	Herbal alternatives or fluoridated varnish				Total number	P < 0.05
	Herbal		Fluoride			
	n	%	*n*	%		
Primary	52	17.3	25	8.3	77	Chi = 18.46
Secondary	47	15.6	37	12.3	84	
High	34	11.3	38	12.6	72	Critical value = 7.8
University	22	7.3	45	15.0	67	d*f* = 3
Total	155	51.6	145	48.3	300	

DISCUSSION

Parental education and attitude are essential for preventing oral problems and improving children's dental health. Sustaining good dental health is a crucial aspect of good health. Untreated and active dental caries creates poor oral and general health for many children [20]. Education, early diagnosis, and preventative measures are essential in reducing the frequency of dental caries, a condition that is largely preventable [21].

According to studies, the use of fluoride products has raised concerns in society [22; 23]. Evaluating the causes of these doubts reveals that they are primarily brought on by unconfirmed fluoride material in print and social media [22].

In a study involving 50 parents, Güler et al. [24] assessed the level of parents' level about fluoride, It was shown that 48% of participants used social media tools for one to three hours per day. The majority of people (24%) used social media (internet) to obtained information and 35% said that social media sites were moderately trust worthy. Our study produced similar findings. 32.6% of the parents said they learned about fluoride from social media or the internet.

In a 2018 study, Öter et al. [25] aimed to understand the attitudes and awareness of parents of children aged 6 to 10 regarding fluoride. They noticed that parents avoided using fluoridated items because they lacked enough knowledge about the applications of fluoride.

We discovered comparable outcomes when we request the parents in our study, Did you let your kids to get fluoridated varnish when they were being screened at school? (38.3%) of the parents, they prevented the school from using fluoride varnish, while (49.6%) of the Parents complained that the school did not use fluoride varnish. These findings were affected by parents' lack of awareness, and parents should get comprehensive information regarding preventative applications, which play a significant role in the design of community activities aimed at promoting oral and dental health.

When asked what kind of toothpaste they preferred for their kids, the participants in our survey gave a range of answers on many topics related to preventive dentistry.

According to the findings, 14% of participants selected fluoridated toothpaste and 50.6% selected non-fluoridated toothpaste while it was discovered that 35.3% of participants knew nothing about the toothpaste options available to their kids. This was in agreement with patients in various cities were questioned by Çobanoğlu et al. [26] regarding the fluoride content of the toothpastes 40% of the patients stated that they believed fluoride-free toothpastes were safer and 13% of them used it. These findings can be connected to the parents' receiving insufficient information from the dentists. In addition to inaccurate and partial information given via social media or television.

We questioned parents in our study, Do you know anything about fluoride? It discovered that 64% of the parents knew nothing about fluoride. There was a significant correlation between these findings and the level of education of the parents. We believe that education parents can aid in the resolution of this problem as well.

According to research in the literature, parents' unfavorable views on fluoride have led to the development of natural or herbal substitute antibacterial substances [19; 27]. We also questioned the parents in this study, What would you prefer if a natural compound were offered in place of fluoride varnish? 51.6% (n = 155) of the parents described that they would prefer natural or herbal alternatives in place of fluorinated varnish.

Despite fluoride's many benefits, alternative remineralization agents are being researched to replace the fluoride used. This is because consuming too much fluoride might be harmful. Its toxicity can be either acute or chronic when consumed in small amounts on a regular basis. In the latter case, it can damage mineralized tissues, such as teeth enamel and bones, resulting in skeletal fluorosis and frequently dental fluorosis [28].

Food component identification and the development of food products for health promotion have received a lot of interest in recent years, both in academia and in research.

It has been demonstrated that a variety of naturally occurring ingredients in meals and vegetables improve health and lower the risk of numerous common diseases. Plant-derived antimicrobial compounds have been suggested as a potential substitute for the chemical compounds often used to prevent dental cavities and plaque [26; 27]. the majority of parents in our study prefer to use natural or herbal substitutes for fluorinated varnish. This finding shows that parents would favor natural-herbal product more in the future if a fluoride-equivalent product becomes available.

CONCLUSION

In conclusion, despite the limitations of these research, it is evident that some parents continue to avoid using fluoride products and that parents lack adequate attitudes and understanding on oral and dental health prevention activities. Therefore, it is necessary to inform parents about fluoride intake and its impact on children's health.

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AUTHOR'S CONTRIBUTION

All the authors made equal contributions to the publication preparation in terms of the idea and design of the article; data collection; critical revision of the article in terms of significant intellectual content and final approval of the version of the article for publication.

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The influence of diode laser (810–980) nm in treatment of the labial frenum in jaws: clinical study

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Abstract

INTRODUCTION. Midline diastema, gingival recession, and functional and aesthetic issues are possible outcomes of a high labial frenum. Although the traditional scalpel frenotomy is still effective, it is often characterized by intraoperative bleeding, the necessity to sew a wound, and a long postoperative period. Diode lasers with wavelengths of 810–980 nm have been reported to provide better hemostasis and reduced tissue trauma. The current study compared the clinical results of the diode laser and scalpel frenotomy.

MATERIALS AND METHODS. A randomized controlled trial was done on 50 patients (age 12 to 55 years) with high labial frenum who were referred to the Al Falah Special Dental Centre in Baghdad in 2024–2025. The subjects were randomly grouped either in the diode laser group (n = 25) or the scalpel group (n = 25). The outcomes of the postoperative period were measured with pain intensity using a visual analogue scale (VAS), bleeding, edema, oral functional status, and patient satisfaction on postoperative day 1, week 1, week 2, and week 4. The data were analyzed by means of the Mann-Whitney U test, and the statistical significance threshold of the test was p below 0.05.

RESULTS. Patients who had laser frenotomy had better outcomes. The laser group did not require any intraoperative bleeding or suturing, compared with the scalpel group. At the conclusion of week 2, the pain and edema scores were significantly lower in the laser group ($p < 0.001$). Oral functional recovery was faster, and patient satisfaction scores were mostly above all the measurements of the same ($p < 0.001$).

CONCLUSIONS. Diode laser frenotomy is a safe, less invasive, and patient-friendly procedure compared to the conventional use of a scalpel. It provides superior hemostasis, reduced postoperative pain and edema, faster functional recovery, and increased patient satisfaction, making it the modality of choice in periodontal practice.

Keywords: diode laser, frenotomy, labial frenum, periodontics, randomized controlled trial

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Влияние диодного лазера (810–980 нм) на лечение губной уздечки челюстей: клиническое исследование

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Резюме

ВВЕДЕНИЕ. Высокая губная уздечка может приводить к медианной диастеме, рецессии десны, а также к функциональным и эстетическим проблемам. Хотя традиционная френотомия скальпелем остается эффективной, она часто сопровождается интраоперационным кровотечением, необходимостью наложения швов и длительным послеоперационным периодом. Сообщается, что диодные лазеры с длиной волны 810–980 нм обеспечивают лучшую гемостазу и меньшую травматизацию тканей.

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Настоящее исследование сравнивало клинические результаты френотомии с использованием диодного лазера и скальпеля.
МАТЕРИАЛЫ И МЕТОДЫ. Рандомизированное контролируемое исследование проведено на 50 пациентах (возраст 12–55 лет) с высокой губной уздечкой, направленных в Специальный стоматологический центр «Аль-Фалах» в Багдаде в 2024–2025 гг. Пациенты случайным образом были распределены на две группы: группа лазера (n = 25) и группа скальпеля (n = 25). Послеоперационные результаты оценивались по интенсивности боли с использованием визуальной аналоговой шкалы (VAS), кровотечению, отеку, функциональному состоянию полости рта и удовлетворенности пациентов на 1-й день, через 1 неделю, 2 недели и 4 недели после операции. Данные анализировались с помощью критерия Манна–Уитни, статистическая значимость считалась при $p < 0,05$.
РЕЗУЛЬТАТЫ. Пациенты, у которых выполнялась френотомия лазером, показали лучшие результаты. В группе лазера не наблюдалось интраоперационного кровотечения и необходимости в наложении швов по сравнению с группой скальпеля. На 2-й неделе после операции показатели боли и отека были значительно ниже в лазерной группе ($p < 0,001$). Восстановление функциональных возможностей рта происходило быстрее, а показатели удовлетворенности пациентов в основном превышали соответствующие показатели группы скальпеля ($p < 0,001$).
ВЫВОДЫ. Френотомия с использованием диодного лазера является безопасной, менее инвазивной и более комфортной для пациента процедурой по сравнению с традиционной френотомией скальпелем. Она обеспечивает лучший гемостаз, снижает послеоперационную боль и отек, ускоряет функциональное восстановление и повышает удовлетворенность пациентов, что делает ее предпочтительным методом в пародонтологической практике.

Ключевые слова: диодный лазер, френотомия, губная уздечка, пародонтология, рандомизированное контролируемое исследование.

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INTRODUCTION

The frenum is a delicate mucosal fold composed of muscle fibers and connective tissue that anchors the lip and buccal mucosa to the underlying periosteum. During normal growth, the attachment of the frenulum typically migrates apically as the alveolar bone develops vertically, often becoming less prominent [1–11]. Frenums in the oral cavity are categorized based on anatomical location as labial, lingual, or buccal. The labial frenum is further classified into superior and inferior types depending on its position. From a clinical perspective, frenal attachments are divided based on their insertion level into four types:

1) **mucosal** – fibers attach at the mucogingival junction;

2) **gingival** – fibers attach to the attached gingiva;

3) **papillary** – fibers extend into the interdental papilla;

4) **papillary Penetrating** – fibers extend beyond the alveolar process to the palatine papilla [2; 9].

Excessively high frenal attachments may cause a continuum of clinical problems, including midline diastema, recessive gingiva, poor oral health, and shallow vestibular depth. It can also be aesthetically inappropriate and hinder the preservation of periodontal health due to such pathology. It was suggested that surgical correction, usually consisting of a frenotomy or frenectomy, is indicated by:

1) high frenular attachment in a patient with midline diastema;

2) flat interdental papillae in co-existence with a closely related frenulum that contributes to the position of the gingival margin, resulting in recession and plaque accumulation;

3) an aberrant frenulum in relation to poorly attached gingiva and a shallow vestibule [3; 9].

Frenotomy is a minor surgery wherein the frenal attachment is removed or redone in order to relieve muscular tension and fix normal oral functionality. Aesthetic considerations and the quest for improved tooth appearance also support the need to intervene in a few cases. Gingival recession may be aggravated when there is excessive tension on the soft tissues due to the proximity to the gingival margin.

Dental lasers have become practical alternatives to traditional scalpel-based methods in contemporary periodontal practice [5]. In the (810–980 nm) wavelength range, diode lasers have become commonly used in soft-tissue surgery since water-containing tissues highly absorb them. The minimal contact with the hard tissues, such as the enamel, makes these devices intraoral. Since oral soft tissues contain more than 90% water, diode lasers offer safety, reduced invasiveness, and therapeutic functionality. In addition, diode lasers are small, affordable, and less technique-sensitive, thus increasing their clinical utility [4].

The research involves a comparative study of frenum management under laboratory conditions, comparing two modalities: a diode laser dual wavelength (810–980 nm) and conventional scalpel dissection.

These goals are to evaluate and compare clinical outcomes, including healing time, pain management, hemorrhage, and postoperative morbidity, to explain the comparative benefits and drawbacks of each method. The study also compares postoperative analgesia, hemorrhage, edema, functional oral recovery, and patient satisfaction using the two interventions.

MATERIALS AND METHODS

Setting and design

This investigation was performed at the Department of Periodontics, AL Falah Specialized Dental Center, Baghdad, Iraq, over eight months between 2024 and 2025. It was designed as a parallel, randomized, controlled clinical trial comparing diode-laser and conventional scalpel frenotomies. The trial was reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines [9]. The overall process of patient enrollment, allocation, follow-up, and analysis is summarized in the CONSORT flow diagram (Fig. 1).

Study population

Inclusion criteria

Patients were eligible if they:

1. We're undergoing fixed orthodontic treatment of the maxilla or both jaws.
2. Presented with a midline diastema between the maxillary central incisors due to a high labial frenum attachment.
3. Were systemically healthy.
4. Maintained good oral hygiene.
5. Had a clinical need for frenectomy.

Exclusion criteria

Patients were excluded if they:

1. We're undergoing active periodontal treatment of the anterior maxilla.
2. Had a dental diastema unrelated to high frenum attachment.
3. Were uncooperative with dental treatment.

Patients were selected by convenience sampling from those referred to periodontal and orthodontic clinics.

Sample size and randomization

a total of 50 patients, aged 12–55 years, were enrolled in the study. Participants were randomly assigned to two groups using simple randomization:

Group I (Laser group): Diode laser frenotomy (n = 25).

Group II (Scalpel group): Conventional scalpel frenotomy (n = 25).

All procedures were performed by a single experienced operator.

Interventions

Anesthesia

Local infiltration anesthesia (2% lidocaine with 1:80,000 epinephrine) was administered when required. All patients in both the scalpel and laser groups required anesthesia.

Scalpel Technique (Control group): Following local infiltration anesthesia, the lip was retracted to put the frenum in tension. The frenum was stabilized with a hemostat. To release the fibrous attachment,

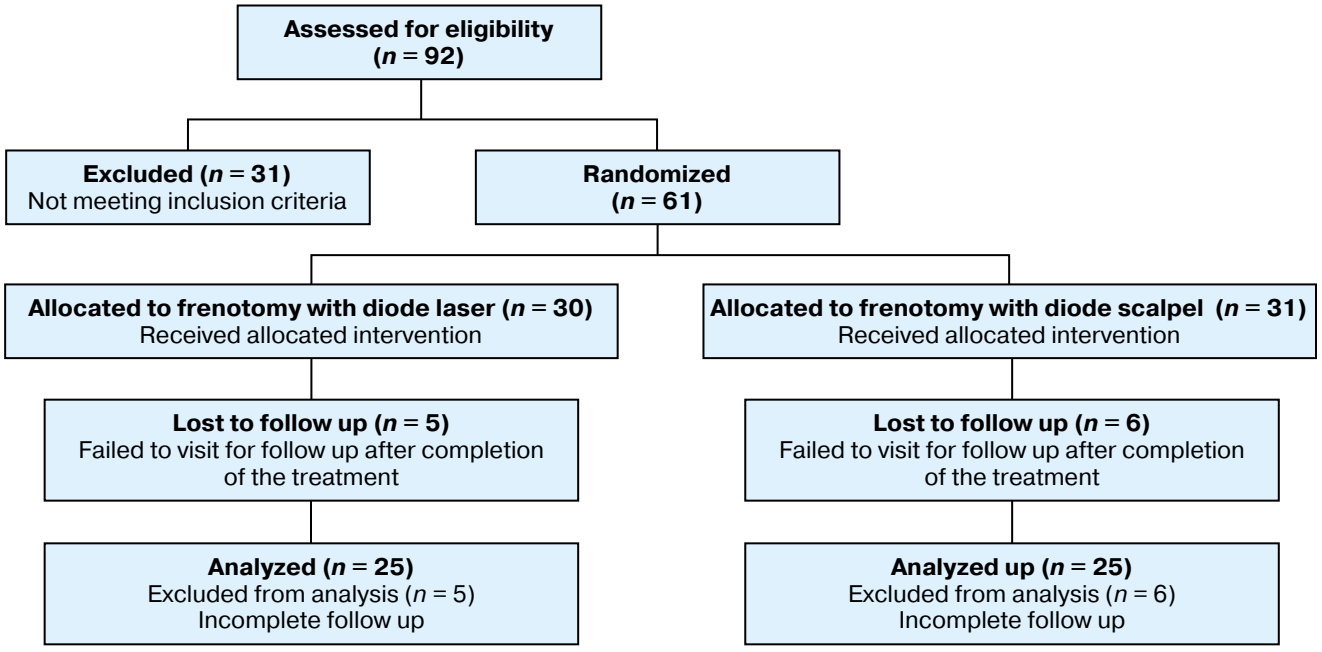

Fig. 1. Consort flow diagram depicting patient enrollment, randomization, allocation, and analysis in a clinical trial comparing diode laser and scalpel frenotomy

Рис. 1. Диаграмма потока CONSORT, демонстрирующая набор пациентов, рандомизацию, распределение по группам и анализ в клиническом исследовании, сравнивающем френотомию с использованием диодного лазера и скальпеля

a controlled scalpel incision was made, and muscle fibers extending toward the papilla or periosteum were detached as needed. Fibrous tissue was excised as needed, and after proper release was confirmed, the wound was sutured (Fig. 2).

Diode Laser Technique (Experimental group): In the experimental group, labial frenotomy was performed using a QuickLase DentaLase diode laser dual wavelength (810–980 nm, 1.2 W, continuous wave mode) with a 400 µm initiated fiber tip applied in a light, contact brushing motion under aseptic conditions. Both operator and patient wore wavelength-specific protective eyewear. The frenum was ablated in a controlled, layer-by-layer manner until adequate release was achieved. Immediate hemostasis was obtained without the need for sutures, and the wound was left to heal by secondary intention (Fig. 3).

Postoperative care

All patients received standardized instructions:

1. Soft, cold diet for the first 12 hours.
2. 0.12% chlorhexidine gluconate rinse once daily for 5 days.
3. Ibuprofen 200 mg if needed for pain relief, with additional analgesics permitted at patient discretion [9].

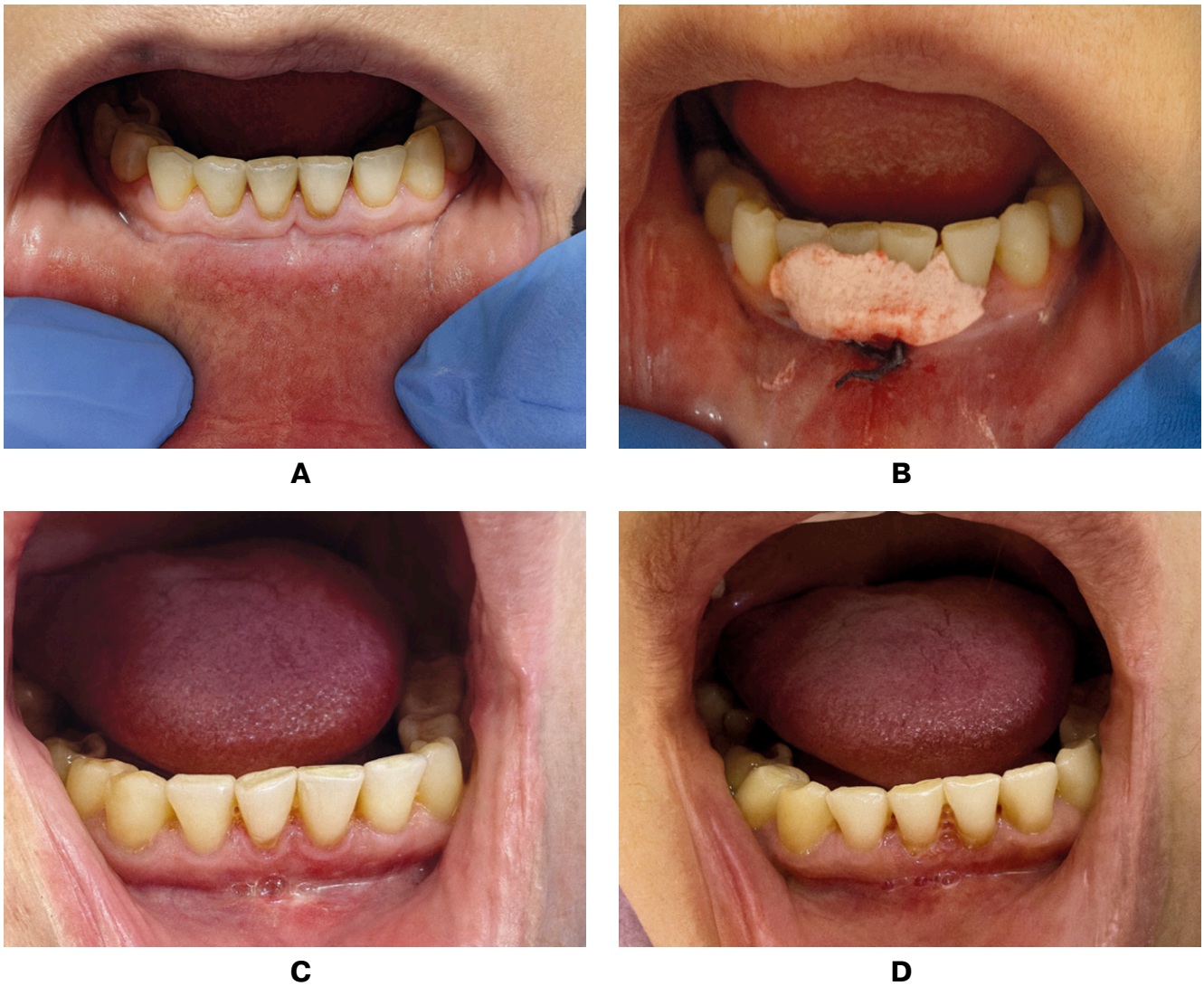

Fig. 2. Surgical blade technique for labial frenotomy in a 43-year-old female patient: (*A*) Preoperative view showing a thick and high-attached labial frenum; (*B*) Frenotomy performed using a scalpel with precise incision and release of the fibrous attachment, followed by suturing; (*C*) One week postoperatively, satisfactory healing is observed with mild scarring; (*D*) One month after surgery, the mucosa appears healthy, and the surgical site shows stable healing with minimal visible scarring

Рис. 2. Методика лабиальной френотомии с использованием скальпеля у 43-летней пациентки: (*A*) предоперационный вид: толстая и высоко прикрепленная губная уздечка; (*B*) выполнение френотомии с помощью скальпеля с точным разрезом и освобождением фиброзного прикрепления, последующее наложение швов; (*C*) через неделю после операции отмечается удовлетворительное заживление с незначительными рубцами; (d) через месяц после операции слизистая оболочка выглядит здоровой, хирургический участок зажил стабильно, видимые рубцы минимальны

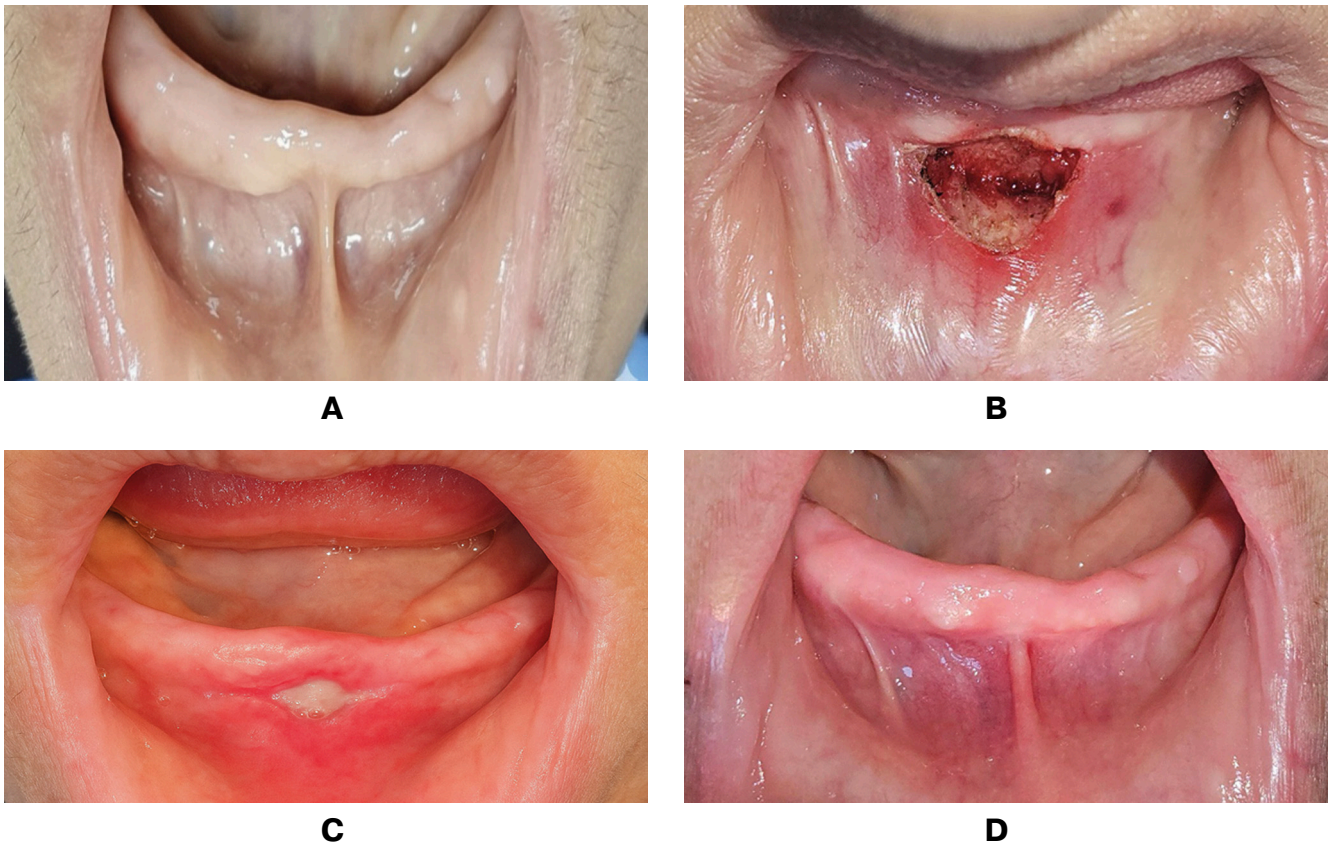

Fig. 3. D iode laser (810–980 nm) technique for labial frenotomy in a 53-year-old female patient: (*A*) Preoperative view showing a thick and high-attached labial frenum; (*B*) Frenotomy performed using a diode laser (810–980 nm) under local anesthesia, allowing for precise incision and minimal bleeding; (*C*) One week postoperatively, the surgical site shows satisfactory healing with minimal edema and no signs of infection; (*D*) One month after the procedure, the mucosa appears healthy with smooth tissue continuity and no visible scar formation

Рис. 3. Методика лабиальной френотомии с использованием диодного лазера (810–980 нм) у 53-летней пациентки: (*A*) предоперационный вид: толстая и высоко прикрепленная губная уздечка; (*B*) френотомия выполнена с использованием диодного лазера (810–980 нм) под местной анестезией, обеспечивая точный разрез и минимальное кровотечение; (*C*) через неделю после операции хирургический участок зажил удовлетворительно, с минимальным отеком и без признаков инфекции; (*D*) через месяц после процедуры слизистая оболочка выглядит здоровой, ткань ровная и непрерывная, видимых рубцов не обнаружено

Outcome measures

Clinical parameters

Postoperative outcomes were assessed on day 1 and at weeks 1, 2, and 4. The following parameters were recorded:

1. **Pain:** Pain was rated on a verbal rating scale (VRS) to assess severity during the first 7 days after the operation. The other levels of pain were rated as 0 (no pain), 1 (substantial discomfort), 2 (moderate pain), and 3 (severe pain). Participants were advised to record their pain experience in a specific form at any time they deemed appropriate [10].

2. **Bleeding:** To determine intraoperative bleeding, clinical assessments were conducted and categorized as follows: no bleeding = 1, self-limiting = 2, requires pressure = 3, requires coagulation = 4, and requires ligation = 5 [11].

3. **Edema:** Clinical assessment of postoperative swelling was scored as no swelling = 1, very slight = 2, moderate (noticeable but not interfering) = 3, severe (prevents eating) = 4, and very severe (prevents eating and limits mouth opening) = 5 [12].

4. **Oral function:** assessed at follow-up appointments based on the ability to consume food, speak, and uphold oral hygiene; “No Interference” = 0, “Mild Interference” = 1, “Moderate Interference” = 2, and “Severe Interference” = 3 [13].

5. **Patient satisfaction:** After the follow-up period had ended, the overall level of satisfaction with the outcome was assessed. The following categories were used to classify the results: excellent (76–100%), good (51–75%), fair (26–50%), and poor (0–25%) [13].

Assessment schedule

1. **Pain, bleeding, and edema:** measured on day 1 and at weeks 1, 2, and 4.

2. **Oral function and satisfaction:** assessed at the same intervals.

Statistical analysis

SPSS version 26 was employed to analyze the data. Categorical data were presented as frequencies and percentages, and continuous data were expressed as the mean ± standard deviation (SD). Normality was tested using the Kolmogorov–Smirnov test. Inter-group comparisons of continuous variables (pain, bleeding, edema, oral function, satisfaction) were performed with the Mann–Whitney U test. A p-value < 0.05 was considered statistically significant.

RESULTS

A total of 50 patients diagnosed with high labial frenum were enrolled and completed the study. The study population included 38 females and 12 males, with an age range of 12–55 years. Participants were equally distributed, with 25 patients undergoing frenotomy using a diode laser (Group I) and 25 patients treated with the conventional scalpel technique (Group II). Baseline demographic and clinical characteristics were comparable between the two groups, as shown in Fig. 4.

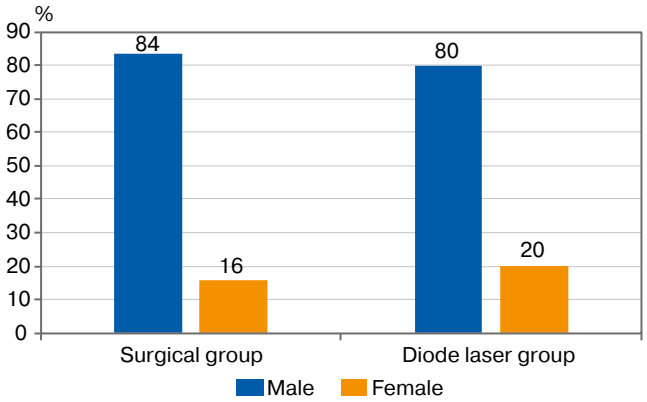

Fig. 4. Distribution of sex group in both diode laser and surgical groups in patients with labial frenum

Рис. 4. Распределение по полу в группах диодного лазера и скальпеля у пациентов с губной уздечкой

During the procedures, all patients in the scalpel group and diode laser group required local anesthesia. Intraoperatively, all laser-treated sites demonstrated adequate coagulation with no bleeding, while all scalpel-treated sites exhibited bleeding that required suturing. None of the diode laser cases required sutures.

Postoperative pain scores were significantly lower in the diode laser group at all time points through week 2. On day 1, the mean pain score was 1.6 ± 0.5 in the diode laser group compared with 2.52 ± 0.51 in the scalpel group ($p < 0.001$). At week 1, pain decreased to 0.84 ± 0.69 in the diode laser group and 1.84 ± 0.80 in the scalpel group ($p < 0.001$). At week 2, no pain was reported in the diode laser group, while mild pain persisted in the scalpel group (1.44 ± 1.04; $p < 0.001$). By week 4, both groups were pain-free (Table 1).

Bleeding was minimal in the diode laser group throughout the study. On day 1, mean bleeding scores were 0.36 ± 0.49 in the diode laser group versus 2.08 ± 1.04 in the scalpel group ($p < 0.001$). At week 1, bleeding was absent in the diode laser group but persisted in the scalpel group with a mean score of 1.24 ± 1.13 ($p < 0.001$). From week 2 onwards, no bleeding was reported in either group (Table 2).

The diode laser treatment significantly reduced edema in the group. The mean edema score was 1.28 ± 0.46 for the diode laser group on day one, which was significantly lower than the score of 2.24 ± 0.66 for the scalpel group ($p < 0.001$). The edema reduced to 0.56 ± 0.51 in the diode laser group and 1.80 0.82 in the scalpel group at week 1 ($p < 0.001$). According to Table 3, there was no observable edema in either group between weeks two and four.

Oral function recovery was faster in the diode laser group. On day 1, the mean oral function score was 0.40 ± 0.50 in the diode laser group compared with 0.00 ± 0.00 in the scalpel group ($p = 0.001$). At week 1, scores were 1.08 ± 0.57 and 0.32 ± 0.48, respectively ($p < 0.001$). By week 4, both groups showed substantial improvement, with significantly better outcomes in the diode laser group (2.36 ± 0.81 vs. 1.76 ± 0.66; $p = 0.006$) (Table 4).

Table 1. Mean pain score in patients with labial frenum operations

Таблица 1. Средний показатель боли у пациентов после операций на губной уздечке

Pain Index (1 to 5)				
Duration	**Groups**	**Mann-Whitney Utest**	**Zvalue**	**Sig (Pvalue)**
Day1	A vs. B	90	–4.775	< 0.001
Week1		123	–3.920	< 0.001
Week2		62.5	–5.507	< 0.001
Week4		312.5	0	1

Note. A – Diode laser group; B – Surgical group. Statistical significance was set at $p < 0.05$.

Примечание. А – группа с диодным лазером; В – хирургическая группа. Статистическая значимость установлена на уровне $p < 0,05$.

Table 2. Mean bleeding score in patients with labial frenum

Таблица 2. Средний показатель кровотечения у пациентов с губной уздечкой

Bleeding index (1 to 5)				
Duration	**Groups**	**Mann-Whitney Utest**	**Zvalue**	**Sig (Pvalue)**
Day1	A vs. B	64.5	–5.025	< 0.001
Week1		100.0	–4.903	< 0.001
Week2		312.5	0	1
Week4		312.5	0	1

Note. A – Diode laser group; B – Surgical group. Statistical significance was set at $p < 0.05$.

Примечание. А – группа с диодным лазером; В – хирургическая группа. Статистическая значимость установлена на уровне $p < 0,05$.

Table 3. Average of characteristic oral edema in patients with labial frenum operations

Таблица 3. Средний показатель отека полости рта у пациентов после операций на губной уздечке

Edema index (1 to 5)				
Duration	**Groups**	**Mann-Whitney Utest**	**Zvalue**	**Sig (Pvalue)**
Day1	A vs. B	93.5	–4.592	< 0.001
Week1		77	–4.931	< 0.001
Week2		312.5	0	1
Week4		312.5	0	1

Note. A – Diode laser group; B – Surgical group. Statistical significance was set at $p < 0.05$.

Примечание. А – группа с диодным лазером; В – хирургическая группа. Статистическая значимость установлена на уровне $p < 0,05$.

Table 4. Average of characteristic oral function criteria in patients with labial frenum operations

Таблица 4. Средние показатели функциональных критериев полости рта у пациентов после операций на губной уздечке

Function index (1 to 5)				
Duration	**Groups**	**Mann-Whitney Utest**	**Zvalue**	**Sig (Pvalue)**
Day1	A vs. B	187.5	–3.500	0.001
Week1		117.5	–4.203	< 0.001
Week2		57.5	–5.673	< 0.001
Week4		180.5	–2.724	0.006

Note. A – Diode laser group; B – Surgical group. Statistical significance was set at $p < 0.05$.

Примечание. А – группа с диодным лазером; В – хирургическая группа. Статистическая значимость установлена на уровне $p < 0,05$.

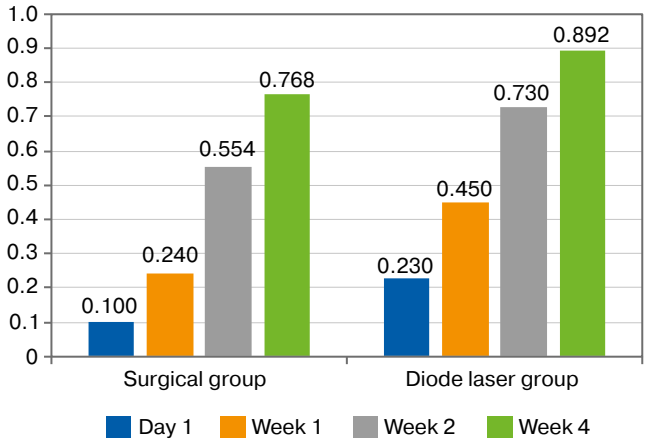

Fig. 5. Postoperative Satisfaction score in the diode laser and surgical groups in patients with labial frenum

Рис. 5. Показатель послеоперационной удовлетворенности в группах диодного лазера и скальпеля у пациентов с губной уздечкой

Patient satisfaction was consistently higher in the diode laser group throughout the study period. On day 1, mean satisfaction scores were 0.23 ± 0.13 in the diode laser group and 0.10 ± 0.00 in the scalpel group ($p < 0.001$). At week 1, scores increased to 0.45 ± 0.15 and 0.24 ± 0.12, respectively ($p < 0.001$). By week 4, satisfaction reached 0.89 ± 0.03 in the diode laser group and 0.77 ± 0.12 in the scalpel group ($p < 0.001$), as shown in Fig. 5.

Diode laser frenotomy demonstrated superior clinical performance compared with the conventional scalpel technique. The laser method reduced the need for anesthesia and sutures, and improved postoperative outcomes in pain, bleeding, edema, oral function, and patient satisfaction.

DISCUSSION

It is a randomized controlled clinical trial that assessed the clinical effectiveness of diode laser frenotomy compared with the standard scalpel approach for the treatment of labial frenum attachments and reported on intraoperative and postoperative outcomes. The study found that diode laser frenotomy showed better clinical outcomes across several parameters, including intraoperative hemostasis, postoperative pain severity, edema resolution, functional recovery, and patient satisfaction.

One key benefit of the intraoperative setting noted with the diode laser method was its high hemostatic effect. None of the patients who were treated using laser needed to be sutured, but all the patients who participated in the scalpel group had to be sutured due to the intraoperative bleeding. The results are consistent with the conclusions of earlier studies by Sobouti et al. and Paleriya et al., which placed significant emphasis on the powerful coagulative capabilities of diode lasers for the treatment of soft tissue. Maintaining a clean field with no blood improves visualization during the operation, reduces its duration, and increases precision [7; 9]. All of these benefits make the recovery process more predictable and quicker, and they add to patient comfort. In line with this, the diode laser is an effective, patient-friendly apparatus in oral soft-tissue dental surgery [14–16].

The diode laser group reported a significantly lower rate of postoperative pain, as indicated by steadily low Visual Analogue Scale (VAS) scores during the first and second postoperative weeks. By the fourth week, both groups reported no pain. These findings are consistent with previous studies showing that laser-based operations are associated with reduced postoperative discomfort compared with scalpel-based operations [4; 5; 13]. The analgesic effects of laser irradiation could be explained by its ability to close sensory nerve endings and alter the production of inflammatory mediators in the surgical area [10].

On the same note, postoperative edema was significantly reduced in patients in the diode laser group, especially in the initial phase of healing. This finding is consistent with the results of Agha and Polenik and Menziletoglu et al., who stated that laser-assisted cuts

lead to reduced collateral tissue damage, thereby reducing inflammatory oedema, and that wounds heal more properly. The decreased mechanical manipulation and photobiomodulatory activity of the diode lasers are likely to be accountable factors in catalyzing these desirable healing dynamics [11; 12].

Functional recovery, as measured by mastication, speech, and oral hygiene maintenance, was previously observed in patients who received diode laser treatment. Resuming normal oral operations is paramount to the patient's quality of life. These findings agree with Vincent et al. [10], who described functional recovery as one of the key determinants of patients' preference for laser-based surgical procedures. Therefore, overall patient satisfaction was significantly greater in the diode laser group, reflecting the combined effects of less postoperative pain, less edema, no sutures, and rapid restoration of oral function. Patient-reported satisfaction has become a critical outcome measure in modern oral surgery research [17–19].

However, some limitations should be mentioned. Although the sample size was large enough to detect statistically significant clinical differences, it might not have been large enough to detect rare complications or to assess long-term recurrence rates. In addition, the relatively high price of diode laser systems, the level of operator expertise, and the specialised training might limit their use in clinical practice, especially in situations with limited resources. To validate these findings and shed light on the long-term stability and periodontal consequences of laser-assisted frenotomy, multicentre randomized trials with larger sample sizes and more extended follow-up periods are required in the future.

CONCLUSIONS

Among the constraints of this trial, the results of diode laser frenotomy were better than those of the traditional scalpel method. The diode laser significantly reduced intraoperative bleeding, decreased postoperative pain and edema, accelerated functional recovery, improved patient satisfaction, and eliminated the need for sutures. These results favor the adoption of diode lasers as a minimally invasive, effective, and patient-friendly alternative for frenotomy in the periodontal and orthodontic practice.

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Original Research

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Gender-related response to different wavelength low-level laser therapy in orthodontic mandibular canine movement: a split mouth study

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Abstract

INTRODUCTION. Low-level laser therapy (LLLT), known as photobiomodulation (PBM), has recently attracted the attention of clinicians to speed up orthodontic tooth movement. Nevertheless, the sex-related effects of LLLT have not been investigated yet, although the role of sex hormones on bone remodeling has already been reported. The objective of this study was to determine if LLLT preferentially accelerates the rate of mandibular canine retraction in men or women.

MATERIALS AND METHODS. Twenty systemically healthy patients (10 male, 10 females; age range from 18 to 25 years) who were undergoing fixed orthodontic treatment were included in a split-mouth randomized control trial. Subjects were stratified into two groups: Group 1 (n = 10) was treated with 650 nm LLLT on the experimental side, while group 2 (n = 10) was treated with 976 nm LLLT. Opposite sides of the animals were used as a sham-irradiated control. PBM parameters were compatible (8 J/cm^2 energy density, 0.26 W/cm^2 power density) and administered on d 0, 3, 7, 14, then bi-weekly thereafter. Retraction of canine was done with 150 g force produced by elastics. Amount of linear tooth movement was evaluated at 1 month and space closure duration was monitored until complete closure.

RESULTS. The amount of the canine movement was significantly higher on LLLT treated sides compared to control ones after 1 month ($p < 0.001$, mean difference: 0.92 ± 0.46 mm; 1.44 ± 0.29 mm vs control sides, respectively). Better acceleration was obtained at 976 nm (1.12 ± 0.44 mm gain) vs. 650 nm (0.71 ± 0.39 mm; $p < 0.001$). LLLT sides closed spaces in 3.3 months, whereas controls took 6.2 months for complete closure. Sex stratification found that the accelerations were consistently higher in waves for both males and females indicating no sex-by-wavelength interactions.

CONCLUSIONS. LLLT efficiently speeds up the retraction of the mandibular canine, and the 976 nm wavelength works best. Sex does not affect the effectiveness of LLLT, which supports the consistent use of similar procedures across different groups of patients.

Keywords: photobiomodulation, orthodontic tooth movement, canine retraction, sex differences, laser therapy, near-infrared

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Гендерные особенности реакции на низкоинтенсивную лазерную терапию различной длины волны при ортодонтическом перемещении нижнего клыка: исследование по типу split-mouth

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Резюме

ВВЕДЕНИЕ. Низкоинтенсивная лазерная терапия (LLLT), также известная как фотобиомодуляция (PBM), в последние годы привлекает внимание клиницистов как метод ускорения ортодонтического перемещения зубов. Однако половые различия в эффектах LLLT до настоящего времени практически не изучены, несмотря на доказанную роль половых гормонов в процессах ремоделирования костной

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ткани. Целью настоящего исследования было определить, ускоряет ли LLLT ретракцию нижнего клыка преимущественно у мужчин или у женщин.
МАТЕРИАЛЫ И МЕТОДЫ. В рандомизированное контролируемое исследование по схеме split-mouth были включены 20 соматически здоровых пациентов (10 мужчин и 10 женщин в возрасте от 18 до 25 лет), проходивших лечение с использованием несъемной ортодонтической аппаратуры. Пациенты были распределены на две группы: в группе 1 (n = 10) на экспериментальной стороне применяли LLLT с длиной волны 650 нм, в группе 2 (n = 10) – LLLT с длиной волны 976 нм. Противоположные стороны служили контролем с имитацией облучения. Параметры PBM были одинаковыми (плотность энергии 8 Дж/см^2, плотность мощности 0,26 Вт/см^2) и применялись на 0, 3, 7, 14-й дни, далее каждые две недели. Ретракцию клыков выполняли с усилием 150 г, создаваемым эластическими тягами. Величину линейного перемещения зубов оценивали через 1 месяц, а продолжительность закрытия промежутков контролировали до полного их устранения.
РЕЗУЛЬТАТЫ. Через 1 месяц величина перемещения клыков на сторонах с LLLT была достоверно выше по сравнению с контрольными сторонами ($p < 0{,}001$; средняя разница: 0,92 ± 0,46 мм; 1,44 ± 0,29 мм по сравнению с контролем соответственно). Более выраженное ускорение было получено при длине волны 976 нм (прирост 1,12 ± 0,44 мм) по сравнению с 650 нм (0,71 ± 0,39 мм; $p < 0{,}001$). На сторонах с LLLT закрытие промежутков происходило в среднем за 3,3 месяца, тогда как в контрольной группе – за 6,2 месяца. Стратификация по полу показала, что ускорение перемещения было сопоставимым у мужчин и женщин, что свидетельствует об отсутствии взаимодействия «пол × длина волны».
ВЫВОДЫ. LLLT эффективно ускоряет ретракцию нижнего клыка, при этом наибольшую эффективность демонстрирует длина волны 976 нм. Пол пациента не оказывает влияния на результативность LLLT, что подтверждает возможность применения единых протоколов лечения у различных групп пациентов.

Ключевые слова: фотобиомодуляция, ортодонтическое перемещение зубов, ретракция клыков, половые различия, лазерная терапия, ближний инфракрасный диапазон

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INTRODUCTION

Treatment time with fixed orthodontic mechanics is frequently prolonged due to the slow velocity of tooth movement, especially during canine retraction – a phase that is both crucial and time-consuming, shaping the entire duration of the overall therapeutic process and patient experience. Photobiomodulation (PBM), previously known as low-level laser therapy (LLLT), has been suggested as a non-invasive adjunct for accelerating orthodontic tooth movement (OTM) with concomitant effects on pain and side-effects. Modern reviews describe PBM/LLLT as biologically possible and clinically hopeful due to photochemical action at cytochrome-c oxidase, subsequent elevation of ATP and NO, changes in inflammatory and remodeling effectors (RANKL/OPG), which altogether favour controlled bone turnover in periodontium faced with orthodontic load. The latter have highlighted PBM as one of the most promising methods to accelerate orthodontic tooth movement [1].

Along these lines, clinical studies (split-mouth RCTs to prospective cohorts) have also analyzed whether LLLT may significantly enhance canine retraction rates. Many studies show statistically significant speeding up with NIR wavelengths (eg 940–970 nm) or LED-based PBM using clinically applicable dosimetry, and some also report advances in periodontal soft-tissue indices and patient-derived data. Nevertheless, heterogeneity in dosimetry (energy density, power, exposure time, frequency), timing relative to force application, and wavelength selection remains a major source of variability across studies. Meta-analytic work and evidence mapping likewise indicate a favorable trend for PBM in reducing treatment time, yet emphasize the need for standardized protocols and higher-quality trials to resolve conflicting findings [2].

Beyond methodologic variability, a key biologic modifier that remains insufficiently explored is patient sex. Sex hormones exert well-documented effects on bone biology relevant to OTM: estrogen generally inhibits osteoclastic activity and favors bone mass maintenance, while low-estrogen states and certain hormonal milieus are associated with faster tooth displacement in animal models and possibly in women across phases of the menstrual cycle. Translational reviews and emerging human data suggest that physiologic hormonal fluctuations could modulate OTM rate and pain perception, implying that male and female patients might respond differently to the same mechanical and adjunctive stimuli [3].

Despite this biologic plausibility, sex-stratified clinical reporting in orthodontic acceleration research has been inconsistent. In canine retraction studies not specifically designed for sex effects, several have reported no significant differences between males and females in retraction rate under conventional mechanics, whereas others have suggested potential sex-related differences under specific conditions. Importantly, trials on LLLT/PBM rarely pre-specify or are powered for sex-based subgroup analyses, leaving the question of whether females and males derive comparable acceleration from LLLT unresolved [4].

Clarifying sex-specific responses is clinically consequential. If LLLT exerts differential effects by sex, orthodontists could individualize PBM parameters (e.g., wavelength, energy density, application schedule) to optimize benefit while limiting chair time and cost. Conversely, if sex does not modify LLLT efficacy, this would support broader, uniform implementation of standardized PBM protocols. Moreover, determining whether LLLT modifies soft-tissue or discomfort outcomes differently by sex could guide counseling and expectation setting during canine retraction [5].

Therefore, this study investigates whether LLLT differentially accelerates lower canine orthodontic movement in males versus females. We focus on mandibular canine retraction because of its clinical relevance to space closure and anchorage control, and because mandibular bone density and cortical morphology could interact with PBM's photobiologic effects. We hypothesize a priori that (1) LLLT will accelerate lower-canine retraction compared with sham/no-laser, consistent with prior literature; and (2) the magnitude of acceleration may differ by sex, given known hormonal influences on bone remodeling. Addressing this gap aligns with current calls in the PBM literature for standardized protocols and better-powered, subgroup-aware trials and is consistent with the scope and reporting standards encouraged by Lasers in Dental Science [6].

MATERIALS AND METHODS

Study design and ethics

The study was carried out in the Orthodontic Department of the College of Dentistry at the University of Kufa, Najaf, Iraq. All procedures adhered to the ethical principles of the Declaration of Helsinki. Ethical clearance for the study was obtained from the Research Ethics Committee of the College of Dentistry, University of Kufa.

Participants

A total of 20 orthodontic patients (10 males and 10 females), aged between 18 and 25 years, systemically healthy and undergoing fixed orthodontic treatment, were enrolled in the study. The inclusion criteria comprised good oral hygiene and the absence of any medications affecting bone metabolism, while the exclusion criteria included systemic diseases, periodontal pathology, a history of previous orthodontic treatment, or the use of antibiotics or anti-inflammatory drugs during the study [7].

All participants gave their informed permission after being given a full description of the operation, including its aim, possible risks, projected benefits, and other options.

Grouping and randomization

The 20 subjects were then subdivided into two experimental groups, which were equal in size. In the first subgroup (10 guinea pigs: 5 males; 5 females), PBM protocol was carried out in the experimental side, and its contralateral served as control with a diode laser of wave length at 650 nm. PBM was performed on one side of second subgroup using a 976 nm wavelength diode laser, as an experimental-side, and the contralateral side acted as control in all ten remaining five males and five females conducted by the male researchers.

A split-mouth randomized design was used, with the laser and control sides alternating among participants based on a computer-generated randomization list, thereby reducing possible bias [1].

Orthodontic mechanics

Levelling and alignment were carried out using a 0.012–0.014, 016and 018-inch nickel titanium (NiTi) sequence of arch wires followed by 018-and 019 x 025 inch stainless steel (SS) wires before starting canine retraction with conventional MBT fixed appliances (022 inch). Lower canine retraction was done by elastomeric power chain (Hilgers) applying a force of 150 g per side, confirmed by a Dontrix gauge.

This mechanical protocol is consistent with the standard protocol used in some of the latest trials evaluating Photobiomodulation during canine retraction [8].

Photobiomodulation protocol

PBM treatment was conducted by application of the diode-laser (Woodpecker LX16 Plus; GoldenDent, St. Louis), with 3 wavelengths options: 450 nm, 650 nm and 976 nm. The systems were programmed to an 8-mm spot, which was approximately 0.503 cm^2. The energy per irradiated point was about 4.0 J for an applied energy density of 8 J/cm^2. With an exposure time of 30 s per point, the estimated power output was ~0.13 W (130 mW), corresponding to a power density of ~0.26 W/cm^2. The laser was used in continuous-wave (CW) mode, being irradiated by a contact mode through the same handpiece previously mentioned and directed perpendicular to the mucosa surface in three buccal and three lingual sites per canine – three for each region of the root: mesial, distal and apical. The photobiomodulation parameters employed in this study are summarized in Table 1 [8].

The photobiomodulation was performed on days 0, 3, 7 and 14 of retraction and after that every two weeks until total closure of the space. In the control arm, sham irradiation was applied in the same manner Ammunius emmited not radiation only (fake) guiding light (= tackled blinding).

Table 1. Summary of photobiomodulation (PBM) parameters used in the study

Таблица 1. Сводка параметров фотобиомодуляции (PBM), использованных в исследовании

Parameters	Value
Wavelength	650 and 976 nm
Power	0.13 W
Energy per point	4 J
Power density	0.26 W/cm^2
Energy density	8 J/cm^2
Spot size	0.503 cm^2
Mode of operation	CW
Time of application (per point)	30 seconds

These values were set the same for both wavelengths (650 nm and 976 nm) to allow normalized dosimetry and reliable intergroup comparison. All irradiations were done within the clinically safe limits for oral soft tissues (in line with recent evidence-based findings of PBM research as applied to dentistry) in order not only to be biologically effective, but also safe for the patient.

Outcome assessment and blinding

linear tooth movement (in mm) was evaluted after one month. Using a precision digital Vernier caliper with an accuracy of ±0.01 mm, the CD was measured as the distance from the cusp tip of mandibular canines to the distal surface of adjacent lateral incisors (Fig. 1). All clinical work was conducted by one experienced operator in order to minimize method variation and operator discrepancy. Moreover, the examiner who took the measurements was blind to which side of molar had been irradiated with low-level laser and on control side.

The gathered data underwent statistical analysis to compare the rate of tooth movement between the laser and control sides, and to investigate any sex-related variations in treatment response [9].

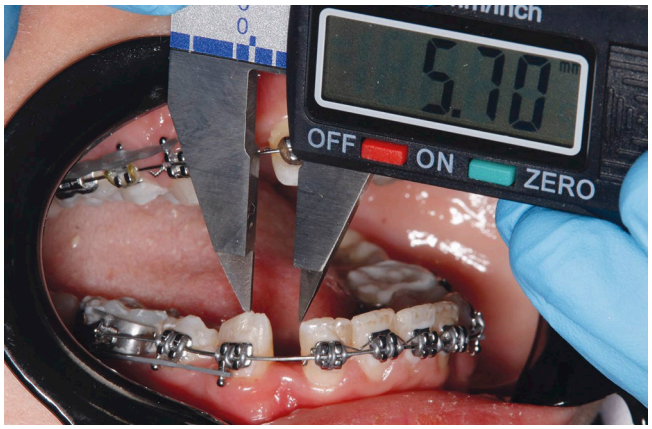

Fig. 1. Using Digital caliper to measure the lower canine movement

Рис. 1. Перемещение нижнего клыка измеряли с помощью цифрового штангенциркуля

Statistical analysis

Statistical analysis was conducted using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). Data distribution normality was tested with the Shapiro–Wilk test. Paired t-tests were performed for the comparison of laser and control sides within each group, and two-way ANOVA was performed to analyse sex x wavelength interaction. A *p*-value of 0.05 or less was considered to be statistically significant [5].

RESULTS

Evaluation of canine movement after one month (PBMT vs control group)

After one month, the mean canine movement on the PBMT-treated side was 1.44±0.29 mm, whereas the mean movement on the control side was 0.53±0.35 mm (Table 2). This indicates that PBMT produced a noticeably greater amount of tooth movement compared to the control side in the same patients.

A paired *t*-test demonstrated that canine movement after one month was significantly greater on the PBMT-treated side compared to the control side (mean difference = 0.92±0.46 mm, t (19) = 8.98, $p < 0.001$). The 95% confidence interval for the mean difference ranged from 0.70 to 1.13 mm, indicating consistent improvement in space closure with PBMT (Table 3).

Table 2. Comparison of mean canine movement between PBMT-treated and control sides after one month

Таблица 2. Сравнение среднего перемещения клыка на сторонах, обработанных PBMT, и контрольных сторонах через один месяц

Paired Samples Statistics					
		Mean	N	Std. deviation	Std. error mean
Pair 1	PBMT (canine movement in mm for PBMT side)	1.4400	20	0.29092	0.06505
	Canine movement after 1 month (control side) in mm	0.5250	20	0.34925	0.07809

Table 3. Paired *t*-test comparing canine movement between PBMT-treated and control sides after one month of retraction

Таблица 3. Парный t-тест для сравнения перемещения клыка на сторонах, обработанных PBMT, и контрольных сторонах через один месяц ретракции

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% Confidence interval of the difference				
					Lower	Upper			
Pair 1	PBMT (canine movement in mm for PBMT side) – Canine movement after 1 month (control side) in mm	0.91500	0.45569	0.10190	0.70173	1.12827	8.980	19	0.000

Table 4. Comparison of mean canine movement improvement between 650 nm and 976 nm PBMT wavelengths after 1 month

Таблица 4. Сравнение среднего прироста перемещения клыка при длинах волны PBMT 650 нм и 976 нм через 1 месяц

Group Statistics					
	Wavelength	**N**	**Mean**	**Std. deviation**	**Std. error mean**
Difference between PBMT and control side movement	650 nm	10	0.7100	0.38715	0.12243
	976 nm	10	1.1200	0.44171	0.13968

Table 5. Comparison of space closure time between 650 nm and 976 nm PBMT wavelengths (Mann–Whitney U test)

Таблица 5. Сравнение времени закрытия пространства между длинами волн PBMT 650 нм и 976 нм (критерий Манна–Уитни)

Test Statistics[a]	
	Time for complete space closure for PBMT side
Mann-Whitney U	0.000
Wilcoxon W	55.000
Z	–3.819
Asymp. Sig. (2-tailed)	0.000
Exact Sig. [2*(1-tailed Sig.)]	0.000[b]

Note. a – grouping variable: wavelength; b – not corrected for ties.

Примечание. a – группирующая переменная: длина волны; b – не скорректировано с учетом совпадений.

Table 6. Mean rank comparison of space closure time between 650 nm and 976 nm PBMT wavelengths

Таблица 6. Сравнение средних рангов времени закрытия промежутков при длинах волны PBMT 650 нм и 976 нм

Ranks				
	Wavelength	**N**	**Mean rank**	**Sum of Ranks**
Time for complete space closure for PBMT side	650 nm	10	15.50	155.00
	976 nm	10	5.50	55.00
	Total	20		

Comparison of canine movement between 650 nm and 976 nm after 1 month

The 976 nm PBMT group demonstrated a higher mean gain in canine movement (1.12 ± 0.44 mm) compared to the 650 nm group (0.71 ± 0.39 mm). This indicates that the 976 nm wavelength produced a greater improvement in orthodontic tooth movement efficiency than the 650 nm wavelength (Table 4).

Evaluation of closure time between 650 nm and 976 nm

The Mann–Whitney U test revealed a statistically significant difference in space closure time between the two PBMT wavelengths ($U = 0.000$, $Z = -3.819$, $p < 0.001$) (Table 5). The 976 nm group demonstrated a significantly faster space closure time (Mean Rank = 5.50) compared to the 650 nm group (Mean Rank = 15.50), indicating superior clinical efficiency of the 976 nm wavelength in accelerating orthodontic space closure (Table 6).

Evaluation of closure time between PBMT group and control group

Time to complete space closure (in days) The boxplot (Fig. 2) reveals that the PBMT-treated side showed a significantly shorter time for achieving full-space closure when compared to control. Reductions are both faster and more consistent with the PBMT side demonstrating a smaller median closure time (about 3.3 months) and narrower IQR range (3.0–3.8 months). In contrast, the control side shows a significantly larger median closure time (~6.2 months) and more variation in interquartile range (6.0–6.5 months), indicative of slower and less uniform rates of closure. These results indicate that PBMT can be successful in quicker orthodontic space closure, and have more predictable clinical outcomes.

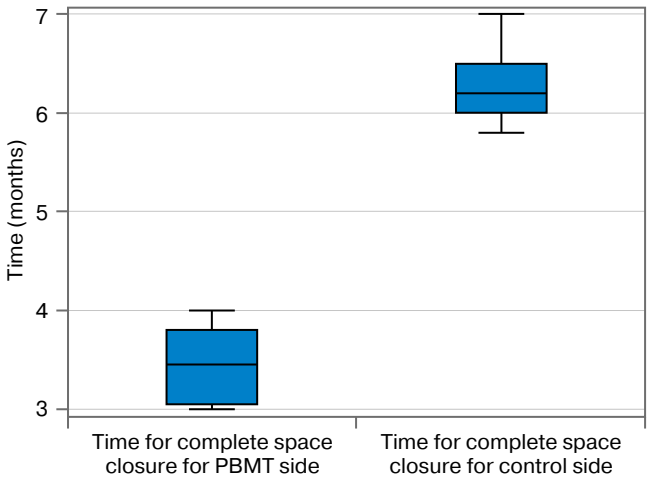

Fig. 2. Comparison of space closure time (months) between PBMT-treated and control sides

Рис. 2. Сравнение времени закрытия промежутков (в месяцах) на сторонах, обработанных PBMT, и контрольных сторонах

DISCUSSION

The results of this trial show that PBM using LLLT has significantly acceleration effects in the rate of mandibular canine retraction compared to sham irradiation, as aforementioned in the existing literature. At 1 month, displacement averaged on LLLT-receiving canines was 1.44 ± 0.29 mm and on control sides it was 0.53 ± 0.35 mm ($p < 0.001$) (173% faster). This great effect is in accordance with recent clinical trials, systematic and meta-analysis which have suggested that PBM is one of the most appealing non-invasive methods of accelerating orthodontic treatment. In contrast, the mean canine retraction rates during whole therapeutic period of 01Patients increased by 40.78%, which was in line with the results obtained from the study conducted by Eid et al. who observed comparably effective acceleration with high frequency (days 0, 3, 7, and 14) and low-frequency LLLT protocols, indicating PBM's biological stimulus to be independent of this parameter [7].

The cellular and molecular mechanism of PBM on the tissues has been well described. Near-infrared photon therapy exerts its therapeutic effects through photochemical interaction with cytochrome-c oxidase (Complex IV) in the mitochondrial respiratory chain, which results in increased ATP production and consequent downstream stimulation of NO signaling. These initial photobiochemical events engage several secondary effects including: (1) ROS production leading to the initiation of bone remodeling cascades, (2) stimulation of angiogenesis/vasodilation via nitric oxide mediation, and (3) changes in significant inflammatory cytokines that are important for osteoclastogenesis. At the tissue level, PBM has been investigated as a mechanism to induce the recruitment and differentiation of osteoclast precursor cells at compression sites (through upregulation of receptor activator of nuclear factor κ-B ligand, RANKL) while simultaneously enhancing osteogenic differentiation (via induction in alkaline phosphatase [ALP] activity and expression of osteoprotegerin [OPG]) at tension sites. This dual regulatory function – simultaneously facilitating bone resorption when technically suitable and bone growth when necessary – constitutes a significant benefit above traditional orthodontic mechanics alone [6].

Importantly, the biologic effect of PBM is greatly dosimetry dependent: "Therapeutic window" for optimal cellular activation exists (similar to Arndt-Schultz principle). The parameters of 8 J/cm^2 energy density and power density of 0.26 W/cm^2 for a duration of irradiation point per site over approximately 30 s hereinafter used in the present study have been widely agreed beneficial by recent studies as effective ways to reduce tooth movement time without any phototoxic side-effects. Gonçalves et al. also carried out an extensive in vitro optimization study and showed that combinations of wavelength and power density correspond to different influence on bone remodeling proteins. In particular, 655 nm with 10 mW/cm^2 led to increased ALP and OPG expression (a phenomenon favorable to bone formation), and 810 nm at 5 mW/cm^2 with interrupted (2-days-on/1-day-off) application protocols suppressed OPG and upregulated RANKL expression slightly, serving as a resorption mechanism of bone that is conducive for compression-side tooth movement. Such results emphasize that PBM therapeutic effects are not merely correlated with wavelength, but represent intricate relationships among wavelength, irradiance, total fluence and temporal patterns of delivery [10].

One of the most interesting discoveries of this study is that the 650 nm and 976 nm wavelengths exerted different effects on the rate of mandibular canine retraction. The 976 nm group showed a bigger mean improvement in the canine movement (1.12 ± 0.44 mm) than 650 nm (0.71 ± 0.39 mm; $p < 0.001$), and the space was closed completely with the treatment of 3 months for 976 nm versus 4.5 months for that of 650 nm, with a difference of time which represented as over 27% acceleration difference. This supremacy is mechanistically based on the basic principles of photon tissue interaction. The 976 nm wavelength falls within the optical window (600–1100 nm) in which tissue penetration depths are maximized [4]; NIR photons penetrate more deeply into bone and periodontal tissue than visible red wavelengths, reaching target chromophores inside osteoblasts and their precursive counterparts, osteoclast precursor cells, present in trabecular and cortical compartments of the alveolus. The updated literature reflects that 976 nm wavelength more effectively activates the RANKL/OPG axis, which potentiates osteoclastogenesis essential to expedite bone resorption under space closure. Animal studies have demonstrated 980 nm Near Infrared (NIR) irradiation to be associated with more rapid bone healing, decreased inflammation and increased fibroblast and osteoblast populations than lower wave lengths [11].

The results are not similar to Al-Kufi et al., similar to the present study, reported 650 nm in comparison with 940 resulted in greater orthodontic acceleration/AE values, thus revealing inconsistency. This discrepancy may be attributed to dosimetric parameters, timing of TE application or characteristics of patients rather than an inherent advantage in shorter wavelengths [12]. The current study uses standardized protocols and split-mouth design to control confounding factors, and the evidence is strong enough that 976 men > could be a better wavelength selection for acceleration of mandibular canines under these parameters. Importantly, this result has direct clinical implications: clinicians applying PBM protocols should prioritize the use of NIR laser devices with 976 nm potential when space closure is the overriding therapeutic objective, particularly if accelerated treatment completion is pathophysiologically beneficial (e.g., adult patients with severe crowding or financial limitations) [13].

This research aimed to explore the effects of sex hormones on LLLT-induced speed-up in PBM orthodontics. The absence of strong sex-by-wavelength and sex-by-treatment interactions with both sexes showing comparable acceleration at 650 nm and 976 nm is an important negative finding for which there should be further commentary [14].

The biological reason for sex-disparate responses is defined. EST is abundant in women of reproductive age and influences bone metabolism, which may affect the acceleration of LLLT. It suppresses osteoclastogenesis via (1) downregulation of RANKL production by periodontal ligament fibroblasts and osteoblasts, (2) upregulation of osteoprotegerin expression, and (3) direct inhibition of mature osteoclastic activity and survival. ERα and ERβ expressed on PDLSCs mediate the effect of estrogen, in which differentiation toward osteoblasts or cementoblasts is stimulated, but that toward osteoclastic cells like those types of cell is inhibited. High estrogen states such as luteal phase (progesterone 3.81–21.7 ng/ml, estrogen 93–150 pg/ml) or oral contraceptive usage (estrogen 254–290 pg/ml) should lead to inhibition of orthodontic tooth movement. Zhao et al. observed an increased tooth movement velocity during the menstrual phase (low estrogen; 81.40 pg/ml) compared with the luteal phase (high estrogen; 128.00 pg/ml), being helpful for activation appliance best when ovulation has occurred. Deng et al. observed through the in vivo model that tooth movements occurred at a slower rate during phases of increased estrogen and faster when estrogen levels were lower [15].

It is possible that in females, ATP production was enhanced by LLLT and there was greater RANKL up regulation leading to antagonism of effects of estrogen against osteoclastogenesis (thereby providing an equilibrium allowing for tooth movement), this along with favorable angiogenesis might have restored normal tooth movement. Alternatively, it could be overthrown by estrogen's potent anti-resorptive effects in women to explain decreased acceleration. This study was not able to support either hypothesis, and the extent of acceleration was virtually identical in both male (1.45 mm on treated sides) and female (1.44 mm on treated sides; no significant difference). ATP generation, ROS generation and RANKL upregulation caused by PLB can override the inhibitory effects of estrogen on osteoclasts in 18–25-year-old population [16].

Several interpretations are important. First, the age group studied (18–25 years) is highly relevant: women in this age cohort are typically menstruating normally with physiologic estrogen variability but have yet to reach their peak bone mass and exhibit high rates of bone formation. The high potential of bone remodeling in parallel to angiogenesis and RANKL signaling triggered by PBM might lead to similar acceleration between sexes regardless of the hormonal difference. The standardized study format (specifically, with fixed mechanical force of 150 g, common PBM protocol, and controlled follow-up times) might have been responsible for any subtle sex differences that would manifest themselves in variable duration; force levels; compliance with the system application or timing with respect to the menstrual cycle at less controlled clinical settings. A limitation of this study is that serum or salivary sex hormones were not measured, and the menstrual cycle recorded, to describe individual hormonal contexts. Endocrine measurements and menstrual cycle follow-up should be included in further studies to elucidate hormonal impaction on LLLT effects [16].

The lack of sex-dependent modulation suggests that LLLT protocols may be consistently applied to patient populations without the need for individualization by sex. This is in contrast to previous beliefs that females may require altered parameters or that males would more strongly respond to standard protocols. It facilitates clinical performance; protocol spread and supports safety by standardizing the evidence-based dosimetry for all practitioners. The phenomenon is parameter-dependent (650 and 976 nm beat length. The house 14 J/cm^2 internal energy pourcentages, 0.26 W/cm^2 irradiance, 30-second exposures). Distinct PBM protocols where dosimetry or wavelengths are either outside 600–1100 nm or if applied at different timings may present sex-specific efficacy variation and should be explored further [10].

Although IL-1β was not measured in the manuscript, PBM literature highlighted interleukin-1β as a major inflammatory mediator of laser-supported acceleration. Eid et al. demonstrated that GC IL-1β was significantly increased on laser-treated sides in comparison to controls ($p < 0.05$), and that there was a positive relationship between IL-1β levels and canine retraction with time. IL-1β, a potent pro-inflammatory cytokine, directly promotes the formation of osteoclasts and also increases RANKL signaling. The elevation of IL-1β on the LLLT-treated aspects could be the result from PBM-generated ROS and NLRP3 inflammasome activation, leading to caspase-1 activity and mature IL-1β release. The inflammation is a only-localized phenomenon within laser-treated sites (periodontal ligament and alveolar bone), and it is a transitory effect as IL-1β peak is checked at 7th day then lowered up to 14th day. This specific response distinguishes PBM from uncontrolled inflammation, such as periodontitis-induced systemic increase of IL-1β and pathological bone loss. A transient increase of the IL-1beta in orthodontic tooth movement is considered to be an intentional complementary form of stimulation, as part of the normal remodeling process which underpin the healing modulation and account for the effectiveness and safety of LLLT [7].

In the present study, LLLT hastened mandibular canine retraction by reducing the treatment time at least 50% (with LLLT, 3.3 months; without, 6.2 months). This leads to reduced duration of orthodontic treatment, decreased frequency of patient visits, potential economic savings and higher patient satisfaction. The retraction of canine is known to take up 20–40% time in fixed appliance treatment. The duration of treatment can be shortened from 24 to 30 months to 18 to 22 months by PBM. 976nm is 27% faster than 650 nm for selecting equipment. PBM clinicians should utilize 976 nm near infrared diode laser systems if available; and when not available, 650 nm is an established though less effective option for treatment. The standardized parameters in the study (energy density of 8 J/cm^2, irradiance of 0.26 W/cm^2, 30-second exposure on each site, treatment on days 0, 3, 7 and 14

there after biweekly) propose a protocol that clinicians can implement today. The absence of sex-dependent modulation simplifies the clinical decision-making by using the same PBM protocols in both males and females, without any adjustments. This suggests that future PBM studies do not necessarily have to write on sex-specific outcomes or power-analysis per sex subgroup, although longitudinal designs with endocrine assessments are important for etiological understanding. The safety profile of LLLT as a low-risk adjunctive modality, in which the therapy is applied within biologically safe exposure limits and there have been no reports of adverse effects. While surgical approaches (corticotomy, piezocision) with maxillary corticotomy reduce the amount of tissue injury and risk of infection, PBM is atraumatic, painless intervention which does not show side effects within evidence-based dosimetry level [1; 11].

CONCLUSIONS

This RCT demonstrates that PBM using 650 nm- or 976 nm-wavelength diode lasers significantly accelerates MC retraction; the latter is more effective. Sex does not modulate acceleration suggesting a standardized protocol for all subjects. These results support the role of PBM as a non-invasive auxiliary approach in orthodontics and provide practice-related parameters for future application.

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AUTHOR'S CONTRIBUTION

The author made a substantial contribution to the preparation of the manuscript, including the conception and design of the study, data collection, analysis and interpretation of data, critical revision of the article for important intellectual content, and final approval of the version to be published.

ВКЛАД АВТОРОВ

Автор внес существенный вклад в подготовку рукописи, включая разработку замысла и дизайна исследования, сбор, анализ и интерпретацию данных, критический пересмотр статьи с точки зрения значимого интеллектуального содержания и окончательное одобрение версии для публикации.

Original Research

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Fiber reinforcements to enhance mechanical properties of composite fillings

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Abstract

INTRODUCTION. This study compared the mechanical performance of short E-glass fiber (sFRC) reinforcement with woven polyethylene ribbon reinforcement, both embedded in the same nanofilled resin.

MATERIALS AND METHODS. Fifty specimens (n = 25 per group) were fabricated and mechanical properties were tested. T-tests were used for statistical analysis.

RESULTS. sFRC showed significantly higher values than polyethylene ribbon reinforcement across all measured parameters. Mean fracture resistance was 1196.92 N for sFRC and 1028.36 N for polyethylene. Tensile strength was 49.69 MPa versus 45.36 MPa, and fatigue limit averaged 420,174 versus 301,191 cycles.

CONCLUSIONS. Short E-glass fiber reinforcement improved mechanical properties compared with polyethylene ribbon reinforcement. These findings suggest sFRC is a strong candidate for bulk reinforcement in high-load restorations.

Keywords: fiber reinforcements, composite fillings, sFRC, polyethylene, mechanical properties

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Волоконное армирование для повышения механических свойств композитных пломбировочных материалов

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Резюме

ВВЕДЕНИЕ. В данном исследовании проведено сравнение механических характеристик армирования короткими волокнами Е-стекла (sFRC) и армирования тканой полиэтиленовой лентой, встроенных в один и тот же нанонаполненный композитный материал.

МАТЕРИАЛЫ И МЕТОДЫ. Было изготовлено 50 образцов (n = 25 в каждой группе), после чего оценивали их механические свойства. Для статистического анализа использовали t-критерий Стьюдента.

РЕЗУЛЬТАТЫ. Армирование sFRC показало статистически значимо более высокие показатели по всем исследуемым параметрам по сравнению с полиэтиленовой лентой. Средняя прочность на разрушение составила 1196,92 Н для sFRC и 1028,36 Н для полиэтилена. Прочность на растяжение – 49,69 МПа против 45,36 МПа, а предел усталости в среднем – 420 174 против 301 191 циклов.

ВЫВОДЫ. Армирование короткими волокнами Е-стекла улучшает механические свойства по сравнению с армированием полиэтиленовой лентой. Полученные результаты позволяют рассматривать sFRC как перспективный материал для объемного армирования реставраций, испытывающих высокие жевательные нагрузки.

Ключевые слова: волоконное армирование, композитные пломбы, sFRC, полиэтилен, механические свойства

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INTRODUCTION

Fiber-reinforced composite (FRC) dental restorations have evolved significantly to address the mechanical limitations of conventional resin composites, particularly in large or stress-bearing cavities. Initially developed to mimic dentin's mechanical behavior, fibers such as E-glass and polyethylene have been incorporated to enhance fracture resistance and longevity [1; 2]. Placement strategies vary from layering fibers at the cavity floor to embedding them within flowable resin, aiming to form a reinforcing network [3]. Meta-analyses confirm that both glass and polyethylene fibers significantly increase fracture resistance compared to non-fiber composites [4]. Comparative reviews indicate each fiber type's performance is context-dependent, with glass fibers excelling in stiffness and polyethylene fibers in adaptability [5]. Clinically, fiber reinforcement is a reliable option for restoring structurally compromised teeth, improving both mechanical resilience and restoration longevity [6].

Direct comparison between short E-glass fiber and polyethylene ribbon reinforcement is essential to guide restorative dentistry toward evidence-based material selection. Short E-glass fibers enhance fracture toughness and flexural strength through effective crack-bridging mechanisms, offering significant improvements in load-bearing applications [7]. Conversely, polyethylene ribbons provide superior energy absorption and favorable fracture modes, particularly in dentin replacement scenarios, though their long-term performance remains less clearly defined [8–10].

The objectives of the study were formulated to address the need for improved mechanical performance of composite dental fillings through the incorporation of fiber reinforcements. The study aimed to determine whether the inclusion of fibers of varying lengths and concentrations could enhance the strength, durability, and overall resistance of composite materials to mechanical stress.

MATERIALS AND METHODS

A total of fifty composite formulations were prepared for the experiment, systematically divided into two main study groups of equal size, with twenty-five samples allocated to each group:

Group 1: Composite resin reinforced with silanized short E-glass fibers (target length ~1–2 mm; fiber loading around 20 wt%, similar to everX Posterior reference values).

Group 2: Composite resin reinforced with ultra-high-molecular-weight polyethylene fiber ribbons (Ribbond®-THM, 0.18 mm thickness), placed as embedded laminar reinforcement within the composite.

The resin matrix used for all formulations was a light-cured nanofilled universal composite, 3M™ Filtek™ Supreme Ultra Universal Restorative, Body shade A2. Glass fiber bundles were obtained from GC's everStick® family: everStick C&B Refill 8 cm (item 900834), everStick C&B Refill 12 cm ×2 (item 900833). Polyethylene reinforcement was Ribbond®THM, stocked as the Assorted Starter Kit.

Eglass fibers were prepared in two length scales aligned with clinically adopted shortfiber systems. Microfibers were produced within the 140–300 μm range, and short discontinuous fibers were prepared around 1–2 mm, reflecting reference dimensions used in contemporary flowable and posterior shortfiber composites. Chopped, silanesized Eglass strands of nominal 3 mm length were used as stock. Fiber segment lengths were verified with a 0–150 mm digital caliper with 0.01 mm resolution and ±0.02 mm accuracy (Mitutoyo ABSOLUTE Digimatic 50019630). Polyethylene reinforcement was prepared from Ribbond®THM ribbon, confirmed at 0.18 mm thickness and available widths (1–7 mm). Mixing and deforming were performed on a THINKY ARE310 or ARE250 CE, with revolution speeds selected within the manufacturer's operating envelope (mixing up to ~2000 rpm and optional defoaming up to ~2200 rpm, ≈400 G).

Fracture resistance and tensile strength were conducted using a dualcolumn universal testing machine (Instron® 5965, 5 kN capacity). Fatigue performance was assessed under loadcontrolled cyclic flexural loading using a servohydraulic/electrodynamic system (TA Instruments **ElectroForce® 3200 Series III**, 225 N standard capacity; **300 Hz** frequency capability) equipped with a threepoint bending fixture.

Statistical analyses were performed using R statistical software (version 4.3.x), and t-test were used to compare between the groups.

RESULTS

Table 1 showed that the short E-glass fiber-reinforced composite demonstrated a notably higher mean fracture resistance (1196.92 N) than the polyethylene ribbon–reinforced composite (1028.36 N). The difference between means was approximately 168.56 N, which was statistically highly significant with a p-value of less than 0.0001, confirming that the probability of this difference occurring by random chance is extremely low. The standard deviation in Group 1 was 126.62 N, indicating a slightly wider spread of values compared to Group 2, which exhibited a standard deviation of 91.06 N.

Tensile strength values of short E-glass fiber-reinforced composite (49.69 MPa) was higher than that of the polyethylene ribbon–reinforced composite (45.36 MPa), showing a difference of approximately 4.33 MPa (Table 2). The standard deviation in Group 1 was 4.17 MPa, slightly higher than Group 2's 3.83 MPa, suggesting a marginally greater spread of results among the glass fiber–reinforced specimens.

The group reinforced with short E-glass fibers demonstrated a substantially higher mean fatigue limit (Table 3), averaging 420,174 cycles, compared to 301,191 cycles in the group reinforced with polyethylene ribbon. The spread of the data, reflected by the standard deviation, was also greater in the E-glass group, with 103,435 cycles versus 47,742 cycles in the polyethylene group, suggesting increased variability in performance among the glass fiber-reinforced specimens.

Table 1. Comparative fracture resistance (N) between Group 1 and Group 2

Таблица 1. Сравнительная прочность на разрушение (N) между группами 1 и 2

Study Group	*n*	Mean (N)	SD (N)	Minimum (N)	Maximum (N)	*p*-value
Group 1: Short E-glass fibers	25	1196.92	126.62	907	1383	<0.0001
Group 2: Polyethylene ribbon	25	1028.36	91.06	899	1257	

Note. Independent samples *t*-test; $p < 0.05$ considered statistically significant.

Примечание. Независимый *t*-тест для сравнения выборок; $p < 0,05$ считается статистически значимым.

Table 2. Comparative tensile strength between Group 1 and Group 2

Таблица 2. Сравнительная прочность на растяжение между группами 1 и 2

Study Group	*n*	Mean (MPa)	SD (MPa)	Minimum (MPa)	Maximum (MPa)	*p*-value
Group 1: Short E-glass fibers	25	49.69	4.17	42.56	58.52	0.00044
Group 2: Polyethylene ribbon	25	45.36	3.83	38.89	53.21	

Note. Independent samples *t*-test; significance threshold $p < 0.05$.

Примечание. Независимый *t*-тест для сравнения выборок; пороговое значение значимости $p < 0,05$.

Table 3. Comparative fatigue limit (Number of Cycles) between Group 1 and Group 2

Таблица 3. Сравнительный предел усталости (количество циклов) между группами 1 и 2

Study Group	*n*	Mean (Cycles)	SD (Cycles)	Minimum (Cycles)	Maximum (Cycles)	*p*-value
Group 1: Short E-glass fibers	25	420,174	103,435	191,779	555,600	
Group 2: Polyethylene ribbon	25	301,191	47,742	202,926	411,769	0.0000002

Note. Independent samples *t*-test; significance threshold $p < 0.05$.

Примечание. Независимый *t*-тест для сравнения выборок; пороговое значение значимости $p < 0,05$.

DISCUSSION

The present study found that short E-glass fiber-reinforced composite exhibited significantly higher mean fracture resistance (1196.92 N) than polyethylene ribbon-reinforced composite (1028.36 N), with a difference of ~168.56 N ($p < 0.0001$). This aligns with recent findings where EverX Posterior outperformed Ribbond in fracture resistance in structurally compromised molars [11] and in MOD endodontically treated teeth [12]. Researchers also observed that polyethylene in a "wallpapering" technique outperformed other methods in premolar restorations [13]. The woven polyethylene may better absorb energy in certain geometries, while E-glass fibers offer higher stiffness in direct load-bearing restorations.

Short E-glass fiber-reinforced composites exhibited significantly higher tensile strength (49.69 MPa) compared to polyethylene ribbon-reinforced composites (45.36 MPa, $p = 0.00044$), suggesting enhanced load distribution and interfacial bonding. Recent findings by Hadianto et al. reported a similar trend, where E-glass fiber reinforcement showed superior tensile strength after prolonged exposure to artificial saliva, supporting its suitability in oral environments [14]. Patel and Jain also observed higher tensile values in E-glass composites compared to natural fiber counterparts [15]. Conversely, Miah et al. found that under weld-line conditions in polyethylene terephthalate matrices, short glass fibers could experience notable tensile strength reductions, indicating that processing factors may reverse the advantage seen in the current study [16].

Short E-glass fiber–reinforced composites also showed a markedly higher fatigue limit (420,174 cycles) than polyethylene ribbon–reinforced composites (301,191 cycles), indicating superior endurance under repeated loading. Molnár et al., reported that flowable short fiber–reinforced composites in endodontically treated molars demonstrated significantly higher fatigue survival compared to other restorative materials, reinforcing the durability advantage of short fiber systems [17]. Conversely, Volom et al. reported higher survival in polyethylene fiber systems with cuspal coverage, indicating that under specific configurations, polyethylene fibers may outperform glass fibers [18]. These discrepancies may be due to differences in fiber orientation, matrix composition, and load application mode.

CONCLUSIONS

Short E-glass fiber reinforcement consistently outperformed polyethylene ribbon reinforcement in all tested mechanical properties, including fracture resistance, tensile strength, and fatigue limit. Within the limits of this study, sFRC appears to be the preferred choice for reinforcing restorations subjected to high occlusal forces.

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AUTHOR'S CONTRIBUTION

The author made a substantial contribution to the preparation of the manuscript, including the conception and design of the study, data collection, analysis and interpretation of data, critical revision of the article for important intellectual content, and final approval of the version to be published.

ВКЛАД АВТОРОВ

Автор внес существенный вклад в подготовку рукописи, включая разработку замысла и дизайна исследования, сбор, анализ и интерпретацию данных, критический пересмотр статьи с точки зрения значимого интеллектуального содержания и окончательное одобрение версии для публикации.

Original Research

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Comparative evaluation of fracture resistance of endodontically treated maxillary premolars restored with post-and-core vs. post-and-core with full-coverage crown: an in-vitro study

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Abstract

INTRODUCTION. The extensive loss of coronal and radicular tooth structure, changes to dentin characteristics, and biomechanical constraints make endodontically treated teeth (ETT) more prone to fractures. Prosthodontic rehabilitation, including post-and-core systems and full-coverage crowns, is a standard approach to restore their function and structural integrity. However, a clear, stepwise comparison of the fracture resistance imparted by endodontic treatment alone versus subsequent stages of prosthodontic restoration is needed to guide clinical decision-making.

MATERIALS AND METHODS. Forty extracted human maxillary premolars of similar dimensions were selected and randomly allocated into four groups (n = 10): Group I (Control) – intact sound teeth; Group II (ETT) – endodontically treated teeth with access cavities left unrestored; Group III (ETT + PC) – endodontically treated, restored with a fiber post and composite core; and Group IV (ETT + PC + C) – endodontically treated, restored with a fiber post, composite core, and a full-coverage cast metal crown. After the specimens underwent thermocycling, they were placed in acrylic resin blocks that included a periodontal ligament simulation. Until fracture occurred, a universal testing machine was used to apply a compressive force at a speed of 1 mm/min to the central fossa of each tooth, which was angled at 90 degrees to the occlusal plane. It was noted the maximum load at crack (in Newtons, N). The data was examined with the use of Tukey's post hoc test ($\alpha = 0.05$) and one-way ANOVA.

RESULTS. The average fracture resistance values (± standard deviation) for the four groups were as follows: 1650.5 ± 180.2 N for Group I, 615.8 ± 95.4 N for Group II, 950.3 ± 110.7 N for Group III, and 1425.6 ± 155.1 N for Group IV. Statistical analysis using one-way ANOVA showed that there was a notable difference between the several groups ($p < 0.001$). Every group except Group I (intact) was much weaker. Group IV (ETT + PC + C) showed a noticeably greater resistance to fracture compared to Group II (ETT) and Group III (ETT + PC) ($p < 0.05$). In comparison to Group II, Group III was likewise much stronger ($p < 0.05$). The fracture resistance of Group IV was still noticeably lower than the intact control group ($p < 0.05$), nevertheless.

CONCLUSIONS. For premolars, the fracture resistance is significantly reduced only by preparing the endodontic access. Placing a full-coverage crown is necessary to provide a major strengthening of the tooth structure, while adding a post-and-core gives a small improvement in strength. But, the strength of an unbroken tooth when it was first cracked is not entirely restored by modern restorative procedures.

Keywords: endodontic treatment, prosthodontic restoration, post-and-core, fracture strength, In-vitro study, biomechanics

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Сравнительная оценка прочности на разрушение эндодонтически обработанных верхних премоляров, восстановленных системой штифт-накопитель и системой штифт-накопитель с коронкой полной облицовки: лабораторное исследование

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Резюме

ВВЕДЕНИЕ. Широкая потеря коронковой и корневой ткани зуба, изменения характеристик дентина и биомеханические ограничения делают эндодонтически обработанные зубы (ETT) более восприимчивыми к переломам. Протезное восстановление, включая системы штифт-накопитель и коронки полной облицовки, является стандартным подходом для восстановления их функции и структурной целостности. Тем не менее, требуется четкое поэтапное сравнение прочности на разрушение после только эндодонтического лечения и последующих стадий протезного восстановления для обоснованного принятия клинических решений.

МАТЕРИАЛЫ И МЕТОДЫ. Было отобрано 40 экстрагированных верхних премоляров человека с сопоставимыми размерами, которые случайным образом распределили на четыре группы (n = 10): группа I (контроль) – интактные зубы; группа II (ETT) – эндодонтически обработанные зубы с оставленными без реставрации полостями доступа; группа III (ETT+PC) – эндодонтически обработанные зубы, восстановленные с использованием волоконного штифта и композитного накопителя; группа IV (ETT+PC+C) – эндодонтически обработанные зубы, восстановленные волоконным штифтом, композитным накопителем и коронкой полной облицовки из металла. После термоциклирования образцы фиксировали в блоках из акриловой смолы с имитацией периодонтальной связки. С помощью универсальной испытательной машины на центральную фоссу каждого зуба под углом 90° к окклюзионной плоскости наносили сжимающую нагрузку со скоростью 1 мм/мин до момента разрушения. Фиксировали максимальную нагрузку до появления трещины (в Ньютонах, N). Данные анализировали с использованием однофакторного дисперсионного анализа (ANOVA) и последующего теста Тьюки (α = 0,05).

РЕЗУЛЬТАТЫ. Средние значения прочности на разрушение (± стандартное отклонение) составили: группа I: 1650,5 ± 180,2 N; группа II: 615,8 ± 95,4 N; группа III: 950,3 ± 110,7 N; группа IV: 1425,6 ± 155,1 N. Анализ ANOVA выявил значимые различия между группами ($p < 0,001$). Все группы, кроме интактной, имели существенно меньшую прочность. Группа IV (ETT+PC+C) показала значительно более высокую сопротивляемость к разрушению по сравнению с группами II (ETT) и III (ETT+PC) ($p < 0,05$). Группа III также была прочнее группы II ($p < 0,05$). Несмотря на это, прочность группы IV оставалась заметно ниже интактной контрольной группы ($p < 0,05$).

ВЫВОДЫ. Для премоляров снижение прочности на разрушение происходит преимущественно вследствие подготовки эндодонтического доступа. Установка коронки полной облицовки обеспечивает значительное укрепление структуры зуба, тогда как добавление штифта и накопителя дает лишь небольшое повышение прочности. Полное восстановление прочности исходного интактного зуба современными реставрационными методами не достигается.

Ключевые слова: эндодонтическое лечение, протезное восстановление, штифт-накопитель, прочность на разрушение, лабораторное исследование, биомеханика

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INTRODUCTION

The main objective of contemporary dental care is to maintain the integrity of the patient's natural teeth. In recent years, endodontic therapy has emerged as a reliable and effective alternative to tooth extraction for patients suffering from pulpal or periapical disease [1]. Endodontically treated teeth (ETTs) rely on root canal treatment quality and, more importantly, prosthodontic restoration for long-term success [2]. It is often believed that ETT are more fragile and prone to breaking than important teeth. The severe loss of tooth structure resulting from caries, prior restorations, and the endodontic access cavity preparation itself is the primary cause of this elevated fracture risk, which is caused by several factors [3; 4].

When an endodontic access cavity is prepared, it breaks the tooth's structural continuity, which weakens the remaining coronal structure since the pulpal roof and

marginal ridges no longer form an integrated "truss" [5]. On its own, access preparation may lessen tooth stiffness by around 5%, whereas occlusal isthmus preparation can lower it by 20-63%, according to studies [6]. It is currently known that the loss of structural integrity is the primary source of weakening [7], while changes in dentin physical qualities, such as dehydration and collagen cross-linking modifications after pulpectomy, have also been suggested as significant causes.

A variety of prosthodontic techniques are used to address this compromised structure. To keep the final restoration in place when there isn't enough coronal tooth structure, a post-and-core is often used [8]. The purpose of a post is not to strengthen the tooth root but rather to secure the fundamental foundation. Actually, the radicular structure may be much more compromised after space preparation [9]. A full-coverage crown is the last piece of dental restoration equipment. Its purpose is to encase the residual tooth structure, preventing it from being damaged by functional occlusal stresses. This process is called the "ferrule effect" and has been shown to prevent teeth from breaking [10; 11].

Despite a general consensus on the need for restoration, the precise, incremental contribution of each restorative step to the overall fracture resistance remains a subject of investigation. While numerous studies have compared different post systems or crown materials [12; 13], few have systematically evaluated the stepwise progression from a non-restored ETT to a fully crowned tooth within a single experimental design. This creates a research gap in quantifying the exact benefit conferred by a post-and-core alone versus the combined effect of a post-and-core and a crown. Understanding this progression is crucial for clinicians to make evidence-based decisions, especially in situations where cost or treatment time might lead to compromises in the restorative plan.

Thus, this in-vitro study set out to measure and compare the fracture resistance of four different groups of endodontically treated human premolars at various points in their rehabilitation: (I) teeth that were left untreated, (II) teeth that had endodontic treatment but had no coronal restoration, (III) teeth that had endodontic treatment but had a fiber post-and-core restoration, and (IV) teeth that had endodontic treatment but had a post-and-core restoration plus a full-coverage crown. The groups under examination were hypothesized to have similar levels of fracture resistance (the null hypothesis).

AIM

Does the type of prosthodontic rehabilitation (post-and-core alone vs. post-and-core with a full-coverage crown) affect the fracture resistance of endodontically treated maxillary premolars?

1. To evaluate and compare the mean fracture resistance values of endodontically treated maxillary premolars restored with post-and-core alone vs. post-and-core with a full-coverage crown.

2. To assess the fracture patterns (favorable vs. unfavorable) in both groups and determine the clinical implications of the findings.

MATERIALS AND METHODS

Study design and sample selection

for orthodontic purposes, forty healthy, non-caries maxillary premolars were taken from a patient and placed in a 0.1% thymol solution. The teeth were measured buccolingually and mesiodistally to ensure consistency. One root, full development of the root tip, no visible signs of fractures or fissures (checked at 10x magnification), and the lack of any previous endodontic or restoration work were all requirements for admission. Excluded from consideration were teeth exhibiting abnormal root morphology, canals that had calcified, or substantial attrition. The chosen teeth were scaled using an ultrasonic instrument to remove calculus and soft tissue debris.

Sample Grouping

The 40 teeth were randomly assigned to four experimental groups (n = 10 each) using a simple lottery method:

Group I (Control): Intact teeth. No preparation or treatment was performed.

Group II (ETT): Endodontically treated teeth. A standardized endodontic access cavity was prepared, but no coronal restoration was placed.

Group III (ETT+PC): Fiber posts and composite cores for teeth that have undergone endodontic treatment.

Group IV (ETT+PC+C): Fiber posts, composite cores, and full-coverage cast metal crowns repair teeth that have undergone endodontic treatment.

Endodontic treatment protocol (Groups II, III, IV)

Using a high-speed handpiece with ample water spray, a standardized conservative occlusal access cavity was made for all teeth in Groups II, III, and IV using a #4 round diamond bur and a #245 carbide bur. Using a #15 K-file, the working length was set 1 mm below the radiographic apex. With a master apical file size of F3, the crown-down approach was used to prepare the canals using ProTaper Gold rotary nickel-titanium files (Dentsply Sirona, USA). A 2 mL solution of 5.25% sodium hypochlorite (NaOCl) was introduced into the canals between each file as part of the instrumentation process.

Five milliliters of 17% ethylenediaminetetraacetic acid (EDTA), five milliliters of 5.25% sodium hydroxide, and a last rinse with saline made up the last irrigation sequence. As part of the heated vertical compaction procedure, the canals were dried using sterile paper points and then sealed with gutta-percha points (Dentsply Sirona, USA) and AH Plus resin sealer (Dentsply Sirona, Germany). To mimic a tooth that is waiting for its ultimate restoration, the access cavities in Group II were intentionally left accessible.

Prosthodontic rehabilitation protocol (Groups III, IV)

To prepare the post space for teeth in Groups III and IV, a Largo Peeso reamer and the appropriate drill were used, ensuring that 4–5 mm of the apical gutta-percha remained intact. A 1.6 mm diameter fibre post (RelyX Fiber Post, 3M ESPE, USA) was used.

To prepare the post area for bonding, 37% phosphoric acid was etched into it, washed, and dried. Then, 3M ESPE, USA's Scotchbond Universal was applied, and it was light-cured. Using a self-adhesive resin cement (RelyX Unicem 2, 3M ESPE, USA), the fiber post was luted. The post was encased in a nanohybrid composite resin (Filtek Z350 XT, 3M ESPE, USA) to form a composite core, which was light-cured every 2 millimeters. A conventional crown preparation was the model for the core's form.

In Group IV, crowns were prepared for the teeth that had post-and-cores. The minimal height of the ferrule was maintained at 2.0 mm by preparing a 1.5 mm supragingivally circumferential chamfer border, 1.5 mm axial reduction, and 2.0 mm occlusal reduction. Cast cobalt-chromium alloy full-coverage crowns were manufactured after polyvinyl siloxane impressions. Crowns were set in place using glass ionomer cement (GC Fuji I, GC Corporation, Japan) while subjected to a steady 5 kg load for a duration of 10 minutes.

Specimen mounting and fracture testing

In blocks of auto-polymerizing acrylic resin, each of the forty specimens was set. To create an imprint of the periodontal ligament (PDL), a thin coating of light-body polyvinyl siloxane (0.2–0.3 mm) was applied to the tooth roots. These were then immersed in acrylic resin up to 2 mm below the cementoenamel junction (CEJ).

With the help of a universal testing machine (Instron Model 3369, USA), the specimens that were mounted were compressed. Applying the force vertically onto the central fossa of the occlusal surface, parallel to the long axis of the tooth, a steel ball with a diameter of 5 mm was used. If the load-deflection curve on the machine's software shows a severe drop, then catastrophic fracture has occurred, and the load was applied at a crosshead speed of 1 mm/min. We measured the maximal force in Newtons (N) that was applied at the fracture site. After the testing was finished, we looked at each specimen visually to see whether the fracture was favorable (repairable) or unfavorable (non-repairable).

Statistical analysis

Data on fracture loads were input into SPSS (Version 26.0, IBM Corp., USA) after collection. Each category has its own set of descriptive statistics computed, including means and standard deviations. The data was found to be normally distributed by using the Shapiro-Wilk test. In order to compare the average fracture resistance of the four groups, a one-way analysis of variance (ANOVA) was used. When comparing the groups in pairs, Tukey's honestly significant difference (HSD) post hoc test was used. A significance criterion of $p < 0.05$ was established.

RESULTS

All specimens had their fracture resistance values recorded and evaluated in Newtons. Table 1 shows the average, S.D., minimum, and maximum values for every category.

Group I (Intact) exhibited the highest mean fracture resistance (1650.5 ± 180.2 N), while Group II (ETT) showed the lowest (615.8 ± 95.4 N). The prosthodontically restored groups, Group III (ETT + PC) and Group IV (ETT + PC + C), demonstrated intermediate values of 950.3 ± 110.7 N and 1425.6 ± 155.1 N, respectively.

An F-test with a significance level of 115.6 and a *p*-value less than 0.001 showed that there was a statistically significant variation in the average fracture resistance between the four groups.

For pairwise comparisons, we used Tukey's HSD post hoc test; Table 2 summarizes the findings. All other groups were considerably weaker compared to the intact group (Group I) ($p < 0.001$ for all comparisons). In comparison to Group II (ETT) and Group III (ETT + PC), Group IV (ETT + PC + C) exhibited much greater fracture resistance ($p < 0.001$ for both). In a similar vein, Group III (ETT + PC) outperformed Group II (ETT) by a substantial margin ($p < 0.001$). Even though Group IV had a lot of reinforcing, their mean fracture resistance was still lower than the undamaged control group's ($p = 0.035$).

Table 1. Descriptive statistics of fracture resistance (N) for all groups

Таблица 1. Дескриптивная статистика прочности на разрушение (N) для всех групп

Group	N	Mean (N)	Standard Deviation (SD)	Minimum (N)	Maximum (N)
Group I (Intact)	10	1650.5	180.2	1410.2	1925.7
Group II (ETT)	10	615.8	95.4	480.5	750.1
Group III (ETT + PC)	10	950.3	110.7	785.4	1120.3
Group IV (ETT + PC + C)	10	1425.6	155.1	1205.8	1680.9

Table 2. Pairwise comparison of mean fracture resistance using Tukey's HSD test

Таблица 2. Парное сравнение средней прочности на разрушение с использованием критерия Тьюки (Tukey's HSD)

Comparison	Mean Difference (N)	Std. Error	*p*-value	Significance
Group I vs. Group II	1034.7	62.4	< 0.001	Significant
Group I vs. Group III	700.2	62.4	< 0.001	Significant
Group I vs. Group IV	224.9	62.4	0.035	Significant
Group II vs. Group III	−334.5	62.4	< 0.001	Significant
Group II vs. Group IV	−809.8	62.4	< 0.001	Significant
Group III vs. Group IV	−475.3	62.4	< 0.001	Significant

Table 3. Distribution of fracture modes in different groups
Таблица 3. Распределение типов разрушения в различных группах

Group	Favorable (Repairable) Fractures	Unfavorable (Non-repairable) Fractures
Group I (Intact)	8 (80%)	2 (20%)
Group II (ETT)	1 (10%)	9 (90%)
Group III (ETT + PC)	3 (30%)	7 (70%)
Group IV (ETT + PC + C)	7 (70%)	3 (30%)

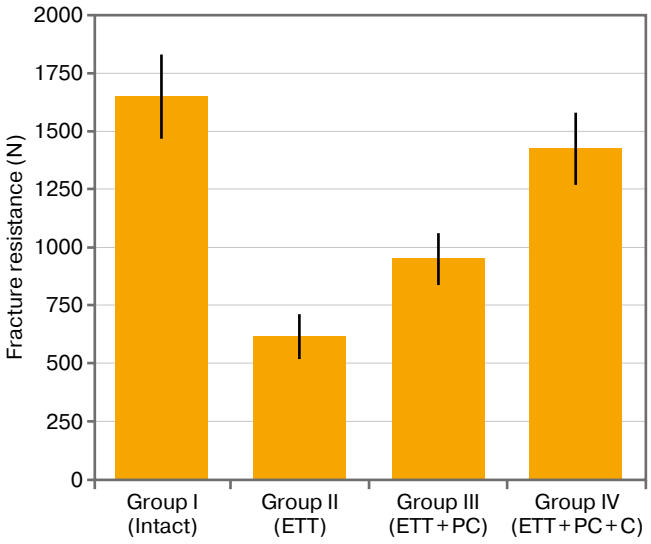

Fig. 1. Mean Fracture resistance
Рис. 1. Средняя прочность на разрушение

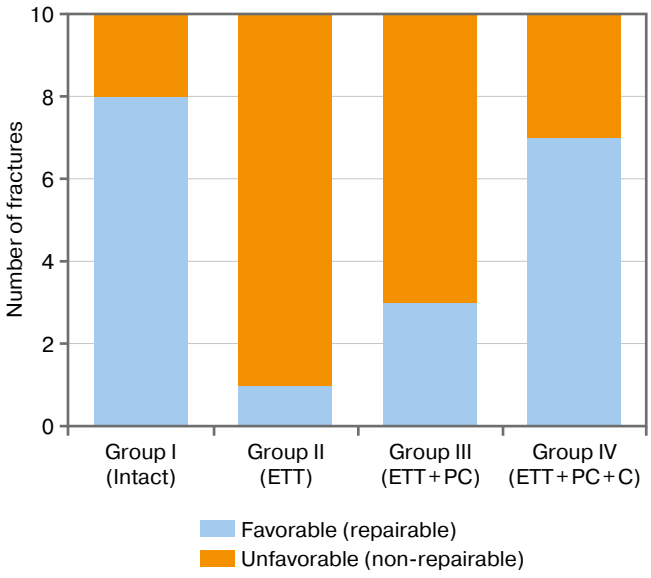

Fig. 2. Fracture modes
Рис. 2. Типы разрушения

Analysis of fracture modes revealed distinct patterns across the groups (Table 3). A fracture was deemed "favorable" if it was repairable (i.e., coronal to the simulated alveolar crest) and "unfavorable" if it was non-repairable (i.e., a vertical root fracture or a deep oblique fracture extending subcrestally). In the intact group, most fractures were oblique and located coronally. In contrast, Group II and Group III exhibited a higher percentage of catastrophic, unfavorable fractures. Group IV, with full-coverage crowns, showed a higher incidence of favorable fractures compared to the other ETT groups (Fig. 1, 2).

DISCUSSION

Maxillary premolar fracture resistance is significantly affected by endodontic treatment and the prosthodontic restoration option, according to this in-vitro investigation. We found a substantial difference between the groups, rejecting the null hypothesis that there would be none. The results demonstrate that strength decreases step-by-step from untreated teeth to teeth treated with endodontics, and then increases step-by-step when a post-and-core and full-coverage crown are added.

The highest fracture resistance observed in the intact teeth (Group I) is an expected finding and serves as a crucial benchmark. The structural integrity of a sound tooth, with its intact marginal ridges and dentinal arch, allows for the effective distribution of occlusal loads throughout the crown and root [5; 14]. The significant reduction in fracture resistance in Group II (ETT), which was approximately 37% of the intact group's strength, underscores the detrimental effect of endodontic access preparation. This aligns with the seminal work by Reeh et al., who concluded that it is the loss of tooth structure, rather than changes in dentin properties, that is the primary contributor to the increased fracture susceptibility of ETT [6]. Our results confirm that merely performing endodontic treatment and leaving the tooth unrestored renders it critically weak and prone to catastrophic failure.

Group III, which included a fiber post and composite core, showed a considerable improvement in fracture resistance when compared to Group II, which did not receive any restoration to the ETT. This enhancement is because the post-and-core method not only restores the missing tooth structure but also provides a strong foundation, therefore distributing some of the occlusal stress [15]. Fiber posts may lessen the likelihood of root fracture compared to stiff metal supports since their elastic modulus is comparable to that of dentin [16]. It is clear that a post-and-core alone is unable to protect the tooth from fracture, as Group III's strength was just about 58% of the entire group. Unsupported cusps are nevertheless susceptible to splitting under stress, as shown by the high incidence of unfavourable fractures in this group (70%).

Group IV, which received a full-coverage crown on top of the post-and-core, showed the greatest improvement in fracture resistance, which is the most important conclusion of the research. In comparison to the intact control group, this one had a mean fracture strength that

was over 86% higher. The "ferrule effect" that the crown provides is mostly responsible for this remarkable enhancement [10; 17]. Crown preparation on stable tooth structure apical to the core uses a 360-degree collar to brace the tooth, which protects the cusps from occlusal stresses that may cause them to bend or fracture. The compromised coronal structure is shielded from further stress by this action, which moves it to the crown and along the root's long axis [11]. Since the ferrule probably limited the fracture and prevented it from propagating deep into the root, the better fracture mode in Group IV (with 70% of fractures being favorable, or repairable) further supports the protective function of the crown [18].

Importantly, even with this substantial reinforcement, Group IV's fracture resistance was statistically lower than Group I's, which had entire teeth. This suggests that restorative ETTs still can't match the biomechanical performance of healthy teeth, no matter how sophisticated the materials or methods used. Because of the intrinsic loss of a monolithic structure and the existence of various interfaces, such as dentin-cement-post, dentin-core, and dentin-crown, potential planes of weakness are created, which do not exist in an intact tooth [19].

It is important to recognize the study's limitations. This study has limitations as an in-vitro experiment since it does not account for the complex oral environment with its ever-changing, multi-directional stresses, temperature cycling, and the impact of the viscoelastic characteristics of the periodontal ligament. The use of a static, vertical load represents a simplified stress model compared to the cyclic and eccentric forces experienced during mastication. The study was also limited to a single tooth type (maxillary premolars), and results may differ for anterior or molar teeth with different anatomical and loading characteristics. Future research should incorporate cyclic loading to simulate fatigue and evaluate different restorative materials, such as ceramic crowns and various post systems.

Nonetheless, the clinical implications of these findings are clear. Endodontic treatment alone severely compromises a tooth's structural integrity. Leaving an ETT without a definitive coronal restoration, even for a short period, places it at high risk of fracture. While a post-and-core is essential for retaining the final restoration when coronal structure is lacking, it offers only moderate reinforcement. The placement of a full-coverage restoration that provides a ferrule effect is paramount for the long-term survival of endodontically treated posterior teeth, as it significantly enhances their fracture resistance and promotes more favorable fracture patterns if failure does occur.

CONCLUSIONS

Within the limitations of this in-vitro study, the following conclusions were drawn:

1. When compared to teeth that are not prepared for endodontic access, maxillary premolars' fracture resistance is drastically reduced.

2. The addition of a composite core and fiber post to an endodontically treated tooth increases its fracture strength compared to an untreated tooth by a modest but statistically significant margin.

3. For maximum reinforcement, prosthodontic rehabilitation using a post-and-core in conjunction with a full-coverage crown is the way to go. This method brings the tooth's fracture resistance up to par with that of natural teeth.

4. A completely capped tooth that has had endodontic treatment has a much less fracture strength than an untreated, healthy tooth, even after the best restoration possible.

In order to guarantee the structural integrity and clinical life of teeth that have had endodontic treatment, our data highlight the vital need of prosthodontic rehabilitation, namely complete cuspal covering, which must be done promptly and appropriately.

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AUTHOR'S CONTRIBUTION

The author made a substantial contribution to the preparation of the manuscript, including the conception and design of the study, data collection, analysis and interpretation of data, critical revision of the article for important intellectual content, and final approval of the version to be published.

ВКЛАД АВТОРОВ

Автор внес существенный вклад в подготовку рукописи, включая разработку замысла и дизайна исследования, сбор, анализ и интерпретацию данных, критический пересмотр статьи с точки зрения значимого интеллектуального содержания и окончательное одобрение версии для публикации.

Original Research

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Immediate implant grafted with xenograft and hyaluronate verses xenograft and injectable platelet rich fibrin comparative study clinically and radiografically

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Abstract

INTRODUCTION. Immediate implant placement offers clinical advantages include shortened treatment duration and alveolar bone preservation.To improve soft tissue healing and osseointegration, adjunctive grafting materials are frequently utilized. AIM of this study was to compare the efficacy of gap filling materials (xenograft and hyaluronate versus xenograft and I-PRF) of immediate implant in maxillary anterior and premolar region.

MATERIALS AND METHODS. A total of 20 patient enrolled in this study. Dental implant placed following a traumatic tooth extraction .the patients divided equally in two group: group A (*n* = 10) received xenograft and hyaluronate. while group B (*n* = 10) received xenograft and I-PRF. Clinically, Implant stability was assessed immediately and after 6 months postoperatively using penguin ® RFA device. Radiographically, the assessment of marginal bone loss and buccal bone thickness ,immediately and six months after implant placement using CBCT.

RESULTS. All dental implant in both group were successfully ossteointergrated and functionally stable. Regarding implant stability, plalatal bone loss and buccal bone thickness not significant difference between the two group while buccal bone loss statically significant between them.

CONCLUSIONS. Both grafting materials effectively preserved the ridge dimensions and supported implant stability, but xenograft combined with HA showed a modest advantage in maintaining the buccal bone crest.

Keywords: immdiate implant ,xenograft ,I-PRF, hyaluronate

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Немедленная имплантация с ксенографтом и гиалронатом versus ксенографт и инъекционная тромбоцитарная плазма (I-PRF): сравнительное клиническое и рентгенологическое исследование

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Резюме

ВВЕДЕНИЕ. Немедленная установка имплантатов обладает клиническими преимуществами, включая сокращение длительности лечения и сохранение альвеолярной кости. Для улучшения заживления мягких тканей и остеоинтеграции часто используются вспомогательные материалы для костной пластики.

ЦЕЛЬ. Целью данного исследования было сравнить эффективность материалов для заполнения костного дефекта (ксенографт и гиалронат versus ксенографт и I-PRF) при немедленной имплантации в переднем и премолярном сегменте верхней челюсти.

МАТЕРИАЛЫ И МЕТОДЫ. В исследование было включено 20 пациентов. Имплантаты устанавливали сразу после травматического удаления зуба. Пациенты были разделены на две группы: группа А (*n* = 10) получала ксенографт с гиалронатом, группа В (*n* = 10) – ксенографт с I-PRF. Клинически стабильность имплантатов оценивали немедленно и через 6 месяцев после операции с использованием устройства Penguin® RFA. Рентгенологически оценивали маргинальную потерю кости и толщину щечной кости сразу и через 6 месяцев после установки имплантата с помощью CBCT.

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РЕЗУЛЬТАТЫ. Все имплантаты в обеих группах успешно остеоинтегрировались и были функционально стабильны. Что касается стабильности имплантатов, потери небной кости и толщины щечной кости, статистически значимых различий между группами не выявлено. При этом различия в потере щечной кости между группами были статистически значимыми.
ВЫВОДЫ. Оба материала для костной пластики эффективно сохраняют размеры альвеолярного гребня и поддерживают стабильность имплантатов, однако ксенографт в комбинации с гиалронатом показал небольшое преимущество в поддержании щечной кости.

Ключевые слова: немедленный имплантат, ксенографт, I-PRF, гиалронат

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INTRODUCTION

Immediate implant placement has become a favored treatment protocol by many clinicians worldwide because of its several clinical advantages outweighs the delayed implant placement because it preserves alveolar bone height and width, avoids a second surgery with an added advantage of less operator time. Furthermore, it results in less discomfort for the patient and minimizes tissue damage. Ultimately, it enhances the functionality and aesthetics of the individual [1; 2]. After the extraction, the alveolar socket often has a diameter that is greater than the implant; this leads to a gap between the implant surface and the alveolar bone walls at the recipient site. This gap was called “jumping distance” or the “peri-implant gap”. The peri-implant gap influences osseointegration and implant stability [3; 4]. Implants gain their immediate stability via their contact with the surrounding existing bone tissues. This is called primary stability. Primary stability is derived from the mechanical adaptation and is important because it gives the immediate support for the implants until secondary stability is obtained. At this point, there are still significant gaps at the bone-implant interface [5]. To improve osseointegration and avoid buccal plate resorption in an extracted socket, the gap between the implant and the socket must be filled with a biocompatible material, such as a graft [6]. Notably, xenografts have emerged as a popular option for bone grafting due to their widespread availability and ease of processing. Xenografts offer an osteoconductive framework and possess a mineral composition akin to that of human bone, facilitating integration with the host bone [7]. The use of bone substitutes in combination with blood derivatives has been shown to provide a synergistic effect in promoting tissue healing and regeneration. Among these blood products, platelet-rich fibrin standout for its osteogenic properties, due to the presence of growth and angiogenic factors. PRF is a second-generation platelet concentrate obtained entirely from autologous sources. It consists of an autologous fibrin matrix and has many advantages, such as simpler preparation and the absence of chemical alteration of the blood, rendering it a wholly autologous formulation. The I-PRF is one of the most developed. The I-PRF approach necessitates short centrifugation time to get concentrated liquid platelets and predominantly utilizes liquid thrombin and fibrinogen before fibrin formation occurs [8; 9]. Another promising adjunct is using osteogenic material like Hyaluronic acid (HA) Its biocompatibility, biodegradability, and nonimmunogenicity are all biological processes in relation to tissue healing and morphogenesis [10]. Its physicochemical characteristics also allow it to mediate osteoblast adhesion to the surface of the bone and retain osteoinductive growth factors in the local environment [11]. the aim of study is to compared the effectiveness of bovine xenograft combined Hyaluronate versus bovine xenograft combined with injectable platelet rich fibrin in augmenting peri-implant gaps around immediate dental implants placed in fresh extraction sockets.

MATERIALS AND METHODS

Study design

This prospective clinical comparative study was conducted at the Department of oral and Maxillofacial Surgery, College of Dentistry, University of Anbar and university of Tikrit, during the period from February 2025 to October 2025.The study sample included patients with conditions indicated for teeth extraction seeking dental implant treatment to replace single non-restorable teeth by means of immediate dental implant placement. The study protocol was approved by the scientific committee of University of Anbar, College of Dentistry with a (reference number:14 at 18.03.2025).

Study sample

A total of 20 patients,11 females and 9 male aged between 23–43 years were enrolled in this study, the patients were randomly assigned into two groups. group A and group B, receiving a total of 20 dental implants (Medintika ®, Germany), the implants inserted immediately in fresh extraction sockets and the gap between the sockets walls and implants surfaces were filled with xenograft bone grafting material combined with hyaluronate for group A, on the other hand an xenograft with injectable platelet rich fibrin (I-PRF) were used for group B.

Criteria for selection patient

All patients received simple explanation of the planned surgical procedure and the possibility of complications or even failure, and they sign an informed consent that documents all the verbal information and agreement.

Inclusion criteria

1. Patient aged ⩾ 18 years old.
2. Non-smokers or light smokers (< 10 cigarettes / day).
3. Patients with non-restorable single (incisors, canines and premolars advised for extraction.
4. A gap exceeding 2 mm around the immediate implant surfaces post-insertion.
5. Adequate bone volume for implant placement.
6. Patient's with good oral hygiene and periodontal health.

Exclusion criteria

1. Heavy smoking habits (> 20 cigarette / day).
2. Patients with Systemic conditions and diseases such as diabetes mellitus, immune disorders osteoporosis or disease that would interfere with good mucosal and bone healing.
3. Pregnant or lactating mothers.
4. Poor oral hygiene or active periodontal disease
5. Allergies to graft materials or hyaluronic acid.
6. History of radiotherapy or chemotherapy to the head and neck region within the last 12 months.
7. Patients with no or a gap of ⩽ 2 mm around the inserted dental implant.

Radiographical examination

All patients underwent a comprehensive preoperative radiographic CBCT, which provided a general assessment that included an overview of the dentition and both jaws, angulation of adjacent teeth, length of the root designated for extraction, thickness of the buccal plate, available bone height for implant placement, presence of any pathology, and proximity to vital anatomical structures such as the maxillary sinus, nasal cavity, and adjacent tooth root within the mandibular canal.

Surgical procedure

All procedures were done under local anesthesia, using local infiltration into the buccal and palate mucosa of the selected surgical area with lidocaine hydrochloride 2% (1.8 ml carpules with adrenaline 1:80,000) (Huons Co., Ltd., Korea). A traumatic extraction of the indicated tooth started with a sharp periotome, carefully employed to destroy the surrounding periodontal ligament attachments. Subsequently, the roots were retrieved using extraction forceps.

Debridement of the extraction socket was performed with a surgical curette to eliminate any residual soft tissue, periapical lesions, and granulation tissue, if present. The socket was washed out using copious saline irrigation. Implant osteotomy was prepared 2–3 mm beyond the apex by using pilot drill and sequential drilling until reaching the requested diameter, with an implant micromotor rotating at a speed of 800 rpm and 35 Ncm torque with copious saline irrigation. Implant was threaded into the bone using motorized method with the engine set at15 rpm and 35 Ncm torque, the implant fixture was placed 1–2 mm below the crest of alveolar ridge to compensate for future ridge resoption, and completion of insertion was done by the ratchet holder of the fixture.

Immediately following implant insertion, the primary stability was assessed using a Penguin RFA device (Integration diagnostic Ltd. Goteborgssvagen, Sweden). The Smart Peg was connected to the smart peg mount then it was screwed onto the implant, the Penguin RFA probe was held approximately 2–3 mm from the Smart-Peg at a right angle to obtain measurements in two directions (buccolingual and mesiodistal), the ISQ value of each fixture represented by the mean of both readings. A cover screw was placed after removing smartpeg.

The peri-implant gap was filled with bone graft according to the treatment group. In group A a xenogenic bovine bone graft with hyaluronate, Cerabone Plus® (Botiss Biomaterials GmbH, Germany) was used. while Group B received Cerabone ® (Botiss Biomaterials GmbH, Germany) with I-PRF. After graft placement, a resorbable collagen membrane was trimmed and adapted over the graft for both group and then the sits closed with nonresorable nylon sutures material (4/0) using interrupted technique.

I-PRF preparation

About 5 mL of autologous blood was collected from from each patient in the i-PRF group before initiating the surgical incision (after giving local anesthesia. from the median cubical vein (forearm) using 5 c.c. sterile disposable syringe. The collected blood was immediately moved to empty plastic tube without any anticoagulant, directly centrifuged for 3 minutes at 700 Rpm at room temperature. yellow-colored liquid layer form I-PRF was then achieved on Top of the tube and the red blood cells (RBCs) sedimented at the bottom. Subsequently, the I-PRF liquid form was collected carefully from the tube by a sterile Plastic Syringe.

Postoperative assessment

Stability evaluation

Immediately following implant insertion, the Stability was measured and Six months later, all the implants were exposed via the removal of the overlaying soft using tissue punch. Healing abutments were placed to the tissue, and after ten days, a penguin® RFA device was utilized to assess secondary stability following osseointegration, in a similar way as measured previously for the primary one the patient.

Radiographic evaluation

All patients were examined immediately on the same day of surgical procedure through CBCT and after 24 weeks to assess:

1. The marginal bone loss. The implant served as a reference for measuring marginal bone loss (MBL) from the cross-sectional view by aligning the panoramic long axis at its center and bisecting it (illustrating the buccolingual dimensions). A line was drawn parallel to the implant at the crest of the buccal plate of bone, exten-

ding to the apical level of the implant, and its height was measured in millimeters immediately and six months postoperatively. Radiographic MBL was determined by subtracting the baseline value from the measurements taken at 6 months postoperative. The identical procedure was repeated from the palatal side.

2. Changes in buccal bone thickness. A perpendicular horizontal measurement was taken from the implant crest to the buccal bone plate immediately after the operation. This measurement serves as a baseline. A same measurement was performed 6 months postoperatively and subtracted from the baseline value to ascertain horizontal bone loss.

Statistical analysis

All statistical analyses were performed using SPSS software, version 28. Data normality was assessed using the Shapiro–Wilk test to determine the suitability of parametric testing. The paired samples t-test was applied to evaluate intragroup differences between immediate and six-month follow-up measurements within each material group (HA and I-PRF). The independent samples t-test was used to compare mean values between the two materials at corresponding time intervals. All results were expressed as mean ± standard deviation (SD), and statistical significance was considered at a p-value < 0.05.

RESULTS

Demographic data

A total of 20 patients, 11 females and 9 males having maxillary non restorable teeth indicated for extraction and immediate implant placement were included in this study. Their ages ranged from 23 to 43 years with the mean age of patients in was 32.57 ± 5.7 years. All patients were followed up for 6 months The results were registered as regards clinical and radiographic variables.

Implant stability

As shown in Table 1 and Fig. 1, the mean and standard deviation of primary and secondary ISQ value of implant within group A (72.60 ± 7.79) ISQ and (85.20 ± 3.61) ISQ respectively. The difference between primary and secondary stability value in group A was statically significant (p = 0.020). Regarding group B, the mean and standard deviation of primary and secondary ISQ value of implant were (67.20 ± 10.43) ISQ and (82.20 ± 3.94) ISQ respectively. The difference between primary and secondary after six-month stability value in group B was statically significant as well as (p < 0.001). when comparing both group regarding the primary and secondary stability after six month the difference not statically significant (p = 0.206 and p = 0.093) respectively.

Marginal bone loss

A bone loss changes was evaluated according to each material. Regarding buccal bone loss, there was significant difference between HA group and I-PRF group after six months postoperatively (p = 0.027). Regarding palatal bone loss, there was no significant difference between study groups after 6 months (p = 0.095). As shown in Table 2.

Table 1. Comparison of implant stability (ISQ) values within the same group and between the two groups for HA and I-PRF materials

Таблица 1. Сравнение значений стабильности имплантата (ISQ) внутри одной группы и между двумя группами для материалов HA и I-PRF

Time	Mean ± S.D.		p-value (between groups)
	HA	I-PRF	
Immediate	72.60 ± 7.79	67.20 ± 10.43	0.206
After 6 Months	85.20 ± 3.61	82.20 ± 3.94	0.093
p-value (within each groups)	0.020*	< 0.001**	–

Note. * Significant (p < 0.05); ** High significant (p < 0.001)
Примечание. * Значимо (p < 0,05); ** высокозначимо (p < 0,001)

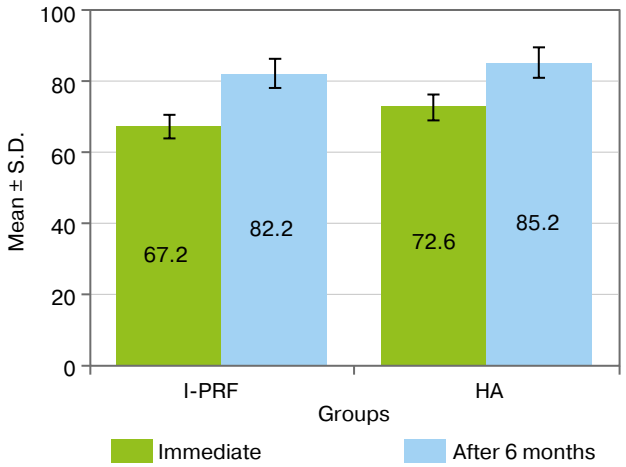

Fig. 1. Mean Stability (Mean ± SD) for Immediate and Six-Month Measurements in HA and I-PRF Groups

Рис. 1. Средняя стабильность (среднее ± стандартное отклонение) при немедленных и шестимесячных измерениях в группах HA и I-PRF

Table 2. Comparison between two study groups according to marginal bone loss after six months

Таблица 2. Сравнение двух исследуемых групп по величине маргинальной потери костной ткани через шесть месяцев

Materials	Mean ± S.D.		p-value (between groups)
	HA	I-PRF	
Buccal bone loss after six months	0.42 ± 0.24	0.75 ± 0.36	0.027*
Palatal bone loss after six months	0.89 ± 0.66	0.66 ± 0.34	0.095^{NS}

Note. * Significant difference between groups (p < 0.05); ^{NS} No significant difference between groups (p > 0.05)
Примечание. * Значимая разница между группами (p < 0,05); ^{NS} значимой разницы между группами нет (p > 0,05)

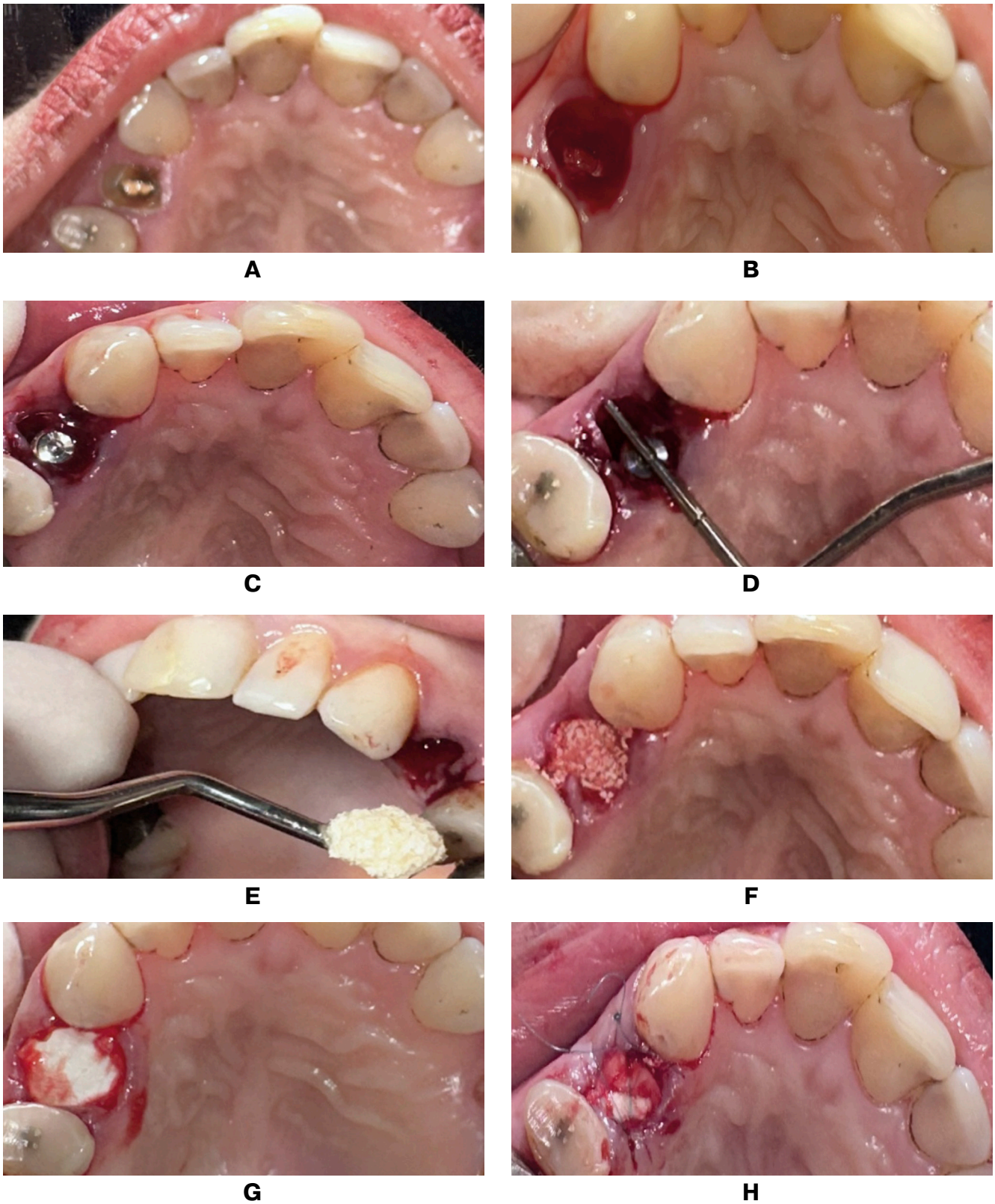

Fig. 2. Case presentation: *A* – non-restorable upper right premolar; *B* – socket after tooth extraction; *C* – implant fixture in place; *D* – measuring of the per implant gap with periodontal probe; *E* – xenograft with hyaluronate (sticky bone); *F* – the horizontal gap filled with bone graft; *G* – application the collagen membrane; *H* – primary closer of the socket

Рис. 2. Презентация клинического случая: *A* – не подлежащий восстановлению правый верхний премоляр; *B* – лунка после удаления зуба; *C* – установка имплантата на место; *D* – измерение периметра вокруг имплантата с помощью пародонтального зонда; *E* – ксенографт с гиалронатом (sticky bone); *F* – заполнение горизонтального промежутка костным трансплантатом; *G* – наложение коллагеновой мембраны; *H* – первичное закрытие лунки

Change in buccal bone thickness

Bone loss changes was evaluated according to each material. Regarding buccal bone thickness changes there not significant difference between HA group and I-PRF group after six-month postoperative (p = 0.135) as shown in Table 3.

Table 3. Change of buccal bone thickness after six-month

Таблица 3. Изменение толщины щечной кости через шесть месяцев

Indicator	Mean ± S.D.		*p*-value
	HA	I-PRF	
Chang of buccal bone thickness	0.220±0.103	0.440±0.432	0.135^{NS}

Note. ^{NS} Nonsignificant difference between groups ($p > 0.05$)
Примечание. ^{NS} статистически незначимая разница между группами ($p > 0,05$).

DISCCUSION

The placement of implants following extraction has emerged as a preferred treatment procedure due to the presence of rich periodontal cells and matrix in the natural socket, which promotes rapid healing and reduces the risk of bone necrosis. Furthermore, it eradicates the waiting period for socket ossification, necessitates fewer surgical sessions, shortens the edentulous period, reduces total costs, preserves alveolar bone height and width, and reduces operative time while causing less trauma to the tissues and reducing discomfort for the patient [12]. After the placing of implants into freshly extracted sockets, it is common for gaps to be present between the implants and the adjacent bone walls. The "jumping gap" is crucial for achieving adequate bone fill and stability surrounding the implant. Multiple approaches and grafting materials have been suggested to enhance this area. Xenograft possesses osteoconductive characteristics that facilitate bone regeneration in peri-implant bone restoration and alveolar ridge augmentation [13]. However, it is biologically inert, indicating that it serves as a scaffold with a minimal tendency for resorption [14]. Consequently, researchers and practitioners initiated the bio-activation of inert biomaterials using various biological adjuncts, including hyaluronic acid, platelet-rich fibrin, enamel matrix derivatives or others [15]. This study aims to examine the efficacy of I-PRF and HA with xenografts along with immediate implant placement in fresh extraction sockets.

In the current study, the stability of the implant, primary and secondary (six-month postoperative) was evaluated using resonance frequency analysis (RFA) Technique provided by penguin® device. The RFA method offer valuable mean of measuring osseointegration [16]. The result show improvement in ISQ values between the immediate and six-month measurements and statistically significant within both groups (I-PRF: $p < 0.001$; HA: $p = 0.020$). These findings indicate that both HA and I-PRF can enhance the biological environment at the implant–bone interface, promoting secondary stability and osseointegration. The improved ISQ values over time are consistent with Po-Sung Fu et al., who reported a progressive increase in the mean Implant Stability Quotient (ISQ) over time for all implants implanted immediately, both with and without provisionalization [17]. This also aligns with the results of Hassanan & El Naas et al., reported that the use of Injectable Platelet Rich Fibrin with xenogeaft around the immediate dental implants may be able to increase and improve healing around dental implants by the anti-inflammatory and antibacterial properties and increase the success rate of dental implants by increase the bone density and stability of dental implant [18].

An implant is deemed successful if the average bone loss does not exceed 1.5 mm in the first year post loading [19]. The present study showed a significant difference in buccal bone loss between the HA and I-PRF groups after six months (p = 0.027), whereas palatal bone loss did not differ significantly (p = 0.095). More Buccal bone loss was noted in the I-PRF group compared to the other group, indicating that the augmentation of the gap with Xenograft and HA resulted in a superior coronal position of the alveolar bone crest than that found in the I-PRF group. Nonetheless, the noted differences stayed within clinically acceptable limits (<1 mm). The present findings are in agreement with those of Abaza et al., who reported The using combination of HA with xenograft demonstrated in socket augmentation superior outcome in preservation bone dimension compared to xenograft alone or combined with I-PRF [20].

Regarding buccal bone thickness change was not statically significant between the two group. This finding suggests both hyaluronic acid and I-PRF with xenograft similarity positive effective in minimal loss of buccal bone thickness. The absence of a significant difference may be ascribed to the synergistic mechanisms of both materials in facilitating bone healing. The Hyaluronic acid hastened the formation of new bone by facilitating the differentiation of mesenchymal cells when combined with xenograft for regeneration of alveolar defects [21; 22]. Also, I-PRF facilitates osteogenesis via many mechanisms. It promotes the migration, adhesion, proliferation, and differentiation of osteoplastic cells, resulting in bone tissue production [23].

THE STUDY'S LIMITATION

The primary limitation of the current study is its sample size, which may constrain statistical power in identifying smaller intergroup differences. Additionally, the analysis was limited to a six-month follow-up period; prolonged assessments with loading the implant are necessary to determine if the identified differences persist or stabilize over time.

CONCLUSION

Both xenograft combination provided effective in reduce marginal bone loss and increase implant stability in immediate implant protocols. However, the combination of the haylronta with xenograft show slightly superior in implant stability and preservation per-implant bone dimension.

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AUTHOR'S CONTRIBUTION

All the authors made equal contributions to the publication preparation in terms of the idea and design of the article; data collection; critical revision of the article in terms of significant intellectual content and final approval of the version of the article for publication.

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Original Research

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The role of radiographic imaging in the assessment of periapical lesions

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Abstract

INTRODUCTION. Radiographic imaging is an essential component in the management of destructive forms of periodontitis. It is used for diagnostic purposes, for assessing the quality of treatment after root canal obturation, and for long-term follow-up evaluation of treatment outcomes.

AIM. To perform a comparative analysis of the effectiveness of different radiographic diagnostic methods in chronic destructive periodontitis.

MATERIALS AND METHODS. To determine diagnostic informativeness, radiographic examinations of 413 patients with destructive forms of periodontitis (454 teeth) were analyzed. Intraoral dental radiography using a 5D2 unit was performed in 122 patients (134 teeth), radiovisiography with SOPIX 2 (Acteon Group, France) in 199 patients (228 teeth), and cone-beam computed tomography (CBCT) using Vatech (Model: ECT-12, Korea) in 88 patients (92 teeth).

RESULTS. The overall detection rate of periapical lesions using radiovisiography and CBCT was 37.28% and 21.73%, respectively. With the use of the intraoral dental X-ray unit, only 5.97% of periapical pathology was detected, indicating the low effectiveness of this diagnostic method, especially in severe cases.

CONCLUSIONS. CBCT is effective in detecting periapical lesions that cannot be identified by radiovisiography, particularly in the maxillary region.

Keywords: periodontitis, radiography, radiovisiograph, CBCT

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Роль рентгенологической визуализации для оценки периапикальных поражений

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Резюме

ВВЕДЕНИЕ. Рентгенологическая визуализация является важным аспектом в лечении деструктивных форм периодонтита. Ее используют с целью диагностики, контроля качества лечения после обтурации корневого канала и для контроля качества лечения в отдаленные сроки.

ЦЕЛЬ ИССЛЕДОВАНИЯ. Провести сравнительный анализ эффективности различных методов рентгенологической диагностики при хронических формах деструктивного периодонтита.

МАТЕРИАЛЫ И МЕТОДЫ. Для выяснения диагностической информативности провели изучение рентгенологических исследований, сделанных 413 пациентам с деструктивными формами периодонтита (454 зуба): с использованием внутриротового рентгенодиагностического дентального аппарата 5Д2 у 122 человек (134 зуба), радиовизиографа SOPIX 2 (Acteon Group France) у 199 пациентов (228 зубов) и КЛКТ Vatech (Model: ECT-12 Korea) у 88 человек (92 зуба).

РЕЗУЛЬТАТЫ. Общая частота выявления периапикальных поражений с помощью радиовизиографии и КЛКТ составила 37,28 % и 21,73 % соответственно. С использованием *внутриротового* рентгенодиаг-

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ностического дентального аппарата выявлено 5,97 % периапикальной патологии, что свидетельствует о низкой эффективности использования данного метода рентгенологической диагностики особенно в тяжелых случаях.
ВЫВОДЫ. КЛКТ эффективна для выявления периапикальных поражений, которые не могут быть обнаружены с помощью радиовизиографии, особенно в области зубов верхней челюсти.

Ключевые слова: периодонтит, рентген, радиовизиограф, КЛКТ

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INTRODUCTION

According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), more than 360 million radiological examinations are performed worldwide each year [1]. Radiographic imaging is a crucial component in the management of destructive forms of periodontitis [2]. It is used for diagnostic purposes, for evaluating the quality of treatment after root canal obturation, and for long-term follow-up assessment of treatment outcomes. Without radiographic data, the diagnosis of periodontal pathology is considerably complicated [3]. However, conventional intraoral radiography in this context proves to be insufficiently effective.

Digital imaging in dental practice offers several advantages over film-based intraoral radiography [4]. The use of a radiovisiograph facilitates visualization; however, cone-beam computed tomography (CBCT) is the most effective modality for these purposes, as it provides images with a lower risk of distortion [5]. The two-dimensional representation of three-dimensional structures, as well as the presence of granulomas, complicates adequate diagnosis using intraoral radiography alone [6]. It is generally accepted that when the lesion diameter is less than 0.8 mm, CBCT image accuracy can be rated from satisfactory to good, whereas for lesions larger than 1.4 mm it can be considered excellent [7]. Pathological changes in the jaw bone tissue are evaluated according to several parameters: number and localization of lesions, their shape, margins, and size, radiographic density, and the condition of the bone tissue within and surrounding the lesion.

Another important factor to consider during radiographic examination is the patient radiation dose. A single film-based radiograph delivers approximately 10–15 μSv (microsieverts), whereas exposure using a radiovisiograph averages 1–3 μSv, which is comparable to daily natural background radiation. Moreover, previous studies have confirmed that radiation doses associated with conventional radiography and CBCT are low and do not exceed permissible limits [8; 9]. Exposure time also differs between modalities: for film-based radiography it ranges from 0.5 to 1.2 s, while for radiovisiography it is approximately 0.03–0.3 s. All these factors influence the selection of the radiographic method for examining dental patients with periapical pathology.

AIM

To perform a comparative analysis of the effectiveness of different radiographic diagnostic methods in chronic destructive periodontitis.

MATERIALS AND METHODS

To determine the diagnostic informativeness, radiographic examinations of 413 patients with destructive forms of periodontitis (454 teeth) were analyzed. Clinical examinations were performed according to standard protocols. The selected group included patients whose diagnoses corresponded to the ICD-10 codes K04.5–K04.8 and K03.39. All patients were free of periodontal disease or non-carious dental lesions.

All patients underwent radiographic imaging using the following modalities: intraoral dental radiography with a 5D2 unit in 122 patients (134 teeth), radiovisiography using SOPIX 2 (Acteon Group, France) in 199 patients (228 teeth), and cone-beam computed tomography (CBCT) with Vatech (Model: ECT-12, Korea) in 88 patients (92 teeth). Imaging was performed in a parallel technique, followed by interpretation according to standard radiographic protocols [10].

Radiographic examinations were conducted prior to treatment, during treatment, immediately after root canal obturation, and at long-term follow-up to assess changes in the surrounding dental tissues. The results of these examinations enabled refinement of the final diagnosis, formulation of a treatment plan, implementation of treatment, monitoring of treatment quality, and evaluation of long-term outcomes. In some patients, radiographic assessment was performed using two imaging modalities: radiovisiography and CBCT.

RESULTS

Intraoral radiography was used for the diagnosis and monitoring of endodontic treatment. For the detection and visualization of broken instruments in root canals, radiovisiography is preferable, as it allows magnification of the region of interest on a computer screen. CBCT provides greater diagnostic informativeness, for instance, for the identification of cysts [11]. Using CBCT, periapical lesions that are not detectable even with radiovisiography can be identified [12].

Table 1. Effectiveness of three radiographic imaging modalities in dental examination

Таблица 1. Эффективность использования трех аппаратных методов рентгенологического исследования зубов

Teeth / Pathology	Radiographic Examination Methods					
	5D2		Radiovisiograph		CBCT	
	n	%	*n*	%	*n*	%
Teeth	13	29.51	228	50.22	92	19.38
Root Resorption	9	6.71	82	35.94	15	16.30
Cysts	1	0.74	3	1.31	11	11.95
Total Pathology Detected	10	7.46	85	37.28	26	28.26

Table 1 presents the statistical data on the effectiveness of different radiographic imaging modalities in dental examination.

Radiographic diagnosis of root resorption presents certain challenges. Destruction of the apical constriction poses particular difficulties not only for treatment but also for diagnosis. Using the 5D2 intraoral radiography unit, root resorption could be detected only in severe cases ($n = 9$), whereas radiovisiography allowed identification in 82 teeth. In particularly complex cases, these patients were referred for CBCT, which confirmed the diagnosis. CBCT enables detection of root resorption even in cases where radiovisiography fails, for example, when the lesion is obscured by granulomatous tissue or a cyst. We consider the use of CBCT for diagnostic purposes necessary when visualization of the target area is not possible with radiovisiography [13]. Radiographic detection of root resorption using conventional intraoral radiography is of limited effectiveness [14]. In such cases, radiovisiography or CBCT is recommended as the most effective modalities.

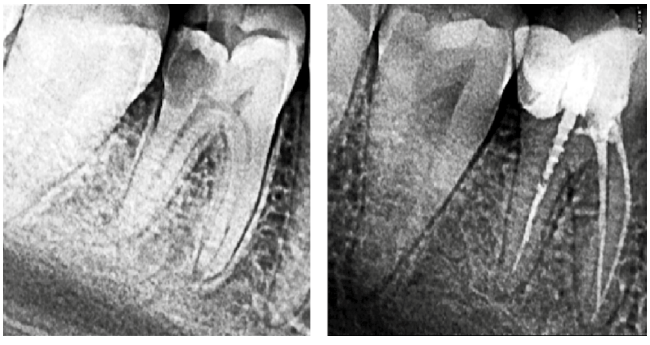
Overall, 11 cysts were diagnosed using radiographic methods, three of which were initially detected with radiovisiography and subsequently confirmed with CBCT. The overall detection rate of periapical lesions using radiovisiography and CBCT was 37.28% and 23.91%, respectively. In contrast, intraoral radiography with the 5D2 unit identified only 7.46% of periapical pathology, indicating the low effectiveness of this method, particularly in severe cases.

DISCUSSION

Film-based radiographs can be used for the diagnosis and monitoring of endodontic treatment (Fig. 1); however, they provide limited information regarding the presence of root resorption or the size of cysts, particularly in cases involving large cysts in the maxilla or in the region of root bifurcations. Figure 2 shows a radiograph of tooth 46, in which it is difficult to determine whether a cyst or bone tissue destruction is present. However, extensive resorption of the mesial root is clearly visible. Examination of the extracted tooth 46 revealed a large lateral cyst with both horizontal and vertical root resorption. Using this type of radiography without magnification, visualization of small instrument fragments is difficult (Fig. 3).

Figure 4, *A* presents a radiograph of teeth 24 and 25 obtained using a radiovisiograph. Overlap of the maxillary sinus prevents diagnosis of both apical root resorption and the presence of a cyst involving the roots of tooth 25, which were successfully identified using CBCT (Fig. 4, *B*). Radiovisiography also failed to detect an odontogenic cyst of the maxillary sinus originating from tooth 17. However, this modality enabled visualization of a pulpo-extractor fragment in the distal-buccal root canal of this tooth and revealed destruction of the apical constriction. Extrusion of a calcium-containing material beyond the apical foramina indicated root resorption and the presence of a cyst (Fig. 4, *C*). CBCT further allowed diagnosis of an interradicular cyst of tooth 26 and precise measurement of its dimensions (Fig. 4, *D*). Large cysts and their boundaries could not be adequately identified without CBCT.

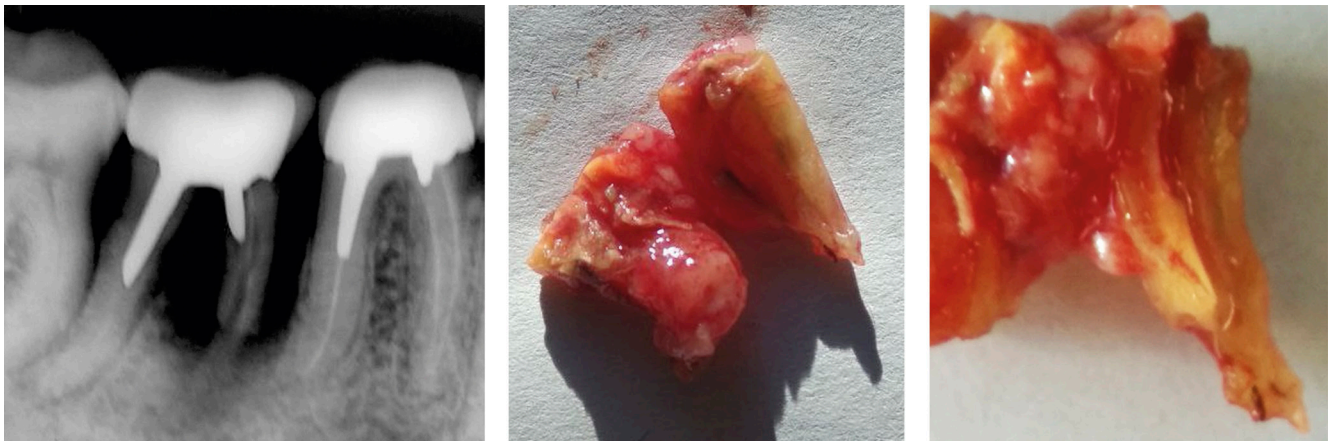
Using the 5D2 unit, bone tissue destruction was visualized in the area of tooth 47; however, radiographically, it was not possible to definitively identify it as a cyst. The presence of the cyst was confirmed after extraction of the tooth (Fig. 2). With this imaging modality, small cysts can be detected and their dimensions measured with a ruler, allowing differential diagnosis between a cyst and a cystic granuloma, which was confirmed in one case according to the data presented in Table 1.



A **B**

Fig. 1. Diagnostic radiograph of tooth 46 (*A*); radiographic control of root canal obturation of tooth 46 (*B*); images obtained using the 5D2 intraoral dental X-ray unit

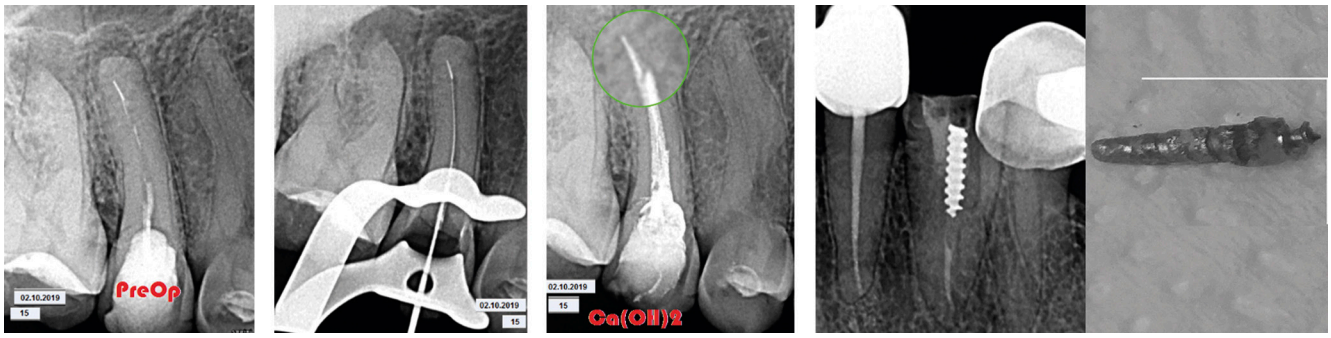
Рис. 1. Диагностический рентген 46 зуба (*A*); рентген контроль обтурации корневых каналов 46 зуба (*B*). Снимки сделаны с помощью внутриротового рентгенодиагностического дентального аппарата 5Д2



A B C

Fig. 2. Diagnostic radiograph of teeth 46 and 47 (*A*); extracted tooth 47 with a cyst (*B*); root resorption of tooth 47 (*C*). Image obtained using the 5D2 intraoral dental X-ray unit

Рис. 2. Диагностический рентген 46, 47 зубов (*A*); удаленный 47 зуб с кистой (*B*); резорбция корней 47 зуба (*C*). Снимок сделан с помощью внутриротового рентгенодиагностического дентального аппарата 5Д2



A B C D

Fig. 3. Radiographs of tooth 15: diagnostic (*A*); during root canal retreatment (*B*); enlarged view of the apical region of the root with an instrument fragment (*C*); diagnostic radiograph of tooth 23 and extracted fragment of an anchor post from the root canal (*D*). Images obtained using the SOPIX 2 radiovisiograph

Рис. 3. Рентгенограммы 15 зуба: диагностический (*A*); в момент перелечивания корневого канала (*B*); Увеличенный участок апикальной области корня с обломком инструмента (*C*); диагностический рентген 23 зуба и извлеченный обломок анкерного штифта из корневого канала (*D*). Снимки сделаны с помощью радиовизиографа SOPIX 2

Radiovisiography facilitates the diagnosis of cysts; however, it failed to detect a large cyst in the region of teeth 16 and 17, which was clearly visualized on CBCT (Fig. 4). This illustrates that diagnosing large cysts in the maxilla remains challenging. Based on these observations, out of six identified cysts, three were initially detected using radiovisiography, accounting for 50% of cases, while final confirmation of the diagnosis with precise determination of cyst size was possible only with CBCT. Radiovisiography does not always allow complete assessment of the location and dimensions of cysts, particularly in the maxilla, where proximity to the maxillary sinus hinders visualization. In such cases, conventional intraoral radiography is largely ineffective due to the limited size of the film. Therefore, among the three tested radiographic modalities, CBCT proved to be the most effective method for detecting cysts and determining both their location and size.

Computer-assisted imaging is informative not only for diagnostic purposes but is also important for evaluating changes in radiographic parameters during follow-up of patients with destructive forms of chronic apical periodontitis. For example, when assessing long-term outcomes of treatment using radiovisiography, the formation of a cementodentinal junction at the apical foramen of tooth 24 can be observed, appearing as a linear radiopaque contour (Fig. 5).

Radiographic methods assist the clinician in establishing an accurate diagnosis and reliably assessing the outcomes of endodontic treatment, taking into account the dynamics observed over time.

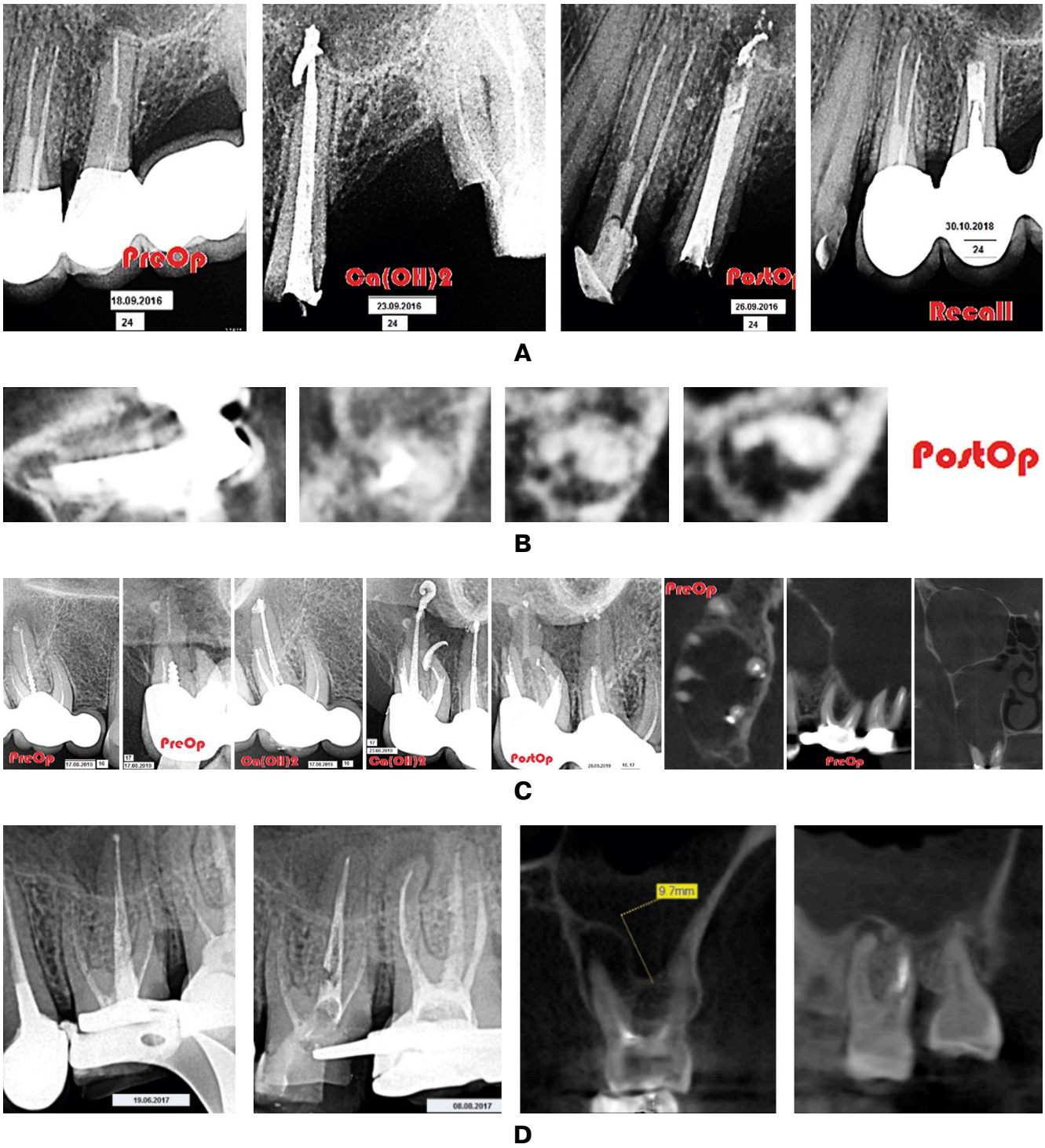


Fig. 4. Diagnostic radiograph of teeth 24 and 25 (*A*); CBCT of teeth 24 and 25 showing a cyst (*B*); radiovisiograph images of teeth 16 and 17: diagnostic and during treatment with calcium-containing material extruded into the cyst cavity; the arrow on the diagnostic radiograph indicates a fragment of a canal obturator in the distal-buccal root of tooth 17; diagnostic CBCT of the cyst occupying two-thirds of the maxillary sinus (*C*); diagnostic CBCT and radiovisiograph images during treatment of teeth 26 and 27 showing cysts in the region of tooth 26 (*D*). Images obtained using the SOPIX 2 radiovisiograph and CBCT

Рис. 4. Диагностическая рентгенограмма 24, 25 зубов (*A*); КЛКТ 24, 25 зубов с кистой (*B*); рентгенограмма помощью радиовизиографа 16, 17 зубов: диагностическая, в процессе лечения с кальцийсодержащим препаратом выведенные в полость кисты; стрелкой на диагностическом рентгене указан обломок каналонаполнителя в дистальном щечном корне 17 зуба; диагностическая КЛКТ кисты заполнившей 2/3 объема гайморовой пазухи (*C*); Диагностический КЛКТ и в процессе лечения с помощью радиовизиографа рентгены 26, 27 зубов с выявленными кистами в области 26 зуба (*D*).
Снимки сделаны с помощью радиовизиографа SOPIX 2 и КЛКТ

A B C D E

Fig. 5. Diagnostic radiograph of teeth 24 and 25 (*A*); during temporary root canal obturation with a calcium-containing material (*B*); after permanent root canal obturation (*C*); one-year post-treatment (*D*); CBCT of teeth 24 and 25 (*E*). Images obtained using the SOPIX 2 radiovisiograph and CBCT

Рис. 5. Диагностическая рентгенограмма 24, 25 зубов (*A*); с кальций содержащим препаратом при временной обтурации корневого канала (*B*); после постоянной обтурации корневых каналов (*C*); через год после окончания лечения (*D*); КЛКТ 24, 25 зубов (*E*). Снимки сделаны с помощью радиовизиографа SOPIX 2 и КЛКТ

CONCLUSION

Within the framework of this study, it can be concluded that intraoral dental radiography may be used for diagnosis and during treatment in cases that do not present clinical complexity. In instances where the clinician suspects complications of periapical inflammation, such as cysts or root resorption, radiographic assessment using a radiovisiograph and CBCT is recommended. Cone-beam computed tomography is particularly effective for detecting periapical lesions that cannot be identified with radiovisiography, especially in the maxillary region. Our results indicate that when interpreting radiographs, the influence of structural interferences in the anterior and posterior regions of the maxilla should not be overlooked.

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AUTHOR'S CONTRIBUTION

All the authors made equal contributions to the publication preparation in terms of the idea and design of the article; data collection; critical revision of the article in terms of significant intellectual content and final approval of the version of the article for publication.

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Original Research

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Comparative analysis of prognostic outcomes between isolated endodontic lesions and endodontic-periodontal combined lesions following microsurgical intervention

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Abstract

INTRODUCTION. Endodontic microsurgery (EMS) has become an effective modality regarding the treatment of enduring periapical pathology after non-surgical failure of retreatment of the root canal. Nevertheless, the predictability of EMS in periodontal destruction that accompanies teeth is still an area of controversy. The aim of the study was to determine the difference in clinical and radiographic healing of isolated endodontic lesions (IEL) and endodontic-periodontal combined lesions (EPCL) after using microsurgical intervention.

MATERIALS AND METHODS. A cohort retrospective study was carried out on 148 teeth among 148 patients who attended EMS between the year 2022 and 2024. Cases were classified into two according to the preoperative probing depths in radiograph and clinical probing depths: Group A (IEL, n = 76) which included lesions of a strictly endodontic nature, and Group B (EPCL, n = 72) which included lesions of a true combined nature with periodontal communication. Each of the procedures involved the use of an operating microscope, ultrasonic retropreparation, and bioceramic retrograde filling. Group B also was targeted with guided tissue regeneration (GTR). Molven criteria were used to determine clinical and radiographic healing at a 12-month follow-up.

RESULTS. The general success rate was 87.2. The success rate of Group A (IEL) was much higher, 94.7% (72/76), than the success rate of Group B (EPCL) was, 79.2% (57/72) (p = 0.006). The average decrease in lesion size was 84.3 ± 12.1 in Group A and 66.8 ± 18.4 in Group B ($p < 0.001$). Although the marginal stability of the bone was attained at 88 per cent in EPCL cases, full regeneration of the periodontial apparatus was not predictable as compared with apical bone healing.

CONCLUSIONS. Although endodontic-periodontal mixed lesions have lower success rate of treatment than endodontic lesion alone, combination of microsurgery with regenerative therapies is still a tooth-saving procedure. But the level of periodontal loss is a decisive prognostic factor.

Keywords: endodontic microsurgery, endodontic-periodontal lesion, periapical surgery, bioceramics, guided tissue regeneration

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Сравнительный анализ прогностических исходов изолированных эндодонтических поражений и комбинированных эндодонто-пародонтальных поражений после микрохирургического вмешательства

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Резюме

ВВЕДЕНИЕ. Эндодонтическая микрохирургия (EMS) стала эффективным методом лечения персистирующей периапикальной патологии после неудачи повторного несургического эндодонтического лечения. Однако предсказуемость EMS при наличии сопутствующего пародонтального разрушения до сих пор остается дискутабельной. Целью исследования было определить различия в клиническом и рентгенологическом заживлении изолированных эндодонтических поражений (IEL) и комбинированных эндодонто-пародонтальных поражений (EPCL) после микрохирургического вмешательства.

МАТЕРИАЛЫ И МЕТОДЫ. Проведено ретроспективное когортное исследование 148 зубов у 148 пациентов, которым выполнялась EMS в период с 2022 по 2024 г. Случаи были распределены на две группы на основании предоперационных рентгенологических данных и клинических показателей глубины пародонтального зондирования: группа A (IEL, $n = 76$) – поражения строго эндодонтической природы; группа B (EPCL, $n = 72$) – истинные комбинированные поражения с пародонтальным сообщением. Все вмешательства выполнялись с использованием операционного микроскопа, ультразвуковой ретропрепарации и биокерамического ретроградного пломбирования. В группе B дополнительно применялась направленная регенерация тканей (GTR). Для оценки клинического и рентгенологического заживления через 12 месяцев использовали критерии Molven.

РЕЗУЛЬТАТЫ. Общая успешность лечения составила 87,2%. Успешность в группе A (IEL) была значительно выше – 94,7 % (72/76), по сравнению с группой B (EPCL) – 79,2 % (57/72) ($p = 0{,}006$). Среднее уменьшение размера очага составило 84,3 ± 12,1 % в группе A и 66,8 ± 18,4 % в группе B ($p < 0{,}001$). Несмотря на достижение маргинальной стабильности кости в 88 % случаев EPCL, полная регенерация пародонтального аппарата была менее предсказуемой по сравнению с апикальным костным заживлением.

ВЫВОДЫ. Несмотря на то, что комбинированные эндодонто-пародонтальные поражения имеют более низкую успешность лечения по сравнению с изолированными эндодонтическими поражениями, сочетание микрохирургии с регенеративными методами остается зубосохраняющей процедурой. При этом степень пародонтальной утраты является определяющим прогностическим фактором.

Ключевые слова: эндодонтическая микрохирургия, эндодонто-пародонтальное поражение, периапикальная хирургия, биокерамика, направленная регенерация тканей

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INTRODUCTION

Conservation of natural dentition is the main goal of the modern endodontics. Although non-surgical root canal treatment (RCT) has high success rates, in some instances, persistence of apical periodontitis (10–15% of cases) is a result of intraradicular infection, extraradicular biofilm or complicated anatomy [1]. Traditional apical surgery has traditionally been considered to be a last resort whose effects are uncertain. Nonetheless, the development of endodontic microsurgery (EMS), which is defined by high-power magnification, ultrasonic root-end preparation, and biocompatible filling materials has transformed the landscape putting reported success rates at more than 90 percent [2].

In spite of these progresses, the prognosis of teeth with concomitant periodontal involvement that can be considered as endodontic-periodontal combined lesions (EPCL) is complicated. And the pulp and the pe-

riodontium have an anatomical relationship through the apical foramen, lateral canals, and dentinal tubules, which forms a bilateral pathway, in which the pathogen spreads [3]. These lesions were firstly categorized by Simon et al. and they said that so called true combinations lesions, in which endodontic and periodontal discrete pathologies converge, are the most difficult ones to treat [4].

Although there is a solid literature on the literature outcome of EMS on isolated endodontic lesions (IEL), there is a lack of comparative literature specifically on EPCLs treated by using modern microsurgical methods. Previous research involving conventional amalgam retrofills and lack of guided tissue regeneration (GTR) showed pathetic success rates of combined lesions which normally resulted in extraction [5]. According to recent research, it can be proposed that the use of GTR membranes and bone grafts in the microsurgery practice could significantly enhance the prognosis of through-and-through defects or dehiscences related to EPCLs [6]. However, the actual effect of marginal periodontal loss on the sealing property of the retrograde filling and the subsequent apical healing is yet to be explained.

The existing studies tended to combine different types of lesions, which does not separate the prognosis difference between the pure endodontic failures and the periodontal communicational failures. Such a gap makes it difficult to offer proper prognostic predictions of the patients with EPCLs by the clinician. Thus, the objective of the research was to compare the prognostic results of the isolated endodontic lesions and endodontic-periodontal combined lesions subject to standardized micro surgical treatment.

MATERIALS AND METHODS

Study design and population

this retrospective cohort study was conducted in a university-affiliated specialized endodontic clinic. The study protocol was approved by the Institutional Review Board. Clinical records of patients who underwent endodontic microsurgery between January 2022 and January 2024 were reviewed.

Inclusion and exclusion criteria

inclusion criteria were: (1) Teeth with persistent apical periodontitis following non-surgical retreatment; (2) 12-month minimum follow-up data; (3) Adequate quality of pre- and post-operative Cone Beam Computed Tomography (CBCT) and periapical radiographs. Exclusion criteria included: (1) Vertical root fractures (VRF); (2) Tooth mobility > Grade II; (3) Unrestorable teeth; (4) Patients with uncontrolled systemic diseases affecting wound healing (e.g., uncontrolled diabetes, bisphosphonate therapy).

Group allocation

Teeth were categorized into two groups:

Group A (Isolated Endodontic Lesions – IEL): Periapical radiolucency present, intact lamina dura along the lateral root surface, and normal probing depths (< 4mm).

Group B (Endodontic-Periodontal Combined Lesions – EPCL): Periapical radiolucency merging with marginal alveolar bone loss, confirmed by a "J-shaped" radiolucency or deep narrow probing defects (>6mm) communicating with the apex, excluding VRF.

Surgical protocol

All surgeries were performed by two board-certified endodontists using an operating microscope (Global Surgical Corp, St. Louis, MO) at 10x–20x magnification. Following local anesthesia (2% Lidocaine with 1 : 50,000 epinephrine), a full-thickness mucoperiosteal flap was elevated. Osteotomy was performed using a sterile round bur under saline irrigation. The apical 3 mm of the root was resected perpendicular to the long axis. The root surface was stained with methylene blue to inspect for fractures or isthmi.

Root-end preparation was extended 3 mm coronally using ultrasonic tips (Kis tips, Obtura Spartan). The cavity was dried and filled with a bioceramic root repair material (EndoSequence BC RRM, Brasseler USA).

Specific Intervention for Group B: In EPCL cases presenting with dehiscence or fenestration, Guided Tissue Regeneration (GTR) was employed using a resorbable collagen membrane (Bio-Gide, Geistlich) and corticocancellous bone graft (Bio-Oss, Geistlich). Flaps were repositioned and sutured with 5-0 monofilament sutures. Sutures were removed after 4–7 days.

Outcome evaluation

Outcomes were assessed at 12 months clinically (absence of sinus tract, swelling, tenderness, mobility) and radiographically (CBCT/PA). Healing was classified according to Molven's criteria:

1. Healed: Complete bone filling or reformation of lamina dura.

2. Incomplete Healing: Reduction in lesion size, irregular outcome.

3. Uncertain / Failure: No reduction or enlargement of lesion. For statistical analysis, "Healed" and "Incomplete Healing" (with no symptoms) were considered "Success". "Uncertain / Failure" and symptomatic cases were "Failure".

Statistical analysis

Data were analyzed using SPSS software (version 25.0). Descriptive statistics (mean ± SD, frequencies) were calculated. Differences in success rates between groups were analyzed using the Chi-square test. Continuous variables (lesion size reduction) were analyzed using the independent t-test. Significance was set at $p < 0.05$.

RESULTS

A total of 148 teeth in 148 patients (68 males, 80 females; mean age 45.2 ± 12.4 years) met the inclusion criteria and were analyzed. Group A (IEL) consisted of 76 teeth, and Group B (EPCL) consisted of 72 teeth. There were no statistically significant differences regarding age, gender, or tooth distribution (anterior/posterior) between the two groups ($p > 0.05$).

Clinical and radiographic outcomes

at the 12-month follow-up, the overall success rate for the entire cohort was 87.2% (129/148). When stratified by group, Group A (IEL) showed a significantly superior outcome compared to Group B (EPCL). Specifically, 72 out of 76 cases in Group A were deemed successful (94.7%), whereas 57 out of 72 cases in Group B achieved success (79.2%). This difference was statistically significant ($p = 0.006$).

Quantitative healing kinetics

Radiographic analysis revealed that Group A experienced a greater percentage of bone fill. The mean reduction in radiolucency size was 84.3 ± 12.1% for Group A, compared to 66.8 ± 18.4% for Group B ($p < 0.001$). While periapical healing was evident in Group B, the marginal bone levels showed less predictable regeneration despite GTR application.

Table 1. Demographic and clinical characteristics of the study population

Таблица 1. Демографические и клинические характеристики исследуемой популяции

Variable	Group A (IEL) (*n* = 76)	Group B (EPCL) (*n* = 72)	*p*-value
Age (Mean ± SD)	44.8 ± 11.5	45.7 ± 13.2	0.645
Gender (M/F)	34/42	34/38	0.812
Tooth Type			
Anterior/Premolar	46 (60.5%)	40 (55.6%)	0.541
Molar	30 (39.5%)	32 (44.4%)	
Pre-op Lesion Size (mm)	6.4 ± 2.1	7.1 ± 2.8	0.092

Table 2. Clinical and radiographic outcomes at 12-month follow-up

Таблица 2. Клинические и рентгенологические результаты через 12 месяцев наблюдения

Outcome Category	Group A (IEL) *n* (%)	Group B (EPCL) *n* (%)
Complete Healing	65 (85.5%)	41 (56.9%)
Incomplete Healing	7 (9.2%)	16 (22.2%)
Uncertain/Failure	4 (5.3%)	15 (20.8%)
Total Success	72 (94.7%)	57 (79.2%)

Note: Total Success = Complete Healing + Incomplete Healing (asymptomatic).

Примечание: Полный успех = Полное исцеление + Неполное исцеление (бессимптомное).

Table 3. Statistical comparison of success rates Group A vs. Group B

Таблица 3. Статистическое сравнение показателей успешности группы А к группе В

Indicator	Value
Success Rate Difference	15.5%
Chi-Square Value	7.642
p-value	0.006*

Significant differences were noted in the failure etiology. In Group A, failures were primarily attributed to persistent apical infection (recrudescence). In Group B, 60% of the failures (9/15) were attributed to progression of periodontal disease or loss of attachment, rather than purely apical pathology.

DISCUSSION

The current research study gives a comparative analysis of the results of microsurgical outcome using isolated endodontic lesions and combined endo-perio lesions. These results support the hypothesis that although the microsurgery in modern practice is very effective, the presence of periodontal involvement has a great impact on the prognostic outcome. The 94.7% success rate of isolated lesions follows the high standards of a recent meta-analysis by Torabinejad et al. and Setzer et al., who quote 89 to 94 percent of modern techniques [7; 8]. Conversely, the success rate of combined lesions is lower at 79.2 percent, but it proves that such affected teeth do not have to be extracted.

The statistically significant difference ($p = 0.006$) between the groups points out to the biological challenge of EPCLs. In single lesions that are situated in isolation in endodontics the defect is a four walled bony crypt that offers an excellent habitat to osteogenesis and clot stability [9]. On the other hand, combined lesions can be in the form of through-and-through defects or dehiscences of the marginal bone. Despite GFR, as used in this case, the absence of a coronal stop of the coagulum, as well as the constant presence of the oral microbiome through the gingival sulcus, makes healing difficult [10].

We have found similar results with EPCLs in the study of Kim et al, who found that marginal bone loss was a notable negative predictor of microsurgical success [11]. Nevertheless, our current success rate of close to 80 percent of EPCLs is greater than the conventional survival data during the pre-microsurgical period. The latter can probably be ascribed to two aspects such as the employability of biocompatible bioceramic root-end fillings and the implementation of GTR. Bioceramics demonstrate osteoconductivity and establish a chemical bond with dentin, which could increase the seal to periodontal pathogen ingress [12; 13]. Moreover, group B was intended to use collagen membranes and bone grafts to eliminate epithelial down-growth, which is recommended by Tsesis et al. to prevent the use on such endodontic-periodontal defects [14].

It is important to note that Group B (22.2) had a higher number of cases of incomplete healing compared to Group A (9.2%). This implies that although, the apical pathology could heal, the periodontal ligament (PDL) and alveolar crest regeneration may be slower and leads to scar tissue instead of complete regeneration [15]. A functional fibrous repair and active disease are some of the things that clinicians have to differentiate during the assessment of EPCL after the surgery.

The shortcomings of this research are its retrospective nature and 12 months follow up period. Although

Song et al. posit that most of the healing or failure processes take place within a year, periodontal breakdown is often a chronic, slow-paced phenomenon that may take a longer period to be completely observed [16]. Prospective randomized controlled trials to compare various GTR materials in EPCLs are recommended in future to streamline the protocols.

Finally, the paper has highlighted the significance of case selection. Whereas IELs are very predictable, EPCLs demand keen evaluation of loss of attachment. In case the periodontal defect involves the furcation or leads to Grade III mobility, the prognosis is likely to be lower than the current 79% and thus, implant replacement will become a more viable solution [17].

CONCLUSION

In the scope of this study, it may be deduced that endodontic microsurgery is of high success rates in isolated cases of endodontic lesions. Concomitant periodontal involvement leads to a high rate of failure of healing and the result shows a success rate of about 79 percent as opposed to almost 95 percent with the isolated lesions. Nevertheless, endodontic-periodontal combined lesions can still be maintained in most of the cases when the adjunct use of guided tissue regeneration and biocompatible retrograde fillings is used. Periodontal communication must be perceived as a prognostic complication, but not a contraindication to the use of microsurgical treatment.

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Original Research

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Effect of smart endodontic motors (AI-based torque control) on file separation and dentinal damage

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Abstract

INTRODUCTION. Implementation of artificial intelligence (AI) in the endodontic motor technology offers improved safety due to real-time torque monitoring and adaptive control. Nevertheless, there is little comparative evidence on their clinical effectiveness in preventing instrument separation and reduction of iatrogenic dentinal damage.

MATERIALS AND METHODS. Ninety human mandibular molars with mesial canals (curvature 25–35°) were randomly divided to three groups (n = 30) Group A (AI-based smart motor with adaptive torque control), Group B (conventional motor with preset torque limits), and Group C (conventional motor with auto-reverse operation). ProTaper Next rotary files were used to prepare the standardized canals. The main variables were file separation rate and dentinal microcracks incidence evaluated through micro-computed tomography (micro-CT). Preparation time, apical transportation, canal centering ratio, and motor operational parameters were the secondary outcomes.

RESULTS. Group A exhibited a much lower file separation rate (0% vs. 10.0% vs. 13.3% in Group B vs. Group C, p = 0.038) and fewer dentinal microcracks formed (16.7% vs. 43.3% vs. 50.0% p = 0.006). Group A recorded significantly lower peak of mean torque (2.1 + 0.4 Ncm compared to 2.8 + 0.6 Ncm in Group B compared to 2.9 + 0.7 Ncm in Group C, $p < 0.001$). Apical transportation (p = 0.284) and canal centering ratio (p = 0.412) showed no significant differences. Time of preparation did not differ among groups (p = 0.156).

CONCLUSIONS. Smart endodontic motors with adaptive torque control powered by AI allow a significantly lower file separation and dentinal microcrack formation than using conventional motors and offer similar shaping efficiency and preparation quality. Based on these findings, AI-based motor technology can be clinically adopted to improve the safety of the procedures.

Keywords: artificial intelligence, endodontic motor, torque control, file separation, dentinal microcracks, root canal preparation, micro-CT, instrumentation safety

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Влияние «умных» эндодонтических моторов (с ИИ-контролем крутящего момента) на перелом инструментов и повреждение дентина

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Резюме

ВВЕДЕНИЕ. Внедрение искусственного интеллекта (ИИ) в технологии эндодонтических моторов обеспечивает повышенную безопасность за счет мониторинга крутящего момента в реальном времени и адаптивного управления. Тем не менее, существует мало сравнительных данных о их клинической эффективности в предотвращении перелома инструментов и снижении ятрогенного повреждения дентина.

МАТЕРИАЛЫ И МЕТОДЫ. Девяносто человеческих нижнечелюстных моляров с мезиальными каналами (изгиб 25–35°) были случайным образом распределены на три группы (n = 30): группа А – «умный» мотор на базе ИИ с адаптивным контролем крутящего момента; группа В – обычный мотор с заранее установленными пределами крутящего момента; группа С – обычный мотор с функцией автообратного вращения.

Для подготовки стандартизированных каналов использовались вращающиеся инструменты ProTaper Next. Основными переменными были частота переломов инструментов и появление дентинных микротрещин, оцененные с помощью микро-компьютерной томографии (micro-CT). Второстепенные показатели включали время подготовки, апикальное смещение, соотношение центрирования канала и параметры работы мотора.

РЕЗУЛЬТАТЫ. В группе А наблюдалась значительно более низкая частота переломов инструментов (0% против 10,0% и 13,3% в группах В и С, p = 0,038) и меньшее количество дентинных микротрещин (16,7% против 43,3% и 50,0%, p = 0,006). В группе А также был значительно ниже пик среднего крутящего момента (2,1 ± 0,4 Н·см против 2,8 ± 0,6 Н·см в группе В и 2,9 ± 0,7 Н·см в группе С, p < 0,001). Апикальное смещение (p = 0,284) и соотношение центрирования канала (p = 0,412) статистически значимо не различались. Время подготовки не различалось между группами (p = 0,156).

ВЫВОДЫ. «Умные» эндодонтические моторы с адаптивным контролем крутящего момента на базе ИИ позволяют существенно снизить частоту переломов инструментов и образование дентинных микротрещин по сравнению с обычными моторами, при этом обеспечивая аналогичную эффективность формирования канала и качество подготовки. На основании этих данных технология ИИ-моторов может быть внедрена в клиническую практику для повышения безопасности процедур.

Ключевые слова: искусственный интеллект, эндодонтический мотор, контроль крутящего момента, перелом инструментов, дентинные микротрещины, подготовка корневого канала, микро-КТ, безопасность инструментирования

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INTRODUCTION

The use of nickel-titanium (NiTi) rotary instrumentation to mechanically prepare root canals is now the modern conventional method in the field of endodontics, and is more efficient, predictable, and effective than manual methods [1]. Nonetheless, unforeseen intracanal instrument separation continues to be a chronic complication occurring in 0.4–5 percent of cases that relate to operator experience, complexity of anatomy and file system used [2; 3]. The disconnected instruments can also interfere with the results of treatment by not allowing proper cleaning and obturation of apical sections of the canal and may require the use of technical retrieval methods or even surgery [4].

The major known mechanisms of NiTi rotary file failure are cyclic fatigue due to repetitive tensile-compressive stress of curved canals, as well as torsional overload because of instrument binding in the canal system [5]. Although cyclic fatigue is majorly deter-

mined by the canal geometry and metallurgical qualities, the torsional failure greatly relies on the working conditions such as the applied torque, rotating velocity and the operator skill [6]. Modern endodontic motors use torque regulated systems aimed at reducing stress and avoiding torsional overloading by predetermined torque limits, as well as automatic reversal [7].

Outside the issue of instrument separation, another important issue is iatrogenic dentinal damage during mechanical preparation. Microcracks characterised as a fracture that propagates incompletely out of the canal wall and into the adjacent dentin have been shown in 14–77% of instrumented roots by micro-computed tomography (micro-CT) [8; 9]. These micro cracks can predispose teeth to vertical root fracture especially over the long term after a massive structural damage [10]. The etiology of dentinal microcracks is also multipolar, which includes stress concentration during rotary instrumentation, the excessive taper, the aggressive apical preparation, and cyclic loading during canal shaping [11].

The recent developments in the field of endodontic motor technology have also incorporated the concept of artificial intelligence (AI) with the view to increasing the safety and efficiency of the procedures [12]. Smart motors based on AI utilize real-time torque monitoring algorithms with machine learning functions to examine patterns of resistance and adapt the operation parameters in real time [13]. In contrast to traditional motors, which have a fixed maximum torque, AI-based systems also constantly act on the change of torques and adjust the rotational speed or reverse rotation, based on predictive algorithms developed using large datasets of instrumentation. Such adaptive control systems in theory maximize stress, reduce over loading, and eliminate situations that are favorable to separation of instruments or dentinal injury [14].

A number of manufacturers have launched AI-based endodontic motors that have adaptive torque control, predictive maintenance indicators, and real-time feedback mechanisms. Nonetheless, there are still few empirical studies that prove their clinical superiority to traditional torque-controlled motors [15]. The majority of the existing research analyses the traditional motor systems or studies file design and metallurgy instead of motor technology [16]. The particular effect of AI-based adaptive algorithms on such critical results as the separation of instruments and the creation of dentinal microcracks have not been thoroughly studied in controlled experimental conditions.

The purpose of the ex vivo study is to assess and compare the impact of AI-based smart endodontic motors with adaptive torque control to standardized canal preparation rates; (2) microcrack formation of dentina measured with micro-CT imaging; and (3) quality parameters of preparation such as apical transportation, canal centering ratio, and preparation time. The null hypotheses that are being tested are that there are no significant differences in the motor type affecting the rate of file separation, incidence of the dentinal microcracks, and quality of canal preparation.

MATERIALS AND METHODS

Study design and ethical approval

this comparative ex vivo experimental study was conducted at the Department of Conservative Dentistry and Endodontics, between March 2024 and February 2025.

Sample selection and preparation

Human mandibular first molars extracted for periodontal or orthodontic reasons were collected and stored in 0.1% thymol solution at 4°C until use (maximum storage: 6 months). Initial screening was performed using digital radiography to assess root anatomy and canal morphology.

Inclusion criteria: (1) Mature permanent mandibular first molars with fully formed apices; (2) mesial roots with Vertucci Type IV canal configuration confirmed by radiography; (3) canal curvature between 25–35° measured using Schneider's method; (4) absence of root caries, resorption, or previous endodontic treatment; (5) absence of calcifications or visible dentinal defects.

Exclusion criteria: (1) Immature teeth with open apices; (2) canal curvature <25° or >35°; (3) evidence of internal or external resorption; (4) root cracks or fractures detected under stereomicroscopy; (5) severe canal calcification preventing initial patency establishment; (6) roots with aberrant anatomy or extra canals.

Based on these criteria, 120 teeth were initially selected. Pre-instrumentation micro-CT scanning was performed to confirm canal anatomy and exclude pre-existing dentinal defects. Following micro-CT analysis, 30 teeth were excluded (pre-existing microcracks = 18, canal anatomy variants = 8, calcifications = 4), resulting in 90 teeth for final inclusion.

Sample size calculation

sample size was calculated using G*Power 3.1.9.7 software (Heinrich Heine University, Düsseldorf, Germany) based on preliminary data showing 35% difference in microcrack incidence between groups. Assuming effect size of 0.50, alpha error of 0.05, and power of 0.85, a minimum of 27 specimens per group was required. To account for potential procedural failures and technical issues, 30 specimens per group were allocated, yielding a total sample of 90 teeth.

Randomization and Group Allocation

Teeth were randomly allocated to three experimental groups (n = 30 per group) using computer-generated randomization:

Group A (Smart Motor): AI-based smart endodontic motor with adaptive torque control (EndoPilot AI, Coxo Medical, China) featuring real-time torque monitoring, machine learning algorithms, and dynamic parameter adjustment.

Group B (Conventional Motor): Conventional torque-controlled motor with preset torque limits (X-Smart Plus, Dentsply Sirona, Switzerland).

Group C (Auto-Reverse Motor): Conventional motor with auto-reverse function at torque threshold (VDW Silver Reciproc, VDW, Germany) operated in continuous rotation mode.

Specimen preparation and access cavity

Teeth were decoronated 2 mm above the cementoenamel junction using a diamond disc under water cooling to standardize root length at 16 mm. Access cavities were refined using Gates-Glidden drills #2 and #3 (Dentsply Maillefer, Ballaigues, Switzerland). Canal patency was established using #10 K-file (Dentsply Maillefer), and working length was determined by subtracting 1 mm from the length at which the file tip was visible at the apical foramen.

Pre-instrumentation micro-CT scanning

All specimens underwent pre-instrumentation micro-CT scanning (SkyScan 1272, Bruker, Belgium) at 80 kV, 125 µA, with 0.5 mm aluminum filter, 10 µm voxel size, and 360° rotation with 0.4° rotation step. Images were reconstructed using NRecon software (Bruker) and analyzed using CTAn software (Bruker) to establish baseline canal morphology and confirm absence of pre-existing microcracks.

Canal instrumentation protocol

All specimens were mounted in custom-fabricated standardized holders ensuring reproducible positioning. Canal preparation was performed by a single experienced operator (> 10 years endodontic experience, > 500 cases annually) calibrated on 15 additional teeth before study commencement.

Instrumentation was performed using ProTaper Next rotary files (Dentsply Maillefer) in the sequence X1 (17/.04), X2 (25/.06), and X3 (30/.075) to full working length. Each motor was programmed according to manufacturer specifications:

– Group A: AI adaptive mode with real-time torque optimization;

– Group B: 300 rpm, 2.5 Ncm torque limit;

– Group C: 300 rpm, 2.5 Ncm torque limit with auto-reverse at 70% threshold.

Canals were irrigated with 2 mL of 2.5% sodium hypochlorite between each file using 30-gauge side-vented needle (NaviTip, Ultradent, USA). Recapitulation with #10 K-file was performed between instruments. Glide path was established using #15 K-file for all specimens.

Preparation time (from X1 insertion to X3 final withdrawal) was recorded using digital chronometer. Motor operational parameters (peak torque, torque fluctuations, auto-reverse activations) were logged automatically by each motor system.

Post-instrumentation assessment

File separation

All file separations during preparation were recorded, including instrument type, separation location, and circumstances. Separated fragment length was measured using digital calipers.

Micro-CT analysis for dentinal microcracks

Post-instrumentation micro-CT scanning was performed using identical parameters as pre-instrumentation scans. Images were analyzed independently by two calibrated examiners blinded to group allocation. Microcracks were identified as lines extending from the canal wall into dentinal structures not present in pre-instrumentation scans. The presence, number, and location of microcracks were recorded for each specimen.

Canal Transportation and Centering Ratio

Pre- and post-instrumentation micro-CT images were superimposed using DataViewer software (Bruker). Canal transportation and centering ratio were calculated at 3, 5, and 7 mm from the apex using established formulas:

Canal transportation = (X1–X2) – (Y1–Y2), where X1 and Y1 represent mesial and distal dentin thickness pre-instrumentation, and X2 and Y2 represent post-instrumentation measurements.

Centering ratio = (X1–X2) / (Y1–Y2) or (Y1–Y2) / (X1–X2), with the lower value used, where perfect centering = 1.

Statistical analysis

Statistical analysis was performed using SPSS version 28.0 (IBM Corporation, Armonk, NY). Inter-examiner reliability for microcrack assessment was evaluated using Cohen's kappa coefficient. Normality of continuous variables was assessed using Shapiro-Wilk test and Q-Q plots.

Categorical variables (file separation, microcrack presence) were compared using chi-square test or Fisher's exact test as appropriate. Continuous variables (torque values, preparation time, transportation, centering ratio) were analyzed using one-way ANOVA followed by Tukey's HSD post-hoc test for multiple comparisons. Non-parametric alternatives (Kruskal-Wallis with Dunn's post-hoc) were applied when normality assumptions were violated.

Statistical significance was set at $\alpha = 0.05$ (two-tailed). Data are presented as mean ± standard deviation, median (interquartile range), or frequencies and percentages as appropriate.

RESULTS

File separation and motor performance

all 90 specimens completed the preparation protocol or experienced file separation during the procedure. Inter-examiner reliability for microcrack assessment was excellent (Cohen's kappa = 0.92, 95% CI 0.85–0.97).

File separation occurred in 0 cases (0%) in Group A, 3 cases (10.0%) in Group B, and 4 cases (13.3%) in Group C, with statistically significant differences between groups ($p = 0.038$, Fisher's exact test). All separations occurred with the X3 file (30/.075) in the apical third. Pairwise comparisons revealed significant differences between Group A and Group C ($p = 0.041$) but not between Groups B and C ($p = 0.692$). Motor performance parameters and preparation efficiency are presented in Table 1.

Group A demonstrated significantly lower peak torque values and reduced torque fluctuation ranges compared to both conventional motor groups ($p < 0.001$). The AI-based system performed significantly more auto-reverse activations and dynamic speed adjustments compared to Group B, while Group C showed the highest number of auto-reverse events due to its preset threshold mechanism.

Dentinal microcrack formation

Dentinal microcrack incidence and characteristics are presented in Table 2. The AI-based smart motor group demonstrated significantly lower microcrack formation compared to conventional motor groups.

Group A demonstrated significantly fewer specimens with dentinal microcracks (16.7%) compared to Group B (43.3%, $p = 0.028$) and Group C (50.0%, $p = 0.009$). No significant differences were observed between Groups B and C ($p = 0.604$). Among specimens that developed microcracks, the number, location, orientation, and length did not differ significantly between groups.

Canal preparation quality

Canal preparation quality parameters assessed by micro-CT analysis are presented in Table 3. No significant differences were observed between groups for canal transportation or centering ratio at any measured level.

Table 1. Motor performance parameters and preparation efficiency

Таблица 1. Показатели моторной деятельности и эффективность подготовки

Parameter	Group A (Smart Motor) *n* = 30	Group B (Conventional) *n* = 30	Group C (Auto-Reverse) *n* = 30	F/χ^2 value	*p*-value
File separation, *n* (%)	0 (0)[a]	3 (10.0)[ab]	4 (13.3)[b]	–	0.038*
Peak torque (Ncm), mean ± SD	2.1 ± 0.4[a]	2.8 ± 0.6[b]	2.9 ± 0.7[b]	18.42	< 0.001
Torque fluctuation range (Ncm), mean ± SD	0.6 ± 0.2[a]	1.2 ± 0.4[b]	1.3 ± 0.5[b]	28.64	< 0.001
Auto-reverse activations, mean ± SD	4.2 ± 1.8[a]	2.1 ± 1.2[b]	8.6 ± 2.4[c]	86.32	< 0.001
Speed adjustments (AI only), mean ± SD	12.6 ± 3.4	N/A	N/A	–	–
Total preparation time (s), mean ± SD	164 ± 32	156 ± 28	178 ± 38	3.82	0.156
Completion rate (%), *n* (%)	30 (100)[a]	27 (90.0)[ab]	26 (86.7)[b]	–	0.038*

Note: Different superscript letters indicate statistically significant differences ($p < 0.05$) in post-hoc pairwise comparisons. * Fisher's exact test; all others one-way ANOVA with Tukey HSD.

Примечание: Различные надстрочные буквы указывают на статистически значимые различия ($p < 0,05$) при попарных post-hoc сравнениях. * Критерий Фишера; для остальных показателей применялся однофакторный ANOVA с тестом Тьюки (HSD).

Table 2. Dentinal microcrack formation and characteristics

Таблица 2. Формирование дентинных микротрещин и их характеристики

Variable	Group A (Smart Motor) *n* = 30	Group B (Conventional) *n* = 30	Group C (Auto-Reverse) *n* = 30	χ^2/F value	*p*-value
Specimens with microcracks, *n* (%)	5 (16.7)[a]	13 (43.3)[b]	15 (50.0)[b]	10.18	0.006
Total microcracks detected, *n*	6	24	28	–	–
Microcracks per affected specimen, mean ± SD	1.2 ± 0.4	1.8 ± 0.6	1.9 ± 0.8	2.86	0.082
Microcrack location, *n* (%)					
Apical third	3 (50.0)	14 (58.3)	16 (57.1)	–	0.918
Middle third	2 (33.3)	8 (33.3)	10 (35.7)	–	0.982
Coronal third	1 (16.7)	2 (8.3)	2 (7.1)	–	0.724
Microcrack orientation, *n* (%)					
Vertical	4 (66.7)	16 (66.7)	18 (64.3)	–	0.973
Horizontal	1 (16.7)	4 (16.7)	5 (17.9)	–	0.994
Oblique	1 (16.7)	4 (16.7)	5 (17.9)	–	0.994
Microcrack length (μm), mean ± SD	486 ± 124	542 ± 168	568 ± 186	1.24	0.294
Complete microcracks (reaching outer surface), *n* (%)	0 (0)	2 (8.3)	3 (10.7)	–	0.368

Note: Different superscript letters indicate statistically significant differences ($p < 0.05$) in post-hoc comparisons.

Примечание: Различные надстрочные буквы указывают на статистически значимые различия ($p < 0,05$) в апостериорных сравнениях.

Table 3. Canal preparation quality parameters

Таблица 3. Параметры качества подготовки корневого канала

Parameter	Group A (Smart Motor) *n* = 30	Group B (Conventional) *n* = 27	Group C (Auto-Reverse) *n* = 26	F value	*p*-value
Canal transportation (mm), mean ± SD					
3 mm from apex	0.08 ± 0.04	0.09 ± 0.05	0.10 ± 0.06	1.18	0.312
5 mm from apex	0.12 ± 0.06	0.14 ± 0.07	0.13 ± 0.06	0.82	0.445
7 mm from apex	0.15 ± 0.08	0.16 ± 0.09	0.18 ± 0.10	0.94	0.395
Overall mean	0.12 ± 0.06	0.13 ± 0.07	0.14 ± 0.07	1.28	0.284
Centering ratio, mean ± SD					
3 mm from apex	0.78 ± 0.12	0.76 ± 0.14	0.74 ± 0.13	0.92	0.402
5 mm from apex	0.82 ± 0.10	0.80 ± 0.12	0.79 ± 0.11	0.68	0.510
7 mm from apex	0.85 ± 0.09	0.83 ± 0.11	0.82 ± 0.10	0.88	0.418
Overall mean	0.82 ± 0.10	0.80 ± 0.12	0.78 ± 0.11	0.89	0.412
Apical debris extrusion, mg ± SD	0.28 ± 0.12	0.32 ± 0.14	0.34 ± 0.16	1.64	0.201
Dentin removal volume (mm^3), mean ± SD	1.86 ± 0.34	1.92 ± 0.38	1.98 ± 0.42	0.96	0.388

Note: All pairwise comparisons non-significant ($p > 0.05$, Tukey HSD).
Примечание: Все попарные сравнения статистически незначимы ($p > 0,05$, Tukey HSD).

Canal transportation values remained below 0.20 mm at all levels for all groups, indicating acceptable preparation quality. Centering ratios approached 1.0, demonstrating good canal centering ability across all motor types. No significant differences were observed in apical debris extrusion or dentin removal volume between groups.

DISCUSSION

This ex vivo study indicates that AI-controlled smart endodontic motors with adaptive-torque control are considerably reduced than standard torque-controlled motors on file separation and dentinal microcracks formation and produce the same quality of canal preparation. The results disapprove the null hypotheses and strongly support the clinical value of an AI-combined motor technology to improve the safety of the procedure during endodontic instrumentation.

The fact that the AI-based motor group (0% versus 10–13% in conventional motor groups) has no separation of files versus conventional motor groups has a clinically meaningful safety benefit. Although the total separation rates in the traditional groups cannot be compared with those measured in clinical sources [2; 3], the AI system predictive algorithms and real-time adaptive control actually avoided the cases of torsional overload conditions leading to the failure of the instruments [5; 6]. The much lower peak torque (2.1 vs. 2.8–2.9 Ncm) and less pronounced changes in torque in Group A indicate that the constant monitoring and manual adjustment of the parameters in the group optimize the distribution of stress and avoid the critical loading levels [12; 13].

The process that would lead to this protective effect would be the ability of the AI algorithm to sense small increments in torque before the catastrophic failure occurs and respond by slowing rotational speed down or reversing rotation before the failures occur [14]. In contrast to traditional motors that operate at constant torque that raises after hitting the threshold, AI-based predictive control prevents the occurrence of high-stress levels. The much greater incidence of Group A (4.2) compared to Group B (2.1) of auto-reverse activations shows more sensitive detection and early intervention, as opposed to Group C (8.6) that kept on activated only after reaching predetermined thresholds.

The fact that AI-based motors reduced dentinal microcracks development by a significant margin (16.7% vs. 43–50) is also another important finding with a strong clinical impact. Long-term vertical root fracture Dental root fracture has been linked to dentinal microcracks, especially in teeth undergoing endodontics and functional loading [10; 11]. According to the hypothesis of stress-concentration, aggressive or uncontrolled instrumentation produces too much radial force on canal walls, which spreads incomplete fractures into adjacent dentin [8; 9]. Under the conditions of ensuring optimal torque distribution and reducing the peaks of stress, AI-adaptive control seems capable of maintaining dentinal strain at levels that are below critical fracture initiation values.

Interestingly, in those specimens which formed microcracks, there was no significant difference in the number, location, orientation, and length of microcracks between groups. This implies that AI control

mainly minimizes the likelihood of microcracks forming as opposed to their growth properties once they have developed. The canal structure, dentin characteristics and the natural concentration points of stresses could contribute to crack growth without any control by the motor once stimulated [11].

The fact that canal preparation quality is preserved throughout the different types of motors proves the fact that the increased safety features do not affect the shaping efficacy [17; 18]. Equal canal transportation and centering ratios show that AI-adaptive control can provide the instrument path and dentin removal patterns equal to the conventional systems. The discovery is essential to the clinical acceptance, since high safety characteristics will not have significant value when they are followed by low quality of preparation. The similarity in the preparation times (156–178 seconds) also suggests that recurring adaptive adjustments do not cause significant delays in the processes, which can be relevant to overcome the concerns about efficiency.

The fact that all groups made similar amounts of dentin removal prove that AI control has no effect on cutting efficiency or preparation aggressiveness. In addition to similar apical debris extrusion, these results indicate that AI algorithms maximize operation parameters in secure limits and maintain basic mechanical cutting behaviors [1].

The comparison of the traditional motor technologies that have been done in the past has proved that the torque-controlled systems are better than the speed-controlled motors in torsional failure prevention [7]. Our results further extend this evidence by showing that smart adaptive control is better than fixed torque limiting. This is in line with the recent research on the application of AI in the dental field where machine learning-based methods prove to be more efficient at recognizing patterns and predicting those likely to emerge than rule-based systems [15].

The clinical implications are great. Although it is uncommon, instrument separation is a serious procedural complication that leads to more time at the chair, retrieval procedures that are specialized, and can result in impaired treatment outcomes [4]. A decrease in 10–13% to 0% separation rate, as observed in this study would help to avoid many clinical complications in vast numbers of patients. On the same note, a 43–50 to 17 percent reduction in the occurrence of microcracks could potentially reduce the long-term fracture hazard, especially in massively restored teeth that retain only a small coronal tooth structure.

Limitations to study: There are a number of limitations to study. Although ex vivo design allows the controlled experimentation and micro-CT analysis, it is not able to recreate the conditions in clinics completely with variable dentin properties, patient-specific anatomy, and operator technique variations. The mandibular molars used containing a particular range of curvature do not generalize to other kinds of teeth and morphological variation. Single-operator instrumentation removed inter-operator variability but does not necessarily indicate the variable level of clinical skills. It was assessed over a relatively short period of time that did not allow any evaluation of long-term microcrack development or possible fracture. A single file system (ProTaper Next) was tested; alternate file designs, tapers or metallurgical properties may exhibit an alternate response to motor control variations. The AI motor system employed proprietary algorithms, the particular training data and decision parameters of which were not available to the manufacturer to aid mechanistic knowledge. Lastly, micro-CT analysis is sensitive in topic of microcracks but can detect defects that are of clinical insignificance and need to be proved by biomechanical analysis and longitudinal, clinical investigations.

CONCLUSION

This comparative study which is based on ex vivo provides conclusive evidence that AI-based smart endodontic motors with adaptive torque control offer great benefits over standard torque-controlled motors in the prevention of file separation and dentinal microcrack formation during root canal instrumentation. This AI-integrated system completely eliminated file separation, cut the presence of microcracks by about 60 percent, on average, as compared to the traditional motors, and real-time torque monitoring, predictive algorithms, and optimization of dynamic parameters. Noteworthily, the effectiveness of these safety improvements has been achieved without negating the quality of canal preparation since the canal transportation, centring ratios, and dentin removal patterns are all similar across all types of motors. The similar preparation times show that increased safety does not require increase of the procedure. The much smaller peak torque measures and lower torque variation in the AI group indicates that there is constant optimization of the stress distribution by continuous adaptive control and avoidance of the critical loads leading to instrument failure or dentinal injury. The results of the research are effective evidence of the clinical implementation of the AI-based endodontic motor technology as a significant improvement in the safety of the procedure. The high decrease in the separation of the instruments and the problem of microcracks formation is the solution to two essential issues in modern endodontic practice immediate complications during the procedures and structural integrity of the treated teeth in the long-term. AI-based smart motors can be considered as an important investment that can be made by clinicians to improve treatment safety, complication rates, and even long-term prognosis of teeth that have received endodontic treatment. Further studies are required on AI motor performance in different anatomical structures, in different file systems, in groups of clinical operators, and in long-term clinical effects to further confirm these laboratory results and set evidence-based rules on the use of technology. Also, longitudinal and cost-efficiency analyses of vertical root fracture prevalence in teeth that underwent various motor technologies would offer meaningful information about the clinical and economic worth of AI-based integrated endodontic systems.

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AUTHOR'S CONTRIBUTION

All the authors made equal contributions to the publication preparation in terms of the idea and design of the article; data collection; critical revision of the article in terms of significant intellectual content and final approval of the version of the article for publication.

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Influence of artificially simulated pulpal temperature on cyclic fatigue resistance of heat treated NiTi files

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Abstract

INTRODUCTION. NiTi rotary files, which have been heat-treated, have shown an increase in the flexibility and cyclic fatigue resistance. But the effect of the changes of intracanal temperature during clinical instrumentation on file performance is not well known.

MATERIALS AND METHODS. NiTi files with heat treatment (n = 108) were used (ProTaper Gold, WaveOne Gold, and Reciproc Blue, n = 60 each) in a standardized artificial canal (angled at 60 and radius of curvature = 5 mm). The files were randomly selected into three temperature conditions (n = 20/group): Group A (20°C – room temperature), Group B (37°C – normal body temperature) and Group C (45°C – higher inflammatory temperature). Fatigue test was carried out in a cyclic manner until file fracture. Fracture time (TTF) and cycles to failure (NCF) were measured. One-way ANOVA and Tukey post-hoc tests (0.05) were used in statistical analysis.

RESULTS. A major difference in cyclic fatigue resistance was found across temperature groups in each file system ($p < 0.001$). ProTaper Gold showed 412±68 NCF at 45°C relative to 584±92 at room temperature (20°C) ($p < 0.001$). WaveOne Gold was found to have 738+114 NCF at 45°C compared to 1024+156 NCF at 20°C ($p < 0.001$). Reciproc Blue used showed 896±128 NCF at 45°C unlike 1246±182 NCF at 20°C ($p > 0.001$). High temperature (45°C) decreased the cyclic fatigue resistance by 28929.5 percent in all the systems subjected to it.

CONCLUSIONS. Artificially reproduced elevated pulpal temperatures have a great influence in reducing cyclic fatigue resistance of heat-treated NiTi files. Endodontic practice requires the clinical awareness of temperature-dependent mechanical behavior to avoid instrument separation and complicate endodontic practice especially in inflamed teeth.

Keywords: cyclic fatigue, heat-treated NiTi, pulpal temperature, rotary files, endodontics, instrument fracture, ProTaper Gold, WaveOne Gold, Reciproc Blue

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Влияние искусственно смоделированной температуры пульпы на сопротивление циклической усталости термообработанных никель-титановых файлов

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Резюме

ВВЕДЕНИЕ. Вращающиеся никель-титановые (NiTi) файлы с термообработкой демонстрируют повышенную гибкость и сопротивление циклической усталости. Однако влияние изменений внутрикоронковой температуры во время клинического инструментирования на характеристики файлов изучено недостаточно.

МАТЕРИАЛЫ И МЕТОДЫ. Для исследования использовались термообработанные NiTi-файлы (n = 108): ProTaper Gold, WaveOne Gold и Reciproc Blue (по 60 файлов каждого типа) в стандартизированном искусственном канале (угол изгиба 60°, радиус кривизны 5 мм). Файлы случайным образом распределили по трем температурным условиям (n = 20/группа): группа А – 20°C (комнатная температура);

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группа B – 37°C (нормальная температура тела); группа C – 45°C (повышенная воспалительная температура). Испытания на усталость проводились циклически до разрушения файла. Измерялись время до разрушения (TTF) и количество циклов до разрушения (NCF). Для статистического анализа применялись однофакторный ANOVA и post-hoc тест Тьюки (уровень значимости 0,05).
РЕЗУЛЬТАТЫ. В каждой системе инструментов выявлено значительное различие сопротивления циклической усталости между температурными группами ($p < 0,001$): ProTaper Gold показал 412 ± 68 NCF при 45°C по сравнению с 584 ± 92 NCF при 20°C ($p < 0,001$); WaveOne Gold – 738 ± 14 NCF при 45°C против 1024 ± 156 NCF при 20°C ($p < 0,001$); Reciproc Blue – 896 ± 128 NCF при 45°C против 1246 ± 182 NCF при 20°C ($p < 0,001$). Повышенная температура (45°C) снизила сопротивление циклической усталости во всех системах на 28,9–29,5%.
ВЫВОДЫ. Искусственно воспроизведенная повышенная пульповая температура существенно снижает сопротивление циклической усталости термообработанных NiTi-файлов. В эндодонтической практике важно учитывать зависимость механического поведения файлов от температуры, чтобы избегать переломов инструментов и осложнений, особенно при работе с воспаленными зубами.

Ключевые слова: циклическая усталость, термообработанный NiTi, пульповая температура, вращающиеся файлы, эндодонтия, перелом инструментов, ProTaper Gold, WaveOne Gold, Reciproc Blue

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INTRODUCTION

The NIti (Nickel-titanium) rotary and reciprocating tools have transformed the endodontics practice by increasing the effectiveness of shaping, minimizing errors in the procedure, and improving the outcomes of treatment [1]. NiTi alloys have a distinctive superelastic behavior that is caused by stress-induced martensitic transformation, which makes these instruments negotiate intricate root canal anatomy with fewer chances of canal transportation [2]. But then, cyclic fatigue and resulting unexpected separation of instruments is also a major clinical issue, which may become problematic in treatment and undermine prognosis [3].

Cyclic fatigue failure is as a result of repetitive tensile and compressive forces on the rotary instruments in their rotation in curved canals, which eventually causes crack propagation and fracture [4]. The cyclic fatigue resistance depends on a great number of factors such as canal curvature, rotational speed, torque, instrument design, metallurgical property, and manufacturing procedures [5; 6]. Recent developments in the thermomechanical processing have created heat treated NiTi alloys which are more flexible and show increased resistance to fatigue of the cyclic type and superior performance in clinical terms than the traditional NiTi files [7].

The crystallographic phase composition and microstructure of NiTi alloys are altered through heat treatment and the austenite to martensite transformation temperatures are optimized as well as mechanical properties [8]. A number of commercially available heat-treated file systems such as ProTaper Gold (Dentsply Sirona), WaveOne Gold (Dentsply Sirona) and Reciproc Blue (VDW) have been shown to have a higher resistance to cyclic fatigue in laboratory studies [9; 10]. The proprietary thermal processes produce mixtures of austenite, R-phase and martensite at different temperatures, which are basically different mixtures of austenite, R-phase and martensite [11].

Phase transformation temperatures of NiTi alloys are very sensitive to temperature with both mechanical properties strongly depending on environmental temperature [12]. Intracanal temperatures during clinical endodontic treatments can be significantly different to normal body temperature (37°C) because of inflammatory events, exothermic effects during obturation, heat generation by friction during instrumentation, and changes in irrigant temperatures [13]. Past reports have indicated that the levels of temperature have risen as much as 10–15°C higher than physiological levels in inflamed pulpal tissues and even during some endodontic sessions [14].

Although the temperature-dependent nature of NiTi alloys is known, the majority of cyclic fatigue tests assess the behavior of instruments at room temperature (20–25°C), which is not a suitable method to simulate clinical conditions [15]. Little of the evidence has been done on how simulated body temperature has an effect on cyclic fatigue resistance with different findings showing the extent of body temperature effects and its clinical applicability [16]. Besides, the effect of high temperatures that mimic inflammatory or procedurally induced temperature on heat-treated NiTi files is scarcely studied.

The purpose of the in vitro study is to compare and assess the cyclic fatigue resistance of three commercially available heat-treated NiTi file systems (ProTaper Gold, WaveOne Gold and Reciproc Blue) in three artificially simulated pulpal temperature conditions namely, room temperature (20°C), normal body temperature (37°C) and elevated inflammatory temperature (45°C). The null hypothesis is that the simulation of the temperature of the palpali does not have a significant effect on the cyclic fatigue resistance of heat-treated NiTi rotary files.

MATERIALS AND METHODS

Study design and sample size

this experimental in vitro study employed a factorial design with three file systems and three temperature conditions. Sample size calculation was performed using G*Power 3.1 software (Heinrich Heine University, Düsseldorf, Germany), based on pilot study data showing effect size of 0.45, alpha error of 0.05, and power of 0.90, resulting in a minimum requirement of 18 files per group. To account for potential measurement errors and ensure statistical robustness, 20 files per experimental group were allocated, yielding a total sample of 180 files.

Instrument selection

Three heat-treated NiTi file systems were evaluated:

– Group PTG: ProTaper Gold (Dentsply Sirona, Ballaigues, Switzerland) – Size 25, 0.08 taper, 25 mm length;

– Group WOG: WaveOne Gold Primary (Dentsply Sirona) – Size 25, variable taper (0.08–0.03), 25 mm length;

– Group RB: Reciproc Blue R25 (VDW, Munich, Germany) – Size 25, variable taper (0.08–0.03), 25 mm length.

All instruments were inspected under stereomicroscope (Leica M80, Leica Microsystems, Wetzlar, Germany) at 16× magnification to exclude manufacturing defects, deformations, or surface irregularities. Only unused files from the same manufacturing batch were included to minimize variability.

Cyclic fatigue testing apparatus

a custom-designed cyclic fatigue testing device was fabricated following established protocols. The apparatus consisted of a stainless-steel artificial canal with standardized dimensions: 60° angle of curvature, 5-mm radius of curvature, and 1.5-mm internal diameter. The curvature was positioned 5 mm from the file tip, simulating severe clinical canal anatomy. The artificial canal was embedded in a temperature-controlled metal block connected to a precision heating system with digital temperature monitoring (accuracy ±0.2°C).

Temperature simulation protocol

three experimental temperature conditions were established:

– Group A (20°C): Room temperature control, representing standard laboratory testing conditions;

– Group B (37°C): Normal body / pulpal temperature, simulating physiological conditions;

– Group C (45°C): Elevated temperature, simulating inflammatory conditions or procedurally induced thermal elevation.

Temperature stability was maintained using a PID-controlled heating system with continuous monitoring via thermocouples positioned adjacent to the testing canal. Synthetic oil (SAE 15W-40 motor oil) was used as the thermal medium to ensure consistent heat transfer and lubrication, as validated in previous studies. Temperature equilibration was confirmed for 10 minutes before each test sequence.

Testing procedure

Computer-generated randomization (random.org) was applied to assign files randomly to temperature groups. The ProTaper Gold files have been used in constant rotation at 300 rpm with a torque-controlled endodontic motor (X-Smart Plus, Dentsply Sirona). The wave One Gold and Reciproc Blue files were driven in recommended manufacturer counterclockwise reciprocating motions (WOG: 170 50 degrees; RB: 150 30 degrees).

All the files were placed into the artificial canal until the working length (18 mm) was achieved and the constant rotation/reciprocation continued until fracture. The testing apparatus had an automatic stop mechanism which was activated by separation of files. Time to fracture (TTF) was measured in seconds using a digital chronometer and the number of cycles to failure (NCF) was determined using time and rotor/reciprocating speed recorded.

After fracture, all the fragments were then gathered and the length of the fracture was taken using the file tip with the help of the digital caliper (precise to 0.01 mm). Scanning electron microscopy (SEM; JEOL JSM-6610LV, JEOL Ltd., Tokyo, Japan) with a magnification of 500 and 1000 was used to determine fracture surfaces that fractured due to cyclic fatigue and to eliminate torsional fracture.

Data collection and management

all measurements were performed by a single calibrated investigator blinded to the experimental groups. Ten percent of samples were randomly re-measured to assess intra-examiner reliability using intraclass correlation coefficient (ICC). Data were systematically recorded in standardized forms and transferred to electronic spreadsheets for analysis.

Statistical analysis

Statistical analysis was conducted using SPSS version 27.0 (IBM Corporation, Armonk, NY, USA). Normality of data distribution was assessed using Shapiro-Wilk test and visual inspection of Q-Q plots. Homogeneity of variance was evaluated using Levene's test. Descriptive statistics were calculated as means and standard deviations for continuous variables.

Two-way analysis of variance (ANOVA) was performed to evaluate the main effects of file system and temperature, as well as their interaction effect, on cyclic fatigue resistance (NCF and TTF). When significant differences were detected, Tukey's honestly significant difference (HSD) post-hoc test was applied for pairwise comparisons. One-way ANOVA followed by Tukey's test was used for comparisons within each file system across temperature groups. Statistical significance was set at $\alpha = 0.05$.

RESULTS

Reliability and fracture characteristics

intra-examiner reliability demonstrated excellent agreement (ICC = 0.96, 95% CI 0.92–0.98). All files fractured within the curved portion of the artificial canal. Mean fracture lengths were 4.8 ± 0.4 mm for ProTaper

Gold, 4.6 ± 0.5 mm for WaveOne Gold, and 4.7 ± 0.3 mm for Reciproc Blue, with no significant differences between temperature groups (p = 0.342). SEM examination confirmed typical cyclic fatigue failure patterns characterized by crack initiation areas and fatigue striations, with no evidence of torsional failure.

Number of cycles to failure (NCF)

Descriptive statistics and comparative analysis of NCF across file systems and temperature conditions are presented in Table 1. Two-way ANOVA revealed significant main effects of both file system (F = 286.4, p < 0.001) and temperature (F = 124.8, p < 0.001), along with a significant interaction effect (F = 3.82, p = 0.006).

Post-hoc comparisons (Tukey HSD): Within each file system, all pairwise temperature comparisons were statistically significant (p < 0.01). Between file systems at each temperature, all comparisons showed significant differences (p < 0.001).

Time to failure (TTF)

Time to failure results paralleled NCF findings, with significant differences across both file systems and temperature conditions (Table 2).

All pairwise comparisons within file systems across temperatures were significant (p < 0.01, Tukey HSD). Between-system comparisons at each temperature showed significant differences (p < 0.001).

Percentage reduction in cyclic fatigue resistance

table 3 presents the percentage reduction in NCF at elevated temperatures compared to room temperature baseline, illustrating the magnitude of temperature effects on instrument performance.

The reduction in cyclic fatigue resistance from 20°C to 45°C ranged from 27.9% to 29.5%, with remarkably consistent patterns across all three heat-treated file systems. Each temperature increment (20°C→37°C→45°C) resulted in statistically significant and progressive reduction in fatigue resistance.

Table 1. Number of cycles to failure (NCF) for different file systems at various temperatures

Таблица 1. Количество циклов до разрушения (NCF) для различных систем инструментов при разных температурах

File System	20°C (Group A)	37°C (Group B)	45°C (Group C)	Overall Mean	*F*-value	*p*-value
ProTaper Gold (n = 60)	584 ± 92	478 ± 76	412 ± 68	491 ± 102	42.6	< 0.001
WaveOne Gold (n = 60)	1024 ± 156	862 ± 128	738 ± 114	875 ± 168	48.2	< 0.001
Reciproc Blue (n = 60)	1246 ± 182	1058 ± 148	896 ± 128	1067 ± 208	52.8	< 0.001
Overall Mean	951 ± 298	799 ± 272	682 ± 238	811 ± 282	–	–
F-value	286.4	–	–	–	–	–
p-value	<0.001	–	–	–	–	–

Table 2. Time to failure (TTF) in seconds for different file systems at various temperatures

Таблица 2. Время до разрушения (TTF) в секундах для различных систем инструментов при разных температурах

File System	20°C (Group A)	37°C (Group B)	45°C (Group C)	Overall Mean	*F*-value	*p*-value
ProTaper Gold	116.8 ± 18.4	95.6 ± 15.2	82.4 ± 13.6	98.3 ± 20.4	42.6	< 0.001
WaveOne Gold	246.2 ± 37.5	207.4 ± 30.8	177.6 ± 27.4	210.4 ± 40.4	48.2	< 0.001
Reciproc Blue	299.8 ± 43.8	254.6 ± 35.6	215.6 ± 30.8	256.7 ± 50.0	52.8	< 0.001
Overall Mean	220.9 ± 82.4	185.9 ± 74.8	158.5 ± 64.6	188.5 ± 77.4	–	–

Table 3. Percentage reduction in NCF at elevated temperatures compared to 20°C

Таблица 3. Процентное снижение количества циклов до разрушения (NCF) при повышенных температурах по сравнению с 20°C

File System	37°C vs. 20°C	*p*-value	45°C vs. 20°C	*p*-value	45°C vs. 37°C	*p*-value
ProTaper Gold	–18.2% (106 cycles)	< 0.001	–29.5% (172 cycles)	< 0.001	–13.8% (66 cycles)	0.004
WaveOne Gold	–15.8% (162 cycles)	< 0.001	–27.9% (286 cycles)	< 0.001	–14.4% (124 cycles)	0.002
Reciproc Blue	–15.1% (188 cycles)	< 0.001	–28.1% (350 cycles)	< 0.001	–15.3% (162 cycles)	0.001
Mean across systems	–16.4%	–	–28.5%	–	–14.5%	–

File system ranking

regardless of temperature condition, the rank order of cyclic fatigue resistance remained consistent: Reciproc Blue > WaveOne Gold > ProTaper Gold. At physiological temperature (37°C), Reciproc Blue demonstrated 121% greater fatigue resistance than ProTaper Gold (1,058 vs. 478 cycles, $p < 0.001$) and 23% greater resistance than WaveOne Gold (1,058 vs. 862 cycles, $p < 0.001$).

DISCUSSION

This paper indicates that the artificially created pulpal temperature has a great effect on the cyclic fatigue resistance of heat-treated NiTi rotary files and high temperatures have a great impact on the life of the instruments. The null hypothesis is thus rejected. The ongoing 28–30 per cent reduction in cyclic fatigue resistance in 45°C relative to the room temperature of all the tested file systems is a significant deterioration of the mechanical performance that is clinically meaningful and therefore requires consideration in endodontic practice.

The mechanical behavior of the NiTi alloys under different temperatures is inherently associated with their phase transformation nature [1; 8]. NiTi files that are heat-treated are designed to maximize their metallurgical phases at a certain temperature and the manufacturers aim at a higher martensitic content at the body temperature resulting in better flexibility [7; 11]. This sensitivity to temperature, however, generates a two-sided effect wherein, although flexibility increases come at the cost of canal negotiation, the same decrease in fatigue resistance is known to increase the risk of separation in some situations.

The results of our study are consistent with other studies that have shown a decreased cyclic fatigue resistance at high temperatures [12; 17]. Our study showing a decrease in NCF by approximately 16 percent between 20°C and 37°C also agrees with the findings of de Vasconcelos et al. who recorded 12–18 percent reductions when using conventional NiTi files at the body temperature [16]. But our research builds up on this information by investigating heat-treated alloys and modeling pathologically high temperatures (45°C), a scenario that is often a part of clinical practice in the inflamed pulpal tissues [14].

The physical process which occurs to explain the fact that temperature reduces fatigue resistance has to do with changes in the martensitic transformation of stress induced behavior [8; 11]. When the temperature gets high, the amount of energy needed to change austenite to martensite is higher and the alloy might lose its capacity to mitigate cyclic stress during phase change. Also, increased temperatures can increase the rate of crack propagation and decrease the plastic deformation resistance of the material [18]. The heat treatment processes on proprietary files establish certain austenite finish (af) temperatures, and once the operational temperatures reach the limits of these temperatures, the mechanical properties can be significantly changed [7].

The performance ranking (Reciproc Blue > WaveOne Gold > ProTaper Gold) of the systems under all the temperature conditions indicates that the high cyclic fatigue resistance of some heat-treated systems remains constant regardless of temperatures [9; 10]. This ranking is probably due to variation in heat treatment procedures, metallurgical stages, cross-sectional shape and metal fabrication [11]. Blue thermal treatment according to Reciproc Blue generates more martensite content at body temperature than that of Gold treatment, which may result in greater flexibility and fatigue resistance [10].

Interestingly, both WaveOne Gold and Reciproc Blue which operated in reciprocating motion displayed a higher fatigue resistance than the continually rotating ProTaper gold [9]. Compensating motion also ensures that cumulative stress is minimized through alternate loading of the tensile and compressive surfaces hence increases the life of instruments. This benefit in kinematics seems to be maintained over a temperature condition though the comparative advantage might be counterbalanced by material property variation over temperature.

Our clinical implications of our findings are significant. Pulpal temperatures could be increased during endodontic treatment of teeth with symptomatic irreversible inflammatory hyperemia of the pulp or acute apical periodontitis [14]. Also, on the instrumentation, the friction especially on the calcified or severely curved canals generates heat which can temporarily increase the local temperatures [13]. Such conditions can lead to a situation where instruments will be less fatigue resistant, and risk separation is greatly enhanced. Clinicians should also be more cautious with the instrumentation of inflamed teeth and may use lower insertion forces, reduced progression, and increased file changes.

Refrigerated or room-temperature irrigants may hypothetically counteract fatigue alleviation during temperature, but the practical feasibility and the possible effects on cleaning performance is yet to be explored [13]. In contrast, the presence of the heated irrigants to improve the antimicrobial activity and removal of debris can unintentionally undermine instrument safety which is an element that should be considered when developing a protocol.

It has a number of limitations that should be mentioned. Although the in vitro design allows standardized controlled testing, it cannot completely recreate the complexity of the clinical situation with irregular anatomy of the canal and differences in dentin hardness and variability in technique of the clinician. Synthetic oil as a thermal medium which has been confirmed in the earlier literature is different to the aqueous conditions of sodium hypochlorite irrigation. The artificial canal model used a harsh, though standardised curvature; radii and angles of curvature with different curvature might have various temperature impacts. The temperature was kept constant during each of the tests, and clinical temperatures are dynamic. The evaluations were limited to size 25 instruments; other sizes could exhibit change in sensitivity to temperature because of differences in mass and cross-sectional areas. Lastly, the observation period was relatively short to assess the effects of long-term exposure of temperature to material properties (until fracture).

CONCLUSSION

This in vitro study conclusively indicates that the artificially designed simulated pulpal temperature can have profound effect on cyclic fatigue resistance of rotary files that have been heat treated using NiTi. High temperature (45°C) decreased the cyclic fatigue resistance of the ProTaper Gold, the WaveOne Gold and the Reciproc Blue systems by nearly 28–30 percent relative to room temperature. Even physiological body temperature (37°C) had 15–18 percent reduction in comparison to the normal laboratory testing conditions. The findings imply that fatigue assessment in the conventional cyclic fatigue at room temperature can overestimate the performance of clinical instruments. The fact that the temperature-dependent behaviour is constant over all of the heat-treated systems shows that it is not the system, but a material property phenomenon. Clinicians are encouraged to pay attention to the fact that endodontic instruments working in inflamed teeth or under the conditions that produce frictional heating can have lower levels of fatigue, which should pay more attention to the manifestations of instrument weariness and implement more lenient rules of endodontic instruments. Future studies are needed to determine the interaction between temperature, canal geometry and instrumentation method and the protective interventions including temperature-controlled irrigation procedures. Knowledge about temperature-dependent mechanical behavior is one significant advance in evidence-based instrument selection and use guidelines that can increase patient safety and treatment outcomes.

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AUTHOR'S CONTRIBUTION

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Original Research

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Push-out bond strength and fracture modes of MTA and bioactive glass-based sealers using different final irrigants: an in-vitro study

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Abstract

INTRODUCTION. The bond between gutta-percha and sealer is crucial for successful root canal (RC) filling, requiring sealers with optimal physical, chemical, and biological characteristics. Newer sealers aim to improve clinical outcomes, especially when smear layer removal enhances sealer flow and adhesion. This study compares the push-out bond strength (POBS) and failure modes of an MTA-based bioceramic sealer and a bioactive glass (BG)-based sealer using four different final irrigants.

MATERIALS AND METHODS. Eighty single-rooted mandibular premolars were decoronated to a length of 16 mm and prepared using ProTaper Gold rotary files with intermittent irrigation using 5.25% NaOCl. Samples were categorised into two main groups depending on the sealer employed [*n* = 40 (Nishika Canal Sealer BG and MTA Fillapex)] and further into four sub-groups according to the final irrigant [*n* = 10 (10% glycolic acid, MTAD, 18% Etidronic acid and normal saline). Following obturation with gutta-percha, the specimens were incubated at 37°C and 95% humidity. POBS was evaluated using a universal testing machine, and failure modes were analysed under a scanning electron microscope.

RESULTS. POBS obtained from the study were in the following order: Nishika Canal Sealer BG + Etidronic acid > MTA Fillapex + etidronic acid > Nishika canal sealer BG + glycolic acid > MTA Fillapex + glycolic acid > Nishika canal sealer BG + Normal saline > MTA Fillapex + MTAD > MTA Fillapex + normal saline > Nishika canal sealer BG + MTAD.

CONCLUSIONS. All irrigants used allowed proper setting of both sealers. This study indicates that the choice of chelating agent affects bond strength, with etidronic acid showing the highest dislodgement resistance for both sealers, while MTAD showed the lowest.

Keywords: bioactive glass, etidronic acid, MTA fillapex, nishika canal sealer BG, pushout bond strength

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Прочность сцепления на выдавливание и типы разрушения герметиков на основе MTA и биологически активного стекла при использовании различных финишных ирригантов: in-vitro исследование

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Резюме

ВВЕДЕНИЕ. Связь между гуттаперчей и герметиком имеет решающее значение для успешного пломбирования корневого канала, что требует использования герметиков с оптимальными физическими, химическими и биологическими свойствами. Новые герметики направлены на улучшение клинических результатов, особенно когда удаление слоя шмара повышает текучесть и адгезию герметика. Настоящее исследование сравнивает прочность сцепления на выдавливание (POBS) и типы разрушения биоцерамического герметика на основе MTA и герметика на основе биологически активного стекла (BG) при использовании четырех различных финишных ирригантов.

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МАТЕРИАЛЫ И МЕТОДЫ. В исследование было включено 80 однокорневых премоляров нижней челюсти, декоронированных до длины 16 мм и подготовленных с использованием ротационных файлов ProTaper Gold с промежуточным орошением 5,25% раствором NaOCl. Образцы были разделены на две основные группы в зависимости от используемого герметика [*n* = 40 (Nishika Canal Sealer BG и MTA Fillapex)] и далее на четыре подгруппы по типу финишного ирриганта [*n* = 10 (10% гликолевая кислота, MTAD, 18% этидроновая кислота и физиологический раствор)]. После пломбирования гуттаперчей образцы инкубировались при 37°C и влажности 95%. Прочность сцепления на выдавливание оценивали с помощью универсальной испытательной машины, а типы разрушения анализировали с помощью сканирующего электронного микроскопа.
РЕЗУЛЬТАТЫ. Порядок POBS в исследовании был следующим: Nishika Canal Sealer BG + этидроновая кислота > MTA Fillapex + этидроновая кислота > Nishika Canal Sealer BG + гликолевая кислота > MTA Fillapex + гликолевая кислота > Nishika Canal Sealer BG + физиологический раствор > MTA Fillapex + MTAD > MTA Fillapex + физиологический раствор > Nishika Canal Sealer BG + MTAD.
ВЫВОДЫ. Все использованные ирриганты обеспечивали адекватное затвердение обоих герметиков. Исследование показывает, что выбор хелатирующего агента влияет на прочность сцепления: этидроновая кислота обеспечивала наибольшее сопротивление выдавливанию для обоих герметиков, тогда как MTAD показал наименьшее.

Ключевые слова: биологически активное стекло, этидроновая кислота, MTA Fillapex, Nishika Canal Sealer BG, прочность сцепления на выдавливание

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INTRODUCTION

A successful root canal (RC) treatment depends on appropriate biomechanical preparation, effective irrigation techniques, and high-quality obturation to ensure a three-dimensional hermetic seal of the RC system. When used alongside gutta-percha, endodontic sealers help eliminate imperfections such as grooves and lateral depressions that gutta-percha alone cannot fill. This combination prevents the entry of microbes or other contaminants into the RC, reducing the likelihood of inflammation and improving the chances of treatment success [1]. The monoblock concept suggests that the RC obturation material and the dentin of the RC wall together create an integrated structure. Therefore, using materials that bond seamlessly with dentin can potentially enhance the fracture resistance of the root and minimise microleakage [2].

Mineral trioxide aggregate (MTA) is a water-based cement that is derived from Type I Portland cement. MTA Fillapex is a recently introduced MTA-based RC sealer. The design of this sealer is based on the incorporation of MTA in its chemical composition. One of the key properties attributed to the MTA Fillapex sealer is its alkaline pH, which is believed to contribute to its antibacterial activity [3]. Bioceramic-based materials have recently emerged as endodontic solutions, serving both as repair cements and root canal sealers. These materials are characterised by their alkaline pH, antibacterial properties, radiopacity, biocompatibility, and their potential to promote hydroxyapatite formation, which enhances the bond between dentin and the filling materials. However, conventional bioceramic sealers present some drawbacks, including challenges in handling, higher cytotoxicity in the freshly mixed state, long setting time, and difficulty in removal during retreatment. To address these limitations, next-generation bioactive glass-based bioceramic sealers were developed. One such material, Nishika Canal Seal Bioactive Glass (CS BG) (Nippon Shika Yakuhin, Yamaguchi, Japan), is a newly introduced BG-based RC sealer [4].

The BG-based bioceramic sealer exhibits capabilities to form hydroxyapatite-like precipitation, biocompatibility, sealing potential and removability, and they have the suitability of being applied to both hard and soft tissue [4]. Smear layer removal during chemo-mechanical preparation of the RC has been proposed by the use of final irrigants. Eradication of the smear layer improves the permeability of the dentinal tubules and also enhances the adaptability of the endodontic filling materials. However, there is no single irrigant capable of removing both the organic and inorganic constituents of the smear layer [5].

Although Ethylenediaminetetraacetic acid (EDTA) and citric acid are widely in use, HEBP (1-hydroxyethylidene-1,1-bisphosphonate), also referred as etidronate or etidronic acid, has gained attention as a promising alternative. Its appeal lies in its enhanced efficacy, as it does not interact with sodium hypochlorite (NaOCl). Furthermore, HEBP is non-toxic and has been systematically employed in the treatment of bone ailments [6]. Like EDTA, it has a chelating characteristic and is frequently used as an adjuvant in personal care and household products such as soaps. HEBP and NaOCl could be mixed and used as a single solution as these components do not interact, which is referred as ‘continuous chelation’ [7]. A prior study demonstrated that HEBP led to a slight, dose-dependent reduction in the chlorine content of NaOCl, while the ability of NaOCl to

eradicate microbes remained intact. Furthermore, according to several studies, this combined solution has a potential of removing hard tissue debris and smear layer and exhibits favourable effects on the bonding of RC sealer [8; 9].

A mixture containing 3% doxycycline, a bacteriostatic antibiotic from the tetracycline group, 4.25% citric acid, a demineralising agent, and 0.5% polysorbate 80 (Tween 80), a detergent that reduces surface tension and enhances the antimicrobial efficacy of irrigation solutions, is commercially available as a bicomponent product under the name Biopure MTAD (Dentsply). The removal of the smear layer by the use of MTAD was improved when low concentrations of NaOCl were employed as an intracanal irrigant during instrumentation, followed by MTAD as the final irrigant [10]. Glycolic acid (GA) is an alpha-hydroxy acid obtained from sugarcane and other sweet vegetables. It is a colourless, odourless compound with a two-carbon molecular structure and excellent water solubility. GA has demonstrated promise as a final irrigant in RC therapy, as it efficiently eliminates the smear layer without altering the properties of dentinal structure when used at a low pH of around 2 [11].

It has been established that contact with different RC irrigants during setting time may influence the push-out bond strength (POBS) of RC sealers, and this has been attributed to a variety of factors related to the compositions of the sealers or the properties of the RC irrigants [12]. Several studies have shown that certain chelating agents inadvertently affect the properties of calcium silicate-based sealers, attributing this to affecting the sealers' setting reaction and their chemical bonding to dentine [13]. Though a large number of in vitro studies are published, no consensus exists evaluating the POBS of BG-based and MTA-based sealer when used in conjunction with irrigants used in chelating agents like HEBP, glycolic acid and MTAD. Therefore, the present investigation aimed to compare the POBS and fracture mode analysis of an MTA-based and a BG-based endodontic sealer under the influence of final irrigants, including etidronic acid, GA, MTAD, and normal saline.

MATERIALS AND METHODS

The present in-vitro investigation was done at the Department of Conservative Dentistry & Endodontics, Mar Baselios Dental College, Kothamangalam, Kerala. The study was approved by the Institutional Ethics Committee (IEC/MBDC/CONS/PG/1/2022). POBS testing was done in Rubber Park, Nellad, Ernakulam. The sample size (n) = 10 for each group, which was calculated using SPSS version 17.0 software. The total sample size was 80. The samples intended for conducting

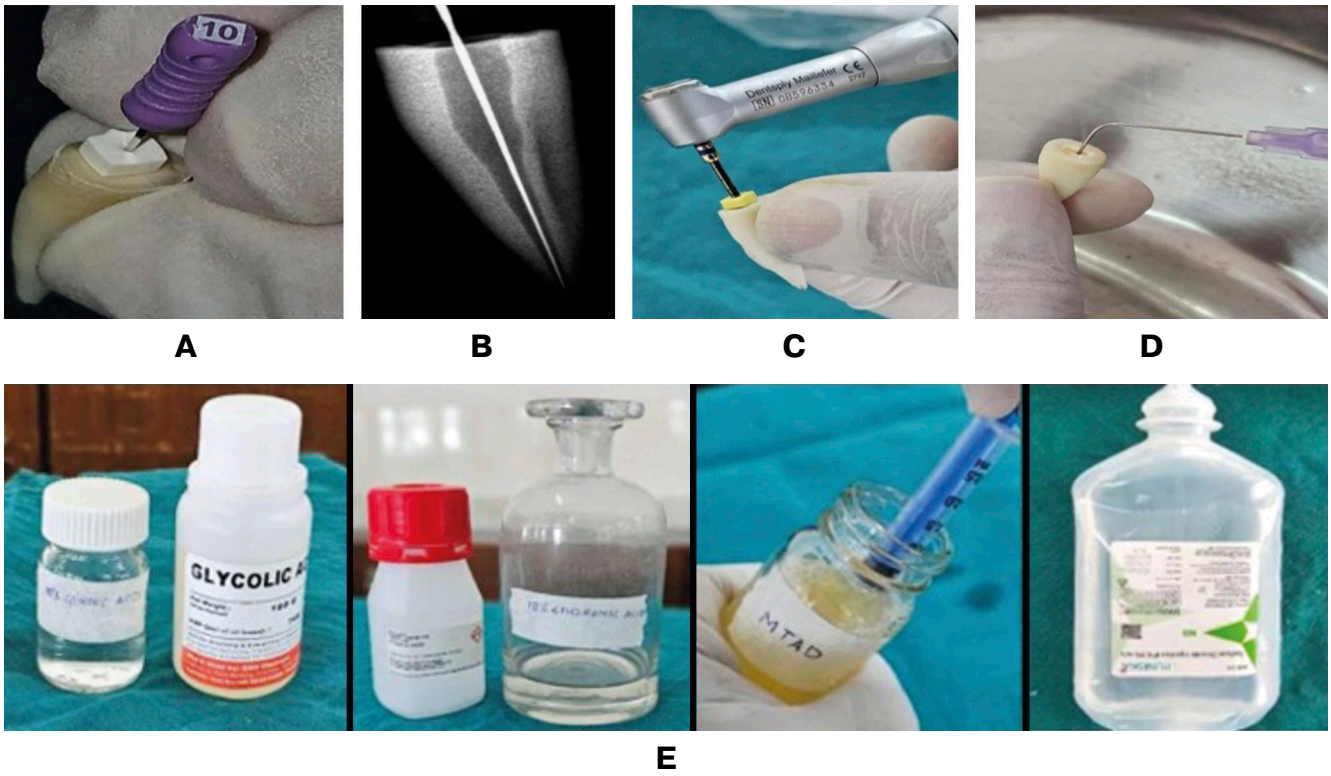


Fig. 1. Instrumentation and biomechanical preparation of the specimens: *A* – negotiating the canal with number 10 size K-file; *B* – working length determination; *C* – cleaning and shaping up to protaper file size F3; *D* – irrigation with NaOCl; *E* – final irrigants: 10% glycolic acid, 18% etidronic acid, MTDA, normal saline

Рис. 1. Инструментальная и биомеханическая подготовка образцов: *A* – прохождение канала К-файлом № 10; *B* – определение рабочей длины; *C* – очистка и формирование канала до размера файла ProTaper F3; *D* – ирригация раствором NaOCl; *E* – заключительные ирригационные растворы: 10% гликолевая кислота, 18% этидроновая кислота, MTDA, физиологический раствор

the study were computed using the G*power software (version 3.1.9.7, Heinrich Heine-Universität Düsseldorf, Düsseldorf, Germany) with an effect size of 0.634 based on a previous study [14], α error of 0.05, statistical power of 0.98, and number of groups = 8.

Fully intact, recently extracted single-rooted human mandibular premolar teeth were included. The teeth with surface defects and cracks, calcified roots, accentuated curvatures, open apices, multirooted teeth, endodontically treated teeth, and restored and fractured teeth were excluded.

Division of specimens

Eighty single-rooted human mandibular premolars were collected and decoronated, then categorised into two main groups depending on the sealer used during obturation. Group A consisted of MTA-based bioceramic sealer (MTA Fillapex – Angelus). Group B comprised BG-based bioceramic sealer (Nishika CS BG). Each group was subdivided into four subgroups based on the final irrigant used, which were: Glycolic acid (subgroup A), MTAD (subgroup B), Etidronic acid (subgroup C), and Normal Saline (subgroup D).

Specimen preparation

The premolars were decoronated at the level of CEJ to provide 16 mm of root length. The root canal was then negotiated with a stainless-steel endodontic K-file – size 10, and the working length was determined by taking radiographs. Standardised biomechanical preparation of the RCs was completed using Protaper gold rotary files in a crown-down technique till F3. Subsequently, RCs were irrigated with 2 ml of 5.25% NaOCl solution intermittently. They were then divided into groups depending on the endodontic sealer used and four subgroups according to the final irrigant used (Fig. 1). The specimens in each subgroup were irrigated with the respective irrigant, and restorative procedures were started.

Restorative procedures

Group A: The MTA fillapex from Angelus comes in a dual syringe. The plunger was pushed to extrude the material in a 1:1 ratio and coated inside the canal with a lentulo-spiral. The RC was then obturated with gutta-percha.

Group B: NISHIKA CS BG is also a two-paste system, dispensed and mixed using a plastic spatula, and on reaching the ideal consistency, it was filled in the canal with a lentulospiral and obturated with a GP cone.

The samples are coronally sealed with Cavit G and stored in an incubator at 37°C and 95% relative humidity for a week before the POBS assessment. After removal from the incubator, the root specimens in each group are fully embedded in clear acrylic. Each root is then horizontally sectioned into 2 mm thick slices, approximately 7 mm from the root apex, utilising a hard tissue microtome (Fig. 2).

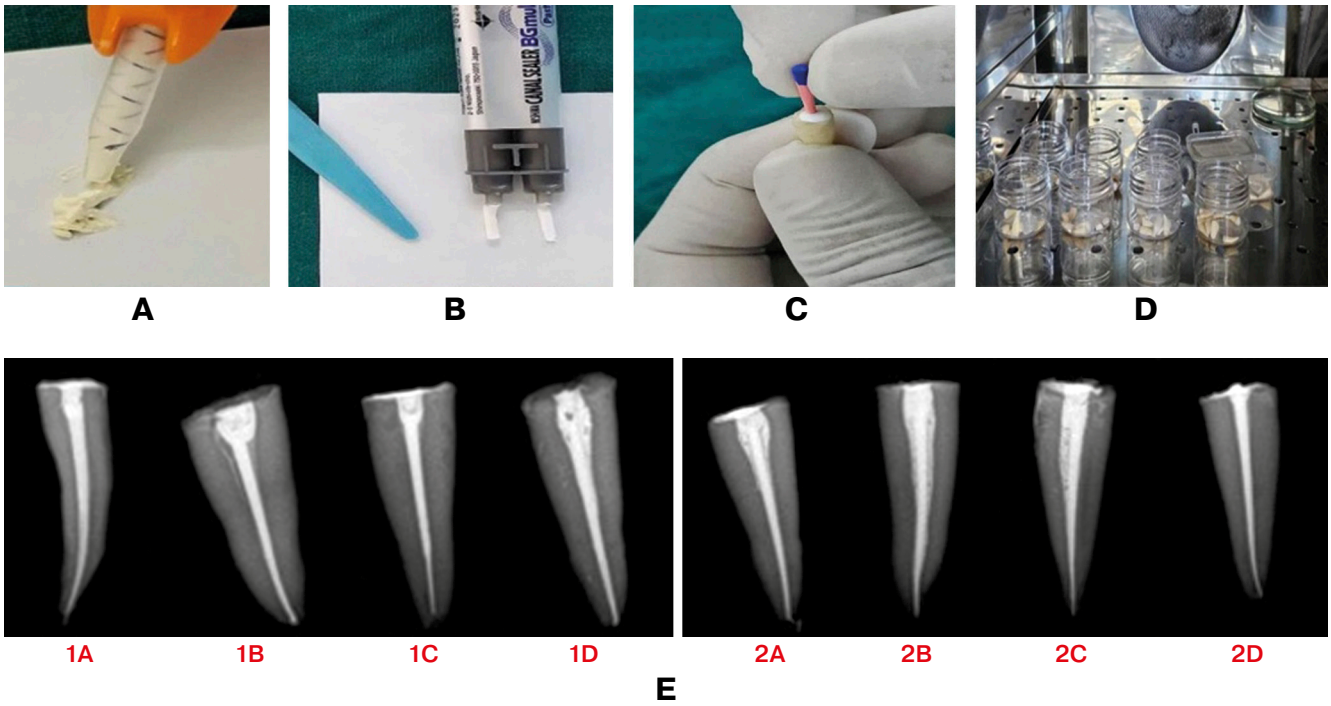


Fig. 2. Restorative procedure followed by incubation of the specimens: *A* – MTA Fillapex extruded through the spiral tip; *B* – manipulation of Nishika canal sealer BG; *C* – obturation with F3 size gutta-percha cone; *D* – specimens kept in incubator at 38°C and 100% relative humidity for 7 days; *E* – specimen X-ray after obturation

Рис. 2. Восстановительная процедура с последующей инкубацией образцов: *A* – экструзия MTA Fillapex через спиральный наконечник; *B* – манипуляции с канальным герметиком Nishika BG; *C* – обтурация гуттаперчевым конусом размера F3; *D* – образцы выдерживались в инкубаторе при температуре 38°C и 100% относительной влажности в течение 7 дней; *E* – рентгеновский снимок образца после обтурации

Pushout bond strength testing

each specimen is subjected to a POBS evaluation by means of a universal testing machine applying a dislodging force in apico-coronal direction at a crosshead speed of 2 mm/min until debonding occurs. The sequential procedure involved is illustrated in Fig. 3.

Analysis of failure modes

debonded specimens, one from each subgroup, were now evaluated under a scanning electron microscope (SEM) to analyse the failure modes, i.e. adhesive, cohesive, or mixed failure.

Statistical analysis

The one-way analysis of variance (ANOVA) was applied to compare the statistically significant differences between the means of the POBS among MTA Fillapex and Nishika CS BG when irrigated with GA, MTAD, etidronic acid and normal saline using SPSS 22.0 software.

RESULTS

The mean POBS was highest for MTA Fillapex with etidronic acid (2.317 ± 1.596 MPa) followed by MTA Fillapex with GA (1.8633 ± 1.32084 MPa). The least mean pushout bond strength value was noted in MTA Fillapex with normal saline group (0.987 ± 0.90372 MPa) (Table 1).

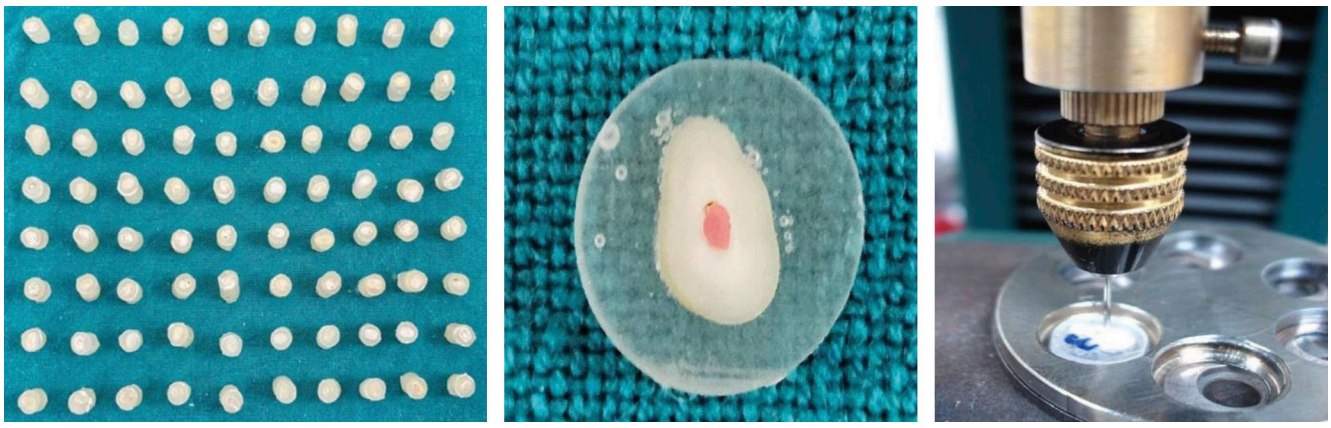
The mean pushout bond strength was least for Nishika Canal Sealer BG with MTAD (0.9818 ± 0.89125 MPa). The mean pushout bond strength was the highest for Nishika Canal Sealer BG with Etidronic acid (2.70001 ± 1.72824 MPa) followed by Nishika Canal Sealer BG with glycolic acid (1.973 ± 0.95195 MPa) (Table 2).

The overall pushout bond strength of the study specimens from the highest to the lowest were as follows: Nishika Canal Sealer BG + Etidronic acid > MTA Fillapex + etidronic acid > Nishika canal sealer BG + glycolic acid > MTA Fillapex + glycolic acid > Nishika canal sealer BG + Normal saline > MTA Fillapex + MTAD > MTA Fillapex + normal saline > Nishika canal sealer BG + MTAD.

Statistical analysis among the groups (Table 3) showed statistically insignificant difference in values (p-value > 0.05) between the groups.

Statistical analysis among the group (Table 4) showed a statistically significant difference in values (p-value < 0.05) between the groups.

MTA Fillapex + Etidronic Acid > MTA Fillapex + Glycolic Acid > MTA Fillapex + MTAD > MTA Fillapex + Normal Saline (Fig. 4).



A **B** **C**

Fig. 3. Evaluation of pushout bond strength using universal testing machine: *A* – specimens after decoronation mounted in acrylic blocks; *B* – 2 mm thick slice of specimen; *C* – specimen in the universal testing machine

Рис. 3. Оценка прочности сцепления на выдавливание с использованием универсальной испытательной машины: *A* – образцы после удаления верхнего слоя, закрепленные в акриловых блоках; *B* – срез образца толщиной 2 мм; *C* – образец в универсальной испытательной машине

Table 1. Mean push-out bond strength obtained in Group 1

Таблица 1. Среднее значение прочности сцепления на выдавливание, полученное в группе 1

Sealer	N	Mean	Standard Deviation	Standard Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
MTA Fill Apex with Glycolic Acid	10	1.8633	1.32084	0.41769	0.9184	2.8082	0.42	4.97
MTA Fill Apex with MTAD	10	1.0815	1.13771	0.35977	0.2676	1.8954	0.03	3.50
MTA Fill Apex with Etidronic Acid	10	2.3170	1.59600	0.50470	1.1753	3.4587	0.29	6.03
MTA Fill Apex with Normal Saline	10	0.9870	0.90372	0.28578	0.3405	1.6335	0.00	3.18
Total	40	1.5622	1.33829	0.21160	1.1342	1.9902	0.00	6.03

Table 2. Mean push out bond strength obtained in Group 2

Таблица 2. Среднее значение прочности сцепления на выдавливание, полученное в группе 2

Sealer	N	Mean	Standard Deviation	Standard Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Nishika Canal Sealer BG with Glycolic Acid	10	1.9739	0.95195	0.30103	1.2929	2.6549	0.19	3.49
Nishika Canal Sealer BG with MTAD	10	0.9818	0.89125	0.28184	0.3442	1.6194	0.03	2.50
Nishika Canal Sealer BG with Etidronic Acid	10	2.7001	1.72824	0.54652	1.4638	3.9364	0.34	6.44
Nishika Canal Sealer BG with Normal Saline	10	1.0871	0.86692	0.27414	0.4669	1.7073	0.34	2.89
Total	40	1.6857	1.32635	0.20971	1.2615	2.1099	0.03	6.44

Table 3. Comparison of push out bond strength in 4 groups of MTA Fillapex by ANOVA

Таблица 3. Сравнение прочности сцепления на выдавливание в четырех группах MTA Fillapex с использованием ANOVA

Group	Sum of Squares	df	Mean Square	F	p-value
Between Groups	12.223	3	4.074	2.545	0.071
Within Groups	57.626	36	1.601		
Total	69.849	39			

Note: $p > 0.05$ – not significant

Примечание: $p > 0{,}05$ – незначимо

Table 4. Comparison of pushout bond strength in 4 groups of Nishika canal sealer BG by ANOVA

Таблица 4. Сравнение прочности сцепления на выдавливание в четырех группах герметика Nishika Canal Sealer BG с использованием ANOVA

Group	Sum of Squares	df	Mean Square	F	p-value
Between Groups	19.659	3	6.553	4.819	0.006*
Within Groups	48.950	36	1.360		
Total	68.609	39			

Note: * Significant

Примечание: * Статистически значимо

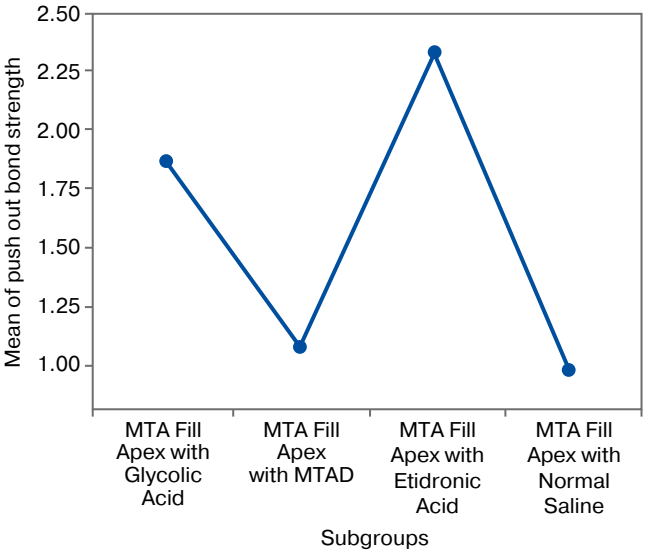


Fig. 4. Graphical illustration of pushout bond strength in 4 groups of MTA Fillapex

Рис. 4. Графическое изображение прочности сцепления на выдавливание в четырех группах MTA Fillapex

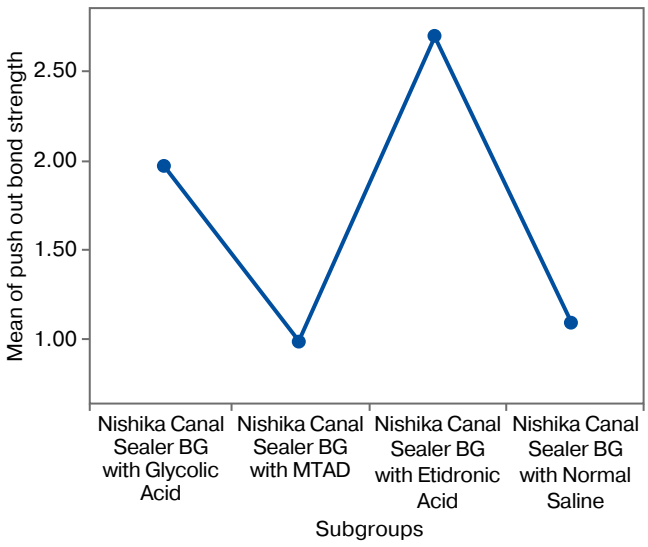


Fig. 5. Graphical illustration of pushout bond strength in 4 groups of Nishika CS BG

Рис. 5. Графическое изображение прочности сцепления на выдавливание в четырех группах Nishika CS BG

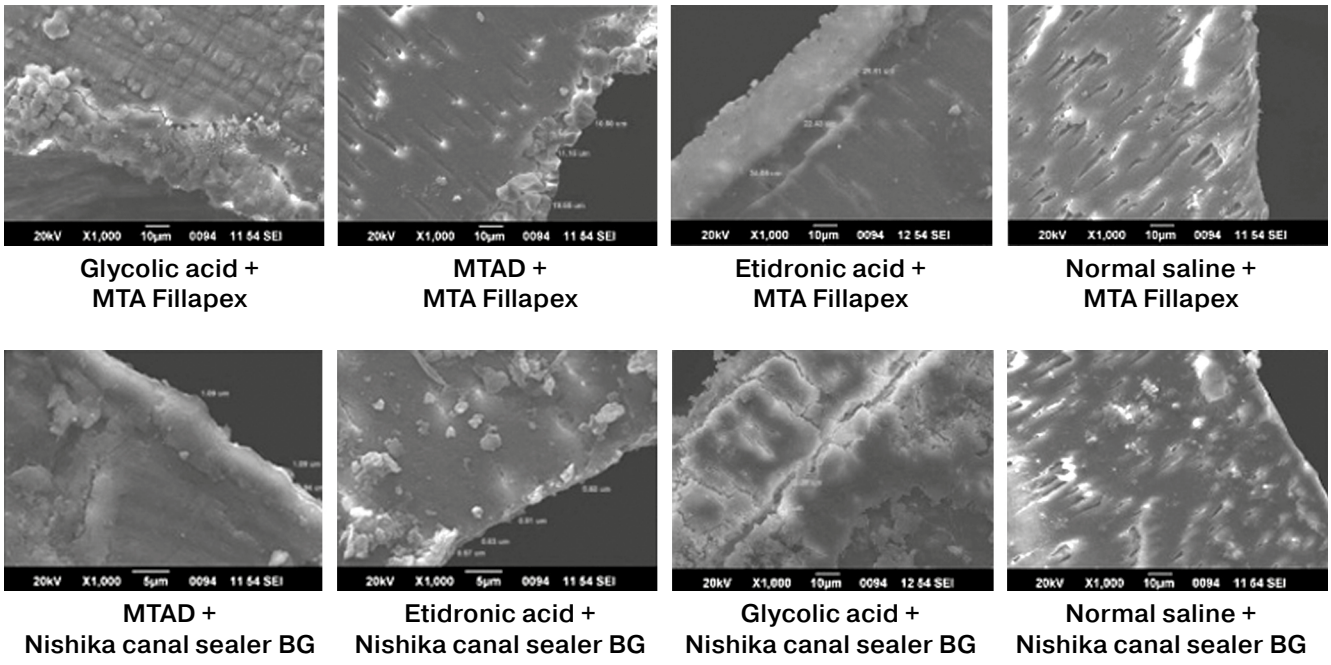


Fig. 6. SEM evaluation of the failure mode of the specimens

Рис. 6. Оценка характера разрушения образцов с использованием СЭМ

Nishika CS BG + Etidronic Acid > Nishika CS BG + Glycolic Acid > Nishika CS BG + Normal Saline > Nishika CS BG + MTAD (Fig. 5).

Considering the failure mode analysis, the predominant pattern of failure was observed between the resin cement and the RC, which indicated that the weak bond displayed between the resin cement and the root dentine (Fig. 6).

DISCUSSION

RC sealers are required to seal the gap between the dentinal wall and the filling material interface. Additionally, they often can penetrate the lateral canals and dentinal tubules, which is crucial for the penetration of sealer cements into dentinal tubules, thereby increasing their surface contact with the RC dentin, and thus improving the sealing ability [15]. Sealer plugs within the dentinal tubules create a mechanical interlock, enhancing the retention of the filling material [16; 17]. The apical 3 to 6 mm region of an RC is the most important area for the placement of an RC sealer. Therefore, RC sealers with high biocompatibility and supreme sealing abilities are warranted [18].

According to the study results, Nishika CS BG has shown superior sealing properties in all the groups. This could be because when the RC is sealed with CS BG, the material comes into contact with a minimal amount of dentinal fluid. During the hardening process, the CS BG releases ions from its matrix, including those from the non-bioactive glass component of the sealer. This ion release helps maintain a pH of approximately 10 in the surrounding dentinal fluid, which is optimal for hydroxyapatite (HAp) formation on the surface of the bioactive glass [2]. The bioactive glass reacts with the dentinal fluid, releasing essential ions such as silica, calcium, phosphorus, and sodium. This results in the formation of a silica-rich gel on the BG surface, which interacts with the ions of the dentinal fluid. This results in the formation of crystals that resemble hydroxyapatite on the surface of the BG, and HAp-like tags grow into the dentinal tubules. This results in a more effective bonding between CS BG and dentinal tubules [4].

Washio et al. [4] documented that Nishika CS BG exhibits properties and dentin reactions similar to those of other bio-ceramic sealers. The high adaptation of Nishika Canal Sealer BG enhances its infiltration into dentinal tubules. Additionally, Akcay et al. [19] and Caceres et al. [20] reported that Nishika CS BG penetrate dentinal tubules more effectively than AH Plus TM, potentially contributing to their prolonged retention and thereby higher pushout bond strength when used as an endodontic sealer. Based on the findings of the study, MTA Fillapex has also shown comparable sealing properties to Nishika CS BG. The elevated alkalinity of MTA-based sealer solutions results from the pozzolanic reaction and the formation of calcium hydroxide during hydration. When calcium hydroxide dissociates into OH- and Ca2+, it not only contributes to antibacterial properties but also serves a pivotal role in promoting osteogenic potential. The Ca2+ supports the regeneration of bone tissue, enhancing the material's ability to encourage healing and tissue growth around the root canal [21].

Nikhil et al. used a confocal laser microscope to compare the penetration depth of MTA Fillapex and AH Plus sealers into dentinal tubules [22]. They found that MTA Fillapex sealer penetrated more extensively into the dentinal tubules. Also, MTA Fillapex sealer contains

nanoparticles of MTA powder and resins, which contribute to its excellent flow properties, allowing its easy penetration into the main and lateral canals of the root and the dentinal tubules. The hydration process generates several by-products, such as calcium silicate hydrate (CSH) gel, ettringite (hexacalcium aluminate trisulfate hydrate), portlandite (calcium hydroxide), and calcium monosulfoaluminate/calcium monocarboaluminate. The CSH gel, being sticky and porous, has good flow characteristics and easily adheres to guttapercha. It solidifies within 4–6 hours, with complete setting occurring over a few days. Phosphate formation is noted at the dentin–MTA interface, and radiographic and SEM evaluation of this layer show similarities to hydroxyapatite, though with a slightly altered calcium-to-phosphate ratio, which reflects excellent adaptation at the margins [23].

This study compared the smear layer removal ability as well as sealing ability of 3 irrigating solutions, namely 18% Etidronic acid, 10% glycolic acid and MTAD. According to the results, the highest sealing ability is shown by etidronic acid, followed immediately by glycolic acid and the lowest value is shown by MTAD. EDTA is one of the most commonly used endodontic irrigants because of its potential to effectively eliminate the smear layer from the dentin surface [24]. Thus, it is an essential agent for cleaning and preparing the root canal for subsequent procedures. However, it has several drawbacks. Prolonged exposure to EDTA, especially beyond three minutes, can lead to collagen denaturation and erosion of peritubular and intertubular dentin, affecting the mechanical strength of the dentinal wall and potentially affecting the long-term treatment outcome. These alterations in the mineral composition of dentin may also compromise its adhesive characteristics, potentially weakening the bond between the endodontic sealer and the dentin, which could negatively impact the canal's sealing effectiveness [11].

Etidronic acid is particularly valuable in endodontic treatments is particularly valuable due to its capacity to inhibit calcium release and reduce the precipitation of calcium hydroxyapatite crystals. This helps manage conditions involving bone resorption in the periapical area, such as periapical lesions or infections [25]. Research has demonstrated that it has a weak chelating property when used alone. This characteristic could be advantageous when using NaOCl and HEDP as a single irrigant during and after RC treatment. Additionally, this approach proves to be as effective as the traditional NaOCl-EDTA sequence in reducing smear layer formation during automated biomechanical instrumentation. Consequently, the NaOCl-HEBP solution can be used as the sole irrigant throughout and after instrumentation [26]. Tartari et al. reported the impact of a continuous chelation protocol utilising 18% HEDP [27]. Their study found that immersing root canal samples for 15 minutes in either 2.25% NaOCl alone or a mixture of 5% NaOCl with 18% HEDP resulted in greater proteolytic activity as opposed to using a Na4EDTA–NaOCl mixture or saline. This is because of the continuous chelation, where HEDP binds calcium ions, boosting NaOCl's efficacy without compromising its antimicrobial properties. As stated by Tartari et al., HEBP, a weaker chelating agent, leads to a smaller reduction in microhardness compared to EDTA, suggesting that the chelating strength of a substance is closely linked to hardness reduction [27].

In this study, Glycolic acid at a concentration of 10% was used, and it had promising results compared to 18% etidronic acid. Glycolic acid, when used as a single irrigant, demonstrates enhanced antibacterial efficacy due to its low pH, high solubility, and the fact that its derivatives are utilised in the production of antibiotics. Furthermore, glycolic acid can effectively "remove the smear layer" by decalcifying the dentin and eliminating the inorganic components of the smear layer [28]. When applied to dentin, higher GA concentrations were associated with a reduced apatite-to-collagen ratio. However, the flexural strength of dentin remained unaffected by changes in GA concentration [29]. Moreover, the small size of glycolic acid (GA) molecules and their acidic pH facilitate effective demineralisation of root dentin, leading to efficient smear layer elimination from dentinal walls, which is a key characteristic of a chelating solution [30].

According to the findings of the study, MTAD and normal saline have shown the lowest bond strength value than the other irrigants, i.e 18 % etidronic acid and 10% glycolic acid. This could be explained based on the findings of Sayin et al. in which they examined the time-dependent decalcifying effects of NaOCl, CHX, and MTAD, and found that MTAD exhibited a significantly lower decalcifying effect [31]. The study also revealed that MTAD resulted in lower bond strength values than other irrigants. This might be because of its reduced decalcifying effect, which leads to insufficient elimination of the smear layer [32].

This study focuses on single-rooted mandibular premolars because they have a single oval canal cross-section, which is difficult to clean effectively with a rounded cross-section endodontic file. Consequently, significant areas of the RC walls remain untreated, resulting in the accumulation of hard-tissue debris in the irregularities of the RC space. According to previous studies, these untreated areas may account for up to 35% of the total RC walls. Therefore, the effectiveness and functionality of the irrigants would be more reliable [28]. In this study, 5 mL of 2.5% NaOCl was applied between each pair of successful files in the control group, as it is considered the gold standard endodontic irrigant due to its antibacterial properties and its ability to break down necrotic pulp tissue and neutralise bacterial byproducts. A study by Zand et al. demonstrated that 2.5% NaOCl effectively disintegrates organic tissues and denatures bacterial toxins [33]. Additionally, NaOCl has a significant impact even in areas that have not been instrumented. However, current literature shows that NaOCl is ineffective at removing the "smear layer" [28].

In this study, a SEM at X1000 magnification was used to detect the modes of failure, as it may yield subjective results depending on the areas selected for examination and the operator's interpretation of

the data. To ensure consistency, images were captured at a standardised distance of 7 mm from the root apex [34]. The SEM analysis showed that most specimens irrigated with etidronic acid exhibited cohesive failure, occurring within the sealer layer, while the sealer-dentin interface remained intact. This might be because of the potential use of etidronic acid and NaOCl together as a combination, which preserves the tissue-dissolving properties of NaOCl. As a result, the sealer may penetrate more deeply into the tubules, offering a more effective seal [26].

Mixed failure was seen in the specimens irrigated with MTAD, where failure occurred both at the sealer-dentin interface and between the sealer particles. This aligns with the POBS results, which disclosed the lowest value for MTAD. This could be because of the reduced decalcifying effect of MTAD, leading to insufficient elimination of the smear layer. As a result, the sealer particles were unable to penetrate efficiently into the dentinal tubules, resulting in poor adhesion [35]. This study is invariably associated with the heterogeneity involving a single-rooted tooth. Further studies are warranted to assess the effect of irrigants and sealers on the pushout bond strength values in multirooted teeth, and also to understand the chemical reactions between the irrigation solutions and the sealers Nishika CS BG and MTA Fillapex. This in vitro assay for the assessment of the POBS of endodontic irrigants and sealers cannot duplicate the oral environment when using endodontic irrigants. In a clinical setting, there is a higher chance of washout by the injection pressure of the irrigants.

CONCLUSION

Within the limitations of this in vitro investigation, the following conclusions are made: RC obturation using Nishika CS BG as endodontic sealer and 18% etidronic acid as RC irrigant showed the highest POBS value. Nishika CS BG showed the highest bond strength value as opposed to MTA Fillapex, which was not statistically significant. 18% etidronic acid as an endodontic irrigant documented the highest bond strength value in comparison with 10% GA, which was not statistically significant. 18% etidronic acid and 10% GA showed the highest bond strength value as opposed to MTAD, which was statistically significant.

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ВКЛАД АВТОРОВ

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Original Research

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Prevention of drug-induced osteonecrosis of the jaw in patients with osteoporosis: clinical recommendations

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Abstract

INTRODUCTION. Drug-induced osteonecrosis of the jaw (MRONJ) is one of the most severe complications of antiresorptive therapy in patients with osteoporosis, significantly impairing the quality of life. Despite the growing awareness of doctors, the frequency of MERS with prolonged use of bisphosphonates or denosumab remains in the range of 0.8–12.0%.

The purpose of this work was to develop a comprehensive preventive strategy based on the analysis of risk factors aimed at reducing the incidence of MRONJ in patients with osteoporosis.

MATERIALS AND METHODS. A retrospective analysis of the medical records of 267 patients who received antiresorptive therapy at the Yizhida Dental Clinic in Shangqiu (China) from 2019 to 2023 was conducted. Dental status, biochemical markers of bone metabolism, treatment regimens, and concomitant risk factors were assessed. Various preventive approaches were compared. The results show that dental screening and oral sanitation before starting antiresorptive treatment reduces the risk of MERS by 72.6%.

RESULTS. Maintaining the level of β-CrossLaps above 150 pg/ml was associated with a 63.8% reduction in risk. Individualized surgical interventions, taking into account risk stratification, reduced the incidence of postoperative complications from 11.1% to 0% (with the combined protocol). The comprehensive preventive model provided a significant reduction in the 4-year cumulative incidence of MRONJ from 7.1% to 1.1%, while the effectiveness of the main antiresorptive therapy was not affected.

CONCLUSIONS. The analysis makes it possible to recommend a multi-level prevention system, including dental screening, biomarker monitoring, and surgical tactics adapted to individual risk, as an effective strategy for preventing MERS in patients with osteoporosis.

Keywords: drug-induced osteonecrosis of the jaw, osteoporosis, bisphosphonates, denosumab, prevention, risk factors, dental screening

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Профилактика медикаментозного остеонекроза челюсти у пациентов с остеопошозом: клинические рекомендации

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Резюме

ВВЕДЕНИЕ. Медикаментозный остеонекроз челюстей (МОНЧ) представляет собой одно из наиболее тяжелых осложнений антирезорбтивной терапии у пациентов с остеопорозом, значительно ухудшающее качество жизни. Несмотря на рост осведомленности врачей, частота медикаментозный остеонекроз при длительном приеме бисфосфонатов или деносумаба остается в пределах 0,8–12,0 %.

ЦЕЛЬ. Целью настоящей работы стало формирование комплексной профилактической стратегии на основе анализа факторов риска, направленной на снижение частоты медикаментозного остеонекроза челюстей у пациентов с остеопорозом.

МАТЕРИАЛЫ И МЕТОДЫ. Был проведен ретроспективный анализ медицинской документации 267 пациентов, получавших антирезорбтивную терапию в стоматологической клинике «Ичжида» г. Шанцю (КНР) в период с 2019 по 2023 г. Оценивались стоматологический статус, биохимические маркеры костного обмена, режимы терапии и сопутствующие факторы риска. Сравнивались различные профилактиче-

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ские подходы. Полученные результаты свидетельствуют, что проведение стоматологического скрининга и санации полости рта перед началом антирезорбтивного лечения снижает риск МОНЧ на 72,6 %.
РЕЗУЛЬТАТЫ. Поддержание уровня β-CrossLaps выше 150 пг/мл ассоциировалось со снижением риска на 63,8%. Индивидуализированные хирургические вмешательства с учетом стратификации риска позволили снизить частоту послеоперационных осложнений с 11,1 до 0 % (при комбинированном протоколе). Комплексная профилактическая модель обеспечила значительное снижение 4-летней кумулятивной частоты медикаментозный остеонекроза с 7,1 до 1,1 %, при этом эффективность основной антирезорбтивной терапии не пострадала.
ВЫВОДЫ. Проведенный анализ позволяет рекомендовать многоуровневую систему профилактики, включающую стоматологический скрининг, мониторинг биомаркеров и хирургическую тактику, адаптированную к индивидуальному риску, как эффективную стратегию предупреждения МОНЧ у пациентов с остеопорозом.

Ключевые слова: медикаментозный остеонекроз челюсти, остеопороз, бисфосфонаты, деносумаб, профилактика, факторы риска, стоматологический скрининг

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INTRODUCTION

Medication-related osteonecrosis of the jaw (MRONJ) is a serious clinical complication characterized by progressive destruction of the maxillofacial bone in patients receiving antiresorptive therapy in the absence of prior radiation exposure to the head and neck region. This pathological condition was first described in the early 2000s in association with bisphosphonate use and was subsequently confirmed as a significant medical problem with other agents, including denosumab and certain antiangiogenic drugs [1]. Despite increased clinician awareness and the implementation of preventive strategies, the risk of MRONJ varies substantially depending on indication and dosage: in patients with osteoporosis receiving standard (low) doses, the risk is extremely low (approximately 0.01–0.1%), whereas considerably higher rates are observed in oncology patients treated with high-dose regimens; in some oncologic cohorts, the risk may reach several percent [2–4]. This maintains MRONJ as a relevant public health issue and necessitates the development and implementation of effective prevention algorithms.

Current pharmacotherapy for osteoporosis implies long-term, often multiyear, administration of bisphosphonates and other antiresorptive agents, which, in combination with comorbidities and age-related changes, significantly increases the likelihood of osteonecrosis, particularly when invasive dental procedures are performed without adequate pre-treatment assessment and subsequent monitoring [5; 6].

The pathogenetic mechanisms underlying MRONJ remain the subject of ongoing debate and investigation; however, a central role is attributed to impaired bone remodeling due to excessive suppression of resorption, compromised microcirculation, reduced reparative capacity, and increased susceptibility to infection under conditions of continuous microtrauma to the oral mucosa [7]. Critical analysis of the literature indicates that the classical pathogenesis of osteonecrosis involves not only disruption of the osteoclast–osteoblast balance with direct effects on bone cells, but also multilevel drug-induced effects on endothelial cells, angiogenic factors, immune responses, and regulation of the oral microbiome. Together, these processes create a complex pathophysiological framework that requires a multifactorial approach to prevention [8]. Additional challenges in developing preventive strategies include individual genetic variability in antiresorptive drug metabolism, differences in the rate of drug accumulation in bone tissue, and heterogeneous safety profiles among various pharmacological classes used in osteoporosis management [9].

The terminology related to MRONJ has undergone significant evolution, shifting from the original term “bisphosphonate-related osteonecrosis of the jaw” to the broader and more accurate concept of “medication-related osteonecrosis of the jaw”, reflecting the expanding range of drugs capable of inducing this complication [10]. According to current recommendations of the American Association of Oral and Maxillofacial Surgeons, the diagnosis of MRONJ is established when three key criteria are met: current or previous treatment with antiresorptive or antiangiogenic agents; exposed bone, or bone that can be probed through a fistula in the maxillofacial region, persisting for more than 8 weeks; and no history of radiation therapy to the jaws or obvious metastatic involvement of the jawbones [2; 11].

Nevertheless, scientific debate continues regarding the need to expand or refine these criteria, particularly in light of emerging evidence on early radiological signs that may precede clinical manifestations and the existence of asymptomatic forms of the disease. This underscores the necessity for further improvement of diagnostic approaches and preventive strategies [12–14]. Comparable recommendations have also been proposed in the work of Otto et al. [15].

Analysis of the contemporary literature reveals several substantial gaps in research devoted to the pre-

vention of MRONJ. First, clear evidence-based algorithms for identifying patients at high risk of developing this complication prior to the initiation of antiresorptive therapy are lacking, which limits the personalization of preventive measures and the optimal allocation of healthcare resources [3; 16]. Second, validated biomarkers capable of accurately predicting the probability of MRONJ development and enabling timely modification of osteoporosis treatment regimens to reduce this risk have not yet been established [17]. Third, unified, internationally recognized protocols for the management of patients requiring dental interventions during antiresorptive therapy are absent, particularly with respect to different drug classes, duration of use, and individual patient-specific risk factors [16].

The relevance of the present study is determined by the need to develop a comprehensive, scientifically grounded system of preventive measures aimed at reducing both the incidence and severity of MRONJ in patients with osteoporosis receiving antiresorptive therapy. The proposed approach is based on the integration of interdisciplinary knowledge from endocrinology, dentistry, pharmacology, and clinical epidemiology, incorporating the most recent data on disease pathogenesis and risk determinants. The novelty of the present investigation lies in the development of algorithms for primary, secondary, and tertiary prevention of MRONJ adapted to different clinical scenarios, with the objective of preserving the therapeutic efficacy of anti-osteoporotic treatment while minimizing its complications. The proposed recommendations are intended to address existing gaps in scientific knowledge and clinical practice by providing clinicians with reliable and structured information to support evidence-based decision-making in the management of patients with osteoporosis.

MATERIALS AND METHODS

The study included 267 patients with a confirmed diagnosis of postmenopausal osteoporosis who were receiving antiresorptive therapy (alendronate, zoledronic acid, or denosumab). The investigation was conducted at the “Yizhida” Dental Clinic in Shangqiu, China, between 2019 and 2023. Patient enrollment was based on a retrospective and prospective review of medical records. Participants were allocated into groups according to the dental procedures performed and the level of MRONJ risk. An advantage of the selected methodology is the ability to evaluate both short- and long-term outcomes and to analyze the impact of multiple risk factors on the probability of osteonecrosis development in a heterogeneous osteoporotic population.

The study workflow comprised the following stages: patient screening according to inclusion and exclusion criteria; comprehensive baseline assessment including dental status evaluation, laboratory tests, and instrumental diagnostics; patient risk stratification; development and implementation of individualized preventive protocols in accordance with an assessment and consent algorithm for planned tooth extraction [18]; and longitudinal monitoring during antiresorptive therapy at predefined follow-up points. Delayed mucosal healing after tooth extraction has been reported in patients exposed to bisphosphonates and was considered during treatment planning [19]. Subsequently, MRONJ cases were recorded, associated risk factors were analyzed, statistical processing was performed, and clinical recommendations were formulated.

Data collection was carried out using an in-house electronic case registration system comparable to electronic data capture platforms such as REDCap [20]. Instrumental diagnostics included panoramic radiography, cone-beam or conventional computed tomography of the jaws, and, when indicated, magnetic resonance imaging assessed using validated protocols.

The study sample consisted of 267 patients with confirmed osteoporosis who were receiving or planning to receive antiresorptive therapy. Inclusion criteria were: age >50 years; verified diagnosis of osteoporosis with a T-score below −2.5 SD on densitometry; prescription of bisphosphonates (alendronate, risedronate, zoledronic acid) or denosumab at standard doses; ability to provide informed consent; and adherence to long-term follow-up. Exclusion criteria were: history of malignancy; previous radiotherapy to the head and neck region; established MRONJ at baseline; severe systemic diseases with an expected life expectancy of less than one year; and severe psychiatric disorders preventing protocol compliance [5]. The mean age of participants was 68.4 ± 7.2 years, with a female-to-male ratio of 4:1, consistent with the epidemiological profile of osteoporosis in the general population.

Patients were allocated according to the type of antiresorptive agent: Group I (n = 102) receiving oral bisphosphonates; Group II (n = 82) receiving intravenous bisphosphonates; and Group III (n = 83) receiving denosumab. Within each group, subgroups were formed based on the applied preventive protocol: Subgroup A – standard follow-up (control); Subgroup B – extended dental screening with preliminary oral sanitation; and Subgroup C – comprehensive preventive protocol with individualized management according to patient-specific risk factors. Assignment to subgroups was based on the preventive protocol actually received by the patient [7].

To ensure study quality, the following measures were implemented: standardization of diagnostic procedures and assessment criteria within the clinic; investigator training seminars prior to patient recruitment; double data entry control in electronic case report forms; independent expert committee verification of MRONJ cases; and regular quality monitoring with interim data analyses. Validity and reliability were supported through the use of standardized and validated assessment tools, including visual analogue pain scales, oral hygiene indices, standardized radiological protocols, and calibrated laboratory equipment [12; 16; 21].

Statistical analysis included calculation of descriptive statistics (mean, standard deviation, median, quartiles) for continuous variables and absolute and relative frequencies for categorical variables. Group comparisons were performed using Student’s t-test for normally

distributed data, the Mann–Whitney U test for non-parametric data, and the χ^2 test or Fisher's exact test for categorical variables. Relative risk of MRONJ development was calculated with 95% confidence intervals. Risk factor analysis was conducted using logistic regression with odds ratio estimation [22]. MRONJ-free survival was assessed using Kaplan–Meier analysis with the log-rank test for curve comparison [23]. Statistical significance was set at $p < 0.05$. Analyses were performed using IBM SPSS Statistics 26[1] and R version 4.1.2.

RESULTS

The demographic and clinical characteristics of the patients included in the study are presented in Table 1. Baseline analysis demonstrated comparability among the groups with respect to key parameters, including age, sex, duration of osteoporosis, bone mineral density, and comorbid conditions, thereby ensuring the validity and reliability of subsequent intergroup comparisons.

Baseline assessment of dental status revealed a high prevalence of oral pathology among patients with osteoporosis, which is consistent with reports from other investigators indicating an increased risk of dental problems in this population. Among the examined patients, 78.6% presented with clinically significant oral conditions requiring treatment: chronic periodontitis of varying severity was diagnosed in 52.3%, dental caries and its complications in 47.9%, periapical infectious lesions in 38.7%, and temporomandibular joint disorders in 22.1%.

Distribution of oral hygiene indices indicated inadequate oral care in 56.4% of patients, representing an additional risk factor for MRONJ development. Integrated analysis showed that only 21.4% of the examined individuals did not require oral sanitation prior to initiation of antiresorptive therapy, emphasizing the importance of comprehensive dental screening.

The incidence of MRONJ according to the type of antiresorptive agent and the applied preventive protocol is presented in Table 2. The results demonstrate statistically significant differences in osteonecrosis occurrence between subgroups receiving different preventive interventions across all patient groups.

Analysis of the data presented in Table 2 indicates that the incidence of MRONJ remains dependent on both the type of antiresorptive agent and the applied preventive protocol. The highest risk of osteonecrosis was observed in patients receiving intravenous bisphosphonates under standard follow-up, with 3 cases among 27 patients (11.1%). The lowest risk was recorded in groups managed with the comprehensive protocol: no cases of MRONJ were observed among 34 patients treated with oral bisphosphonates and 28 patients receiving denosumab (0%).

In the overall cohort of 267 participants, the transition from standard follow-up to preventive interventions reduced the cumulative MRONJ incidence from 6.7% (6/90) to 3.4% with dental screening alone (OR = 0.49; 95% CI 0.14–2.02; $p = 0.497$) and to 1.1% with the comprehensive protocol (OR = 0.16; 95% CI 0.04–1.33; $p = 0.118$). Although these differences did not reach statistical significance due to the limited sample size, the observed trend supports the clinical relevance of a multilevel preventive strategy.

Multivariable analysis of MRONJ risk factors is presented in Table 3. The regression results allowed identification of key predictors of osteonecrosis development that should be considered when planning individualized preventive measures.

[1] IBM Corp. IBM SPSS Statistics 26 Documentation: Regression. Armonk, NY: IBM, 2019. Available at: https://www.ibm.com/support/pages/ibm-spss-statistics-26-documentation (accessed: 27.12.2025).

Table 1. Baseline demographic and clinical characteristics of the study participants ($n = 267$)

Таблица 1. Исходные демографические и клинические характеристики участников исследования ($n = 267$)

Parameter	Group I ($n = 102$)	Group II ($n = 82$)	Group III ($n = 83$)	p-value
Age, years (Mean ± SD)	68.2 ± 7.1	68.7 ± 7.3	68.3 ± 7.2	0.889
Women, *n* (%)	82 (80.4)	65 (79.3)	67 (80.7)	0.954
BMI, kg/m^2 (Mean ± SD)	24.9 ± 3.7	25.2 ± 3.9	25.0 ± 3.8	0.866
Duration of postmenopause, years (Mean ± SD)	18.5 ± 8.4	18.9 ± 8.6	18.7 ± 8.5	0.951
Lumbar spine T-score (Mean ± SD)	–3.2 ± 0.7	–3.3 ± 0.8	–3.2 ± 0.7	0.589
Hip T-score (Mean ± SD)	–2.9 ± 0.8	–2.9 ± 0.7	–2.9 ± 0.8	1.000
Previous fractures, *n* (%)	48 (47.1)	39 (47.6)	40 (48.2)	0.996
Type 2 diabetes mellitus, *n* (%)	15 (14.7)	12 (14.6)	13 (15.7)	0.997
Rheumatoid arthritis, *n* (%)	10 (9.8)	9 (11.0)	8 (9.6)	0.999
Glucocorticoid use, *n* (%)	13 (12.7)	11 (13.4)	12 (14.5)	0.985
Smoking, *n* (%)	14 (13.7)	10 (12.2)	11 (13.3)	0.998

Note: BMI – body mass index; CKD-EPI – estimated glomerular filtration rate calculated using the CKD-EPI equation; CTx – C-terminal telopeptide of type I collagen; P1NP – N-terminal propeptide of type I procollagen.

Примечание: ИМТ – индекс массы тела; CKD-EPI – скорость клубочковой фильтрации по формуле CKD-EPI; CTx – С-телопептид коллагена I типа; P1NP – N-терминальный пропептид проколлагена I типа.

Table 2. Incidence of MRONJ according to antiresorptive drug type and preventive protocol during the 4-year follow-up period

Таблица 2. Частота возникновения МОНЧ в зависимости от типа антирезорбтивного препарата и профилактического протокола в течение 4-летнего периода наблюдения

Group	Preventive protocol	Number of patients	MRONJ cases, *n* (%)	OR (95% CI)	*p*-value
Group I (Oral bisphosphonates)	A (Standard follow-up)	35	1 (2.9)	1.0 (reference)	–
	B (Dental screening)	33	1 (3.0)	1.06 (0.11–10.73)	1.000
	C (Comprehensive protocol)	34	0 (0)	0.33 (0.01–8.47)	1.000
Group II (Intravenous bisphosphonates)	A (Standard follow-up)	27	3 (11.1)	1.0 (reference)	–
	B (Dental screening)	28	1 (3.6)	0.30 (0.05–2.79)	0.353
	C (Comprehensive protocol)	27	1 (3.7)	0.31 (0.05–2.90)	0.610
Group III (Denosumab)	A (Standard follow-up)	28	2 (7.1)	1.0 (reference)	–
	B (Dental screening)	27	1 (3.7)	0.50 (0.07–4.87)	1.000
	C (Comprehensive protocol)	28	0 (0)	0.19 (0.01–4.05)	0.491
All groups	A (Standard follow-up)	90	6 (6.7)	1.0 (reference)	–
	B (Dental screening)	88	3 (3.4)	0.49 (0.14–2.02)	0.497
	C (Comprehensive protocol)	89	1 (1.1)	0.16 (0.04–1.33)	0.118

Note: OR – odds ratio; CI – confidence interval; MRONJ – medication-related osteonecrosis of the jaw. ORs and 95% CIs were calculated using the Haldane–Anscombe correction (0.5 added to each cell).
Примечание: ОШ – отношение шансов; ДИ – доверительный интервал; МОНЧ – медикаментозный остеонекроз челюсти; ОШ и 95 % ДИ вычислены с поправкой Халдейна–Анскомба (добавлено 0,5 к каждой ячейке).

Table 3. Results of multivariable analysis of risk factors for MRONJ in patients with osteoporosis receiving antiresorptive therapy

Таблица 3. Результаты мультивариантного анализа факторов риска развития МОНЧ у пациентов с остеопорозом, получающих антирезорбтивную терапию

Risk factor	OR	95% CI	*p*-value
Intravenous bisphosphonates (compared with oral)	3.9	1.1–13.8	0.040
Duration of antiresorptive therapy > 3 years	3.2	1.0–10.4	0.052
β-CrossLaps < 150 pg/mL	3.5	1.2–11.2	0.033
Tooth extraction during therapy	6.1	1.5–25.0	0.010
Chronic periodontitis	2.8	1.0–8.0	0.041

Note: OR – odds ratio; CI – confidence interval.
Примечание: ОШ – отношение шансов; ДИ – доверительный интервал.

Table 4. Incidence of MRONJ following tooth extraction in patients with osteoporosis receiving antiresorptive therapy, according to the applied perioperative protocol

Таблица 4. Частота развития МОНЧ после экстракции зубов у пациентов с остеопорозом, получающих антирезорбтивную терапию, в зависимости от применяемого периоперационного протокола

Perioperative protocol	Number of Extractions	MRONJ cases, *n* (%)	OR (95% CI)	*p*-value
Standard protocol (antibiotic prophylaxis)	18	2 (11.1)	1.0 (reference)	–
Protocol with temporary discontinuation of antiresorptive therapy*	16	1 (6.3)	0.64 (0.06–6.90)	1.000
Protocol with PRF application	9	0 (0.0)	0.35 (0.02–6.62)	0.603
Combined protocol **	9	0 (0.0)	0.35 (0.02–6.62)	0.351

Note: OR – odds ratio; CI – confidence interval; MRONJ – medication-related osteonecrosis of the jaw; PRF – platelet-rich fibrin.
Примечание: ОШ – отношение шансов; ДИ – доверительный интервал; МОНЧ – медикаментозный остеонекроз челюсти; PRF – богатый тромбоцитами фибрин.

Multivariable analysis identified tooth extraction during antiresorptive therapy as the strongest independent predictor of MRONJ development (OR = 6.1; p = 0.010). Additionally, β-CrossLaps levels below 150 pg/mL (OR = 3.5; p = 0.033), intravenous bisphosphonate administration compared with oral intake (OR = 3.9; p = 0.040), and a duration of antiresorptive therapy longer than 3 years (OR = 3.2; p = 0.052, trend) significantly increased the risk of this complication. The presence of chronic periodontitis nearly tripled the likelihood of MRONJ (OR = 2.8; p = 0.041). The final model demonstrated satisfactory predictive performance (AUC = 0.84), although these estimates require validation in a larger cohort.

To evaluate the effectiveness of preventive measures in reducing MRONJ risk during dental surgical procedures, outcomes of 52 tooth extractions in patients receiving antiresorptive therapy were analyzed. The results are presented in Table 4.

Temporary discontinuation of antiresorptive therapy was performed according to a predefined algorithm: for oral bisphosphonates, therapy was paused 2 months before and up to 3 months after the procedure; for denosumab, discontinuation was synchronized with the end of the 6-month dosing interval. The combined protocol included temporary cessation of antiresorptive therapy, use of platelet-rich fibrin (PRF), minimally traumatic extraction, and flap closure of the extraction site.

Analysis of dental surgical outcomes demonstrated that the standard protocol with antibiotic prophylaxis alone remained the highest-risk approach: MRONJ occurred in 2 of 18 extractions (11.1%). Temporary discontinuation of antiresorptive therapy prior to extraction reduced the incidence of osteonecrosis to 1 of 16 cases (6.3%); however, this difference compared with the standard protocol did not reach statistical significance (OR = 0.64; 95% CI 0.06–6.90; p = 1.000). Application of PRF for socket filling (9 procedures) completely prevented MRONJ, with the relative risk reduced more than threefold, although the effect was not statistically significant due to the small sample size (OR = 0.35; 95% CI 0.02–6.62; p = 0.603). The combined protocol – temporary therapy discontinuation + PRF + atraumatic

Table 5. Dynamics of biochemical markers of bone metabolism and risk of MRONJ according to type of antiresorptive therapy

Таблица 5. Динамика биохимических маркеров костного метаболизма и риск развития МОНЧ в зависимости от типа антирезорбтивной терапии

Type of Antiresorptive Therapy	Time Point	CTx, pg/mL (M ± SD)	P1NP, ng/mL (M ± SD)	CTx/P1NP Ratio	MRONJ Incidence, % (*n*/*N*)
Oral bisphosphonates	Baseline	483.6 ± 259.3	58.6 ± 24.7	8.25	–
	3 months	267.1 ± 142.8*	42.3 ± 18.5*	6.31	0.0 (0/102)
	6 months	186.4 ± 98.7*	31.9 ± 14.2*	5.84	0.0 (0/102)
	12 months	154.3 ± 82.6*	29.8 ± 12.7*	5.18	0.0 (0/102)
	24 months	142.1 ± 75.8*	28.3 ± 11.9*	5.02	0.9 (1/102)
	36 months	133.9 ± 72.4*	27.1 ± 11.6*	4.94	1.0 (1/101)
	48 months	129.7 ± 68.8*	26.5 ± 11.2*	4.89	1.0 (1/99)
Intravenous bisphosphonates	Baseline	527.4 ± 282.1	62.3 ± 27.9	8.47	–
	3 months	157.6 ± 94.3*	33.5 ± 15.4*	4.70	0.0 (0/82)
	6 months	103.8 ± 62.7*	25.8 ± 11.6*	4.02	0.0 (0/82)
	12 months	86.5 ± 48.9*	22.7 ± 10.1*	3.81	1.2 (1/82)
	24 months	79.3 ± 42.6*	21.1 ± 9.7*	3.76	2.4 (2/81)
	36 months	72.8 ± 39.4*	20.3 ± 9.2*	3.59	3.7 (3/80)
	48 months	69.4 ± 36.8*	19.7 ± 8.9*	3.52	2.5 (2/79)
Denosumab	Baseline	502.8 ± 268.5	60.1 ± 25.8	8.37	–
	3 months	118.4 ± 71.2*	27.9 ± 12.3*	4.24	0.0 (0/83)
	6 months	72.6 ± 43.8*	20.4 ± 9.7*	3.56	0.0 (0/83)
	12 months	64.9 ± 38.5*	18.9 ± 8.8*	3.43	1.2 (1/83)
	24 months	62.7 ± 36.9*	18.2 ± 8.5*	3.45	1.2 (1/82)
	36 months	60.8 ± 35.4*	17.8 ± 8.2*	3.42	2.4 (2/81)
	48months	59.6 ± 34.2*	17.3 ± 8.0*	3.45	1.2 (1/80)

Note: * $p < 0.01$ compared with baseline; CTx – C-terminal telopeptide of type I collagen; P1NP – N-terminal propeptide of type I procollagen; MRONJ – medication-related osteonecrosis of the jaw.

Примечание: * $p < 0{,}01$ по сравнению с исходным значением; CTx – С-телопептид коллагена I типа; P1NP – N-терминальный пропептид проколлагена I типа; МОНЧ – медикаментозный остеонекроз челюсти.

extraction with flap closure (9 procedures) – was the most favorable: no MRONJ cases were observed; compared with the standard protocol, the difference did not reach significance (OR = 0.35; 95% CI 0.02–6.62; p = 0.351), likely due to the limited number of observations.

The dynamics of biochemical markers of bone metabolism during antiresorptive therapy and their correlation with MRONJ risk are presented in Table 5. Monitoring markers of bone resorption and formation enables evaluation of anti-osteoporotic therapy effectiveness and potential risk of complications.

Analysis of the dynamics of biochemical markers of bone metabolism demonstrated that intravenous bisphosphonates and denosumab suppress bone resorption more rapidly and profoundly than oral agents. At 3 months, mean CTx levels decreased by approximately 45% with oral therapy, 70% with intravenous bisphosphonates, and 77% during denosumab treatment; by 12 months, reductions reached 68%, 84%, and 87%, respectively. A significant inverse correlation was observed between the degree of CTx reduction and MRONJ incidence (* r = –0.73; p < 0.001). The highest number of complications occurred in patients with CTx < 100 pg/mL, whereas maintaining levels > 150 pg/mL was associated with minimal risk (< 1% over 4 years). These findings underscore the necessity of regular monitoring of bone resorption and formation markers during prolonged antiresorptive therapy.

Based on these results, a differentiated preventive algorithm for MRONJ in patients with osteoporosis was developed, incorporating the following key components: mandatory dental screening with oral sanitation prior to initiation of antiresorptive therapy; risk stratification based on identified MRONJ predictors [24]; selection of the optimal antiresorptive agent according to its safety profile; regular monitoring of biochemical markers with adjustment of dosing or administration schedules upon reaching critical thresholds; implementation of specialized protocols for invasive dental procedures; and patient education on meticulous oral hygiene and early recognition of MRONJ symptoms.

The effectiveness of the comprehensive preventive algorithm was evaluated in a subgroup of 89 patients who received multilevel preventive care. During 4 years of follow-up, MRONJ developed in 1 of 89 patients (1.1%), whereas in the standard follow-up group (n = 90), the incidence was 6.7% (6/90). The relative risk of the complication was reduced nearly sixfold (OR = 0.16; 95% CI 0.04–1.33; p = 0.118). Although statistical significance was not reached due to the limited number of events, the reduction represents a clinically meaningful decrease in relative risk.

Importantly, implementation of the comprehensive protocol did not compromise anti-osteoporotic efficacy: lumbar spine bone mineral density increased by 6.7 ± 2.5% at 24 months, compared with 7.0 ± 2.7% in the control group (p = 0.148), and the incidence of new low-energy fractures was comparable (11.6% vs. 11.0%; p = 0.832). These data support the safety of the proposed algorithm while demonstrating its potential to substantially reduce MRONJ risk.

CONCLUSION

MRONJ remains one of the most severe and limiting complications of antiresorptive therapy in patients with osteoporosis, as it significantly impairs quality of life and may necessitate discontinuation of effective treatment. Our single-center retrospective study of 267 medical records enabled the development and evaluation of a comprehensive preventive system based on individual risk stratification, personalized drug selection, regular monitoring of bone turnover markers, and a differentiated approach to dental interventions. Mandatory dental screening with panoramic radiography and management of infectious foci prior to initiation of antiresorptive therapy demonstrated a marked preventive effect: the overall incidence of MRONJ decreased from 6.7% (6/90) under standard follow-up to 3.4% (3/88) following implementation of screening, with the relative risk reduced nearly twofold (OR = 0.49; 95% CI 0.14–2.02; p = 0.497).

The most compelling results were achieved with the multilevel preventive algorithm (screening + dynamic CTx/P1NP monitoring + individualized therapy and perioperative measures): among 89 patients who received the full program, MRONJ developed in only one case over four years (1.1%) compared with 6.7% in the standard follow-up group, corresponding to an almost sixfold reduction in relative risk (OR = 0.16; 95% CI 0.04–1.33; p = 0.118). Although statistical significance was borderline, the trend indicates a clinically meaningful effect.

Comparative analysis of antiresorptive regimens showed that oral bisphosphonates were associated with the lowest incidence of osteonecrosis (2.0%), whereas intravenous formulations reached 6.1% and denosumab 3.6%; therefore, in patients with multiple risk factors, oral regimens may be preferred. Regular CTx monitoring confirmed its prognostic value: levels < 150 pg/mL were associated with a threefold increase in risk (OR = 3.5; p = 0.033), and the highest MRONJ incidence occurred at CTx < 100 pg/mL, whereas maintaining CTx > 150 pg/mL kept the risk near 1%.

Perioperative prevention was also critical: among 52 tooth extractions, MRONJ occurred in 11.1% with antibiotic prophylaxis alone, 6.3% with temporary cessation of antiresorptive therapy, whereas application of platelet-rich fibrin (PRF) and a combined atraumatic protocol (cessation + PRF + flap closure) completely prevented necrosis. Multivariable analysis identified key independent risk factors: tooth extraction during therapy (OR = 6.1; p = 0.010), therapy duration > 3 years (OR = 3.2; p = 0.052), CTx < 150 pg/mL (OR = 3.5; p = 0.033), and chronic periodontitis (OR = 2.8; p = 0.041); accounting for these predictors enables formulation of individualized preventive strategies.

Importantly, neither lumbar spine bone mineral density gain (6.7 ± 2.5% vs. 7.0 ± 2.7%; p = 0.148) nor the incidence of new low-energy fractures (11.6% vs. 11.0%; p = 0.832) differed significantly between the comprehensive protocol and standard follow-up groups, confirming the safety of the proposed scheme without compromising anti-osteoporotic efficacy.

In summary, a multilevel algorithm incorporating pre-treatment dental screening, dynamic monitoring of CTx/P1NP, optimization of antiresorptive drug selection and administration regimens, and specialized perioperative interventions can substantially reduce the clinical risk of medication-related osteonecrosis of the jaw without compromising osteoporosis treatment outcomes. Implementation of this strategy requires coordinated efforts among endocrinologists, rheumatologists, dentists, and oral and maxillofacial surgeons, as well as the development of local clinical protocols and educational programs. Future directions include multicenter studies with larger cohorts to validate the proposed algorithm, refine target thresholds for biochemical markers, and optimize the integration of antiresorptive and anabolic therapies in high-risk patients.

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AUTHOR'S CONTRIBUTION

All the authors made equal contributions to the publication preparation in terms of the idea and design of the article; data collection; critical revision of the article in terms of significant intellectual content and final approval of the version of the article for publication.

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Histological and histomorphometric investigation of SiO_2 nanoparticle-coated PEEK implants on the osseointegration in rabbit

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Abstract

INTRODUCTION. Metal, polymer, and ceramic implants are examples of biocompatible implants that are frequently suggested to enhance osseointegration and promote bone formation. The goal of this study was to improve osseointegration by developing a new interface. This contact exists between bone tissue and the polymeric component. Silicon dioxide material is applied to PEEK (polyether ether ketone) plastic in this work coat.

MATERIALS AND METHODS. Thirty New Zealand rabbits received sixty implants. Each rabbit has two implants in its tibia. Ten rabbits were scarified at two, four and six, weeks following implantation. The left tibia implant was experimental (coated with silicon dioxide), while the right tibia implant was control (uncoated) for every animal. Following hematoxylin and eosin staining, each section was histologically inspected and evaluated for histomorphometric analysis to count bone cells (osteoblast, osteocyte, and osteoclast) and the area of new bone is formed.

RESULTS. In comparison to control groups, histological results for silicon dioxide-coated PEEK implants showed a more rapid of bone growth, mineralization, and maturation. Significant difference of histomorphometric examination of every bone parameter was very high between the control and experimental groups during the course of all healing intervals.

CONCLUSIONS. According to the current study, the nano-silicon dioxide coating promotes faster osseointegration than an uncoated implant, improving bone formation and increasing the healing rates.

Keywords: bone formation, silicon dioxide, implant, osseointegration, PEEK

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Гистологическое и гистоморфометрическое исследование имплантатов PEEK с наночастицами SiO_2 и их влияние на остеоинтеграцию у кроликов

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Резюме

ВВЕДЕНИЕ. Металлические, полимерные и керамические имплантаты являются примерами биосовместимых имплантатов, которые часто рекомендуются для улучшения остеоинтеграции и стимуляции формирования костной ткани.

ЦЕЛЬ. Повышение остеоинтеграции за счет разработки нового интерфейса, который формируется между костной тканью и полимерным компонентом. В этой работе на пластик PEEK (полиифенилсульфонэтилкетон) наносится покрытие из диоксида кремния.

МАТЕРИАЛЫ И МЕТОДЫ. Тридцати кроликам породы Новая Зеландия имплантировали в общей сложности шестьдесят имплантатов. У каждого кролика были по два имплантата в большеберцовой кости. Десять кроликов забивали на сроках 2, 4 и 6 недель после имплантации. Имплантат в левой большеберцовой кости был экспериментальным (покрыт диоксидом кремния), а в правой – контрольным (без покрытия). После окрашивания гематоксилином и эозином каждый срез подвергался гистологическому исследованию и гистоморфометрическому анализу для подсчета костных клеток (остеобластов, остеоцитов и остеокластов) и оценки площади вновь образованной кости.

РЕЗУЛЬТАТЫ. В сравнении с контрольными группами, гистологические данные показали, что имплантаты PEEK с покрытием из диоксида кремния способствовали более быстрому росту кости, минерали-

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зации и ее созреванию. Различия по всем гистоморфометрическим параметрам костной ткани между контрольной и экспериментальной группами были высокими на всех этапах заживления.
ВЫВОДЫ. Согласно результатам исследования, нанопокрытие из диоксида кремния ускоряет остеоинтеграцию по сравнению с непокрытыми имплантатами, улучшает формирование костной ткани и повышает скорость заживления.

Ключевые слова: формирование кости, диоксид кремния, имплантат, остеоинтеграция, PEEK

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INTRODUCTION

The goal of biomedical implants is to get the patient's biomechanical activity back to normal. Using a range of technical materials, the implant device is matched with the surrounding tissue to produce effective results. which, given the complexity of biological systems, is a difficult undertaking [1; 2]. In order to support a dental prosthesis, a dental implantation surgical process is utilized to connect the implanted tooth or teeth to the jaw bone. Osseointegration, the biological process that allows a close link to the materials with bone, serves as the foundation for modern implants [3–5].

On the other hand, osseointegrated dental implants are those with pores that osteoblast cells and the connective supportive tissue can migrate into. In the context of oral implantology, this describes bone that grows directly up to the surface of dental implants without a layer of soft tissue in between [6]. It can also be defined as a process that is immune-driven which leads to the formation of the new bone surrounding the surface of the implant rather than a pure response of the bone [7]. Due to earlier differentiation and proliferation of bone-forming cells, osseointegration can be augmented by the new bone formation and mineralization that accelerate the treatment of surface of the implant site [8].

The topography and chemical characteristics of the implant surface are crucial for osseointegration. In order to promote cell growth and proliferation, and improve wettability. There are also chemical, physical and mechanical techniques used for treating implant surface that alter implant surface energy and topography [9]. Implant surface roughness has a direct impact on the quality of the bone-implant contact [10]. The primary techniques that are known to produce roughness in implants are titanium plasma spraying, sandblasting, acid etching, and coating with bioactive material. To enhance biological properties of dental implants modern innovation like microtopography and nano-topography are being used [11]. In general, the implant rough surface is preferable for osteoblasts for the adhesion, multiplication, and collagen making. While implant smooth surface is preferable for the secure adhesion of epithelial and fibroblast cells. Additionally, implants with moderate surface roughness demonstrated improved stability and bone ingrowth, enabling early mechanical loading [12; 13].

The thermoplastic (PEEK) polyether ketone ketone is suitable for a variety of sterilizing processes, including as autoclaving, ethylene oxide, and gamma irradiation, because to its inert chemical structure and high temperature tolerance. Furthermore, PEEK's modulus of elasticity is half that of cortical and trabecular bone. Because PEEK has fewer mechanical incompatibilities with bone tissue than metal implants, which could lessen stress shielding, it is favored in a range of therapeutic applications [14]. Consequently, the majority of implant applications began utilizing polymers in addition to metals since they offer superior peri-implant tissue recovery detection [15]. Some employ polymers as basic components in the design, while others use them as a material to coat the metal component [16]. To raise the likelihood that the implanted portion will be accepted and to enhance the body's capacity to integrate with it. Reduce the inflammatory reaction as well [17; 18].

Inorganic nanomaterials made of silicon dioxide, and silica nanoparticles are classified as either nonporous or mesoporous. They have high biocompatibility, easily modifiable surfaces because of the presence of silanol groups (Si-OH), and customizable size and pore volume [19]. Because Si-OH groups can react with biological fluids, it has been demonstrated that they contribute to bioactivity. This study sought to assess the impact of covering PEEK implants with SiO_2 nanoparticles on the osseointegration of rabbits both histologically and histomorphometrically.

MATERIALS AND METHODS

A circular target with a diameter of 50 mm and thickness of 3 mm was made to accomplish the RF plasma sputtering of SiO_2 powder. To create a uniform target and prevent target fracture, 30 grams of SiO_2 powder were mixed, then loaded and pressed in a cylindrical stainless-steel mold that measured with a diameter of 50 mm and height of 3 mm. Pressing is carried out using an electrical press for two minutes at 8 tons of pressure. To prevent cracks, the samples were left to cure gradually at room temperature for a whole day.

In the stainless-steel system chamber, radio frequency magnetron sputtering was carried out. The substrates were connected to the rotating cathode (negative charge) disc, while the target was connected to the system's anode (positive charge).

After inserting the PEEK substrates and target into the sputtering chamber, the chamber window was securely shut. A set distance of 10 cm separated the substrates and the target. To improve distribution consistency, the deposition was carried out at 2 rpm. There were three runs or sputtering intervals [20].

Thirty male New Zealand white rabbits, all weighed from 1.5 to 2 kg, aged from 10 to 12 months, had sixty machined surface implants from PEEK placed in them. Each rabbit had two implants put in its tibia: one in the experimental left tibia and one in the control right tibia.

Ten rabbits were sacrificed at two, four- and six-weeks following implantation. The implants were divided into two groups: the experimental group (30 PEEK coated implants) for three healing periods, 10 implants for each period, for the control group there has also been (30 uncoated implants).

The sterilizing implants were inserted into the 5 mm prepared hole in the tibiae of both rabbits. The uncoated implants were fixed straight into the right tibial bone of the rabbits, while those implants with coated implant was inserted into the left tibia following the rabbits' sacrifice in the conclusion of the suggested times. To create implant-contained bone blocks, the soft tissue was removed from the right and left tibias after the rabbit model had been sacrificed, to reveal the whole bone, which was then sliced 5 mm from both implant sides.

The samples underwent a 48-hour fixation process in 10% formalin, followed by decalcification using a formic acid solution, alcohol-dehydrated bone tissue, and paraffin embedding. Hematoxylin and eosin were used to stain 5 µm sections that were produced as normal. A light microscope was used for the histological evaluation.

A new bone production ratio was calculated by histomorphometrically evaluating the bone cells (osteoblast, osteocyte, and osteoclast).

RESULTS

The histology and histomorphometry performance of PEEK covered with SiO_2 were examined in this work. All animals generally recovered well from surgery and experienced no notable negative effects. They moved normally during the study period and showed no symptoms of infection, inflammation, or allergic reaction at the surgery site. The animal's general health, temperament, or diet were unaffected by the interventional procedures. There was no way to manually move the screws in order to assess osseointegration. Two groups were examined: the control group, which had no coated material, and the second group, which had SiO_2-coated PEEK specimens.

The degree of osseointegration of coated and uncoated samples with the bone, however, is revealed by the histological analysis. Following the completion of the implantation phase, several processing procedures are carried out to get ready for histological analysis. Various magnifications are used to capture the images. In terms of bone development, the first and second groups are compared.

Specimens of new bone of the experimental group were deposited more than the control group specimens at intervals of 2, 4, and 6 weeks. At increased magnification, it was discovered that the osteoblastic osteoid of the experimental group lining the immature bone surface was more recognizable.

Control 2-week

In certain areas, the histological findings revealed the deposition of osteoid tissues with the fibrous connective tissue, which was populated by progenitor cells, fibroblasts, inflammatory cells, and osteoblasts. (Fig. 1).

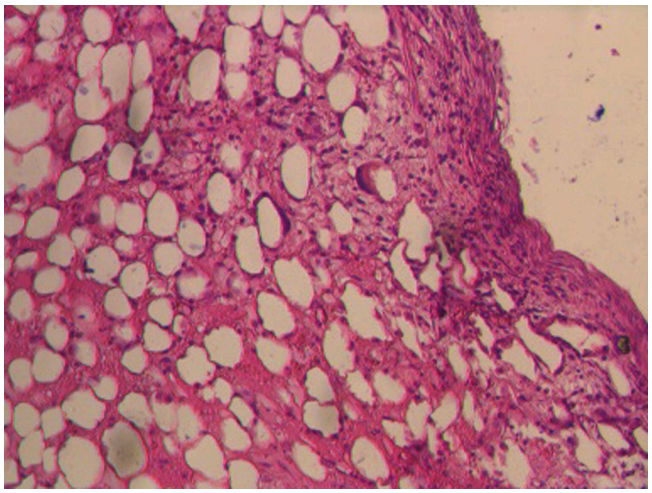

Fig. 1. Histological view of 2-week duration control group shows area filled with fibrous C.T. and osteoid tissue) H&E ×10

Рис. 1. Гистологическая картина контрольной группы на 2-й неделе: область заполнена фиброзной соединительной тканью и остеоидной тканью; окраска гематоксилином и эозином (H&E) ×10

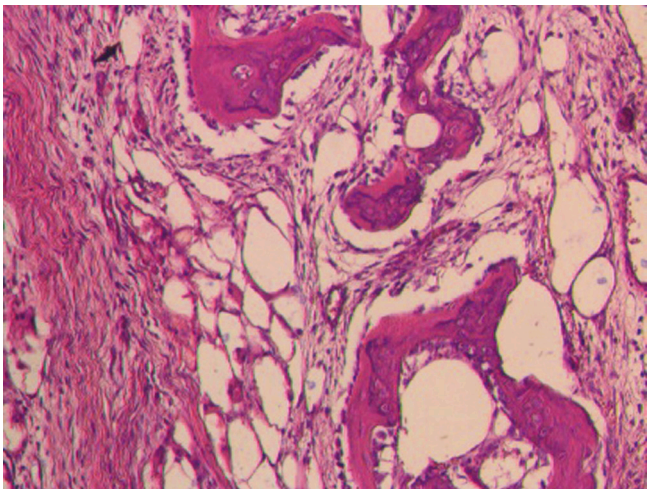

Fig. 2. View of two-week experimental group reveals woven bone a and blood vessels H&E ×4

Рис. 2. В препаратах экспериментальной группы на 2-й неделе выявляются грубоволокнистая костная ткань и кровеносные сосуды; окраска гематоксилином и эозином (H&E) ×4

Experimental 2-week

The histology results showed that the implant shape was followed by woven bone in the thread area. Higher magnification revealed that the thread area was packed with thin bone trabeculae, with osteocytes occupying their vast lacunae and osteoblasts grouped in a single mass at their margins. (Fig. 2).

Control 4-week

A few thin bone trabeculae filled with osteocytes and reosteocytes were seen in the histological image of the woven bone (Fig. 3).

Experimental 4-week

The histological view of experimental group in a 4-week period shows new bone trabeculae which demarcated from basal bone by reversal line. These bone trabeculae filled with osteocytes and surrounded by osteoblasts and osteoclasts (Fig. 4).

Control 6 week

The histological view shows formation of dense bone trabeculae filled with large-size osteocytes and surrounded by active osteoblasts. Also, the presence of osteoclasts and reversal line in higher magnification this indicates continuous bone remodelling (Fig. 5).

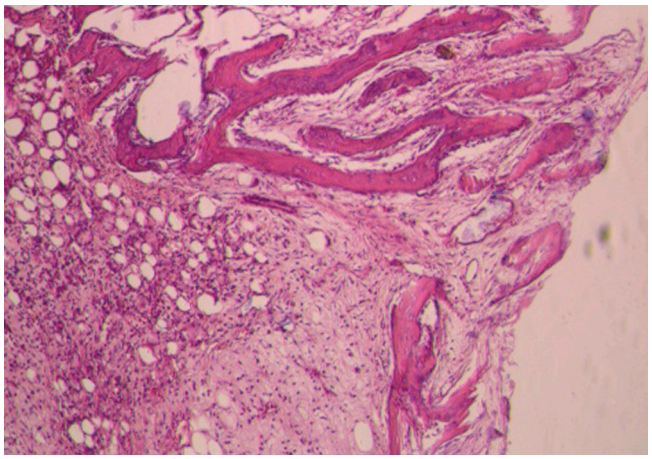

Fig. 3. Histological view of 2-week control group shows woven bone and thin bone trabeculae filled thread area, H&E ×10

Рис. 3. Гистологическая картина контрольной группы на 2-й неделе: выявляются грубоволокнистая кость и тонкие костные трабекулы, заполняющие область дефекта; окраска гематоксилином и эозином (H&E) ×10

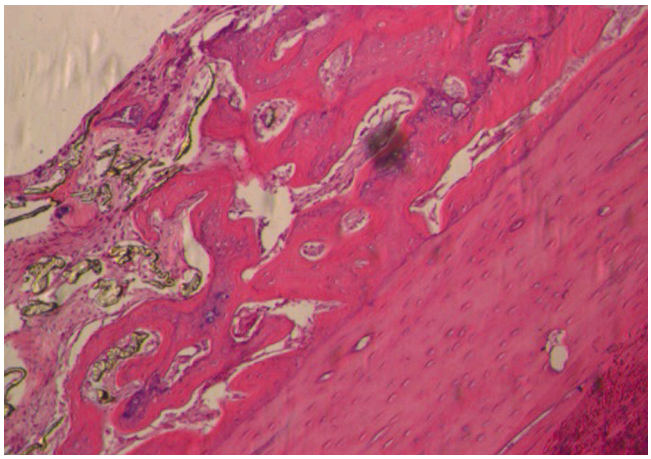

Fig. 5. View of 6-week control group shows osteoblasts, osteoclasts (OCL), and osteocytes (OC) H&E ×20

Рис. 5. Гистологическая картина контрольной группы на 6-й неделе: выявляются остеобласты, остеокласты (OCL) и остеоциты (OC); окраска гематоксилином и эозином (H&E) ×20

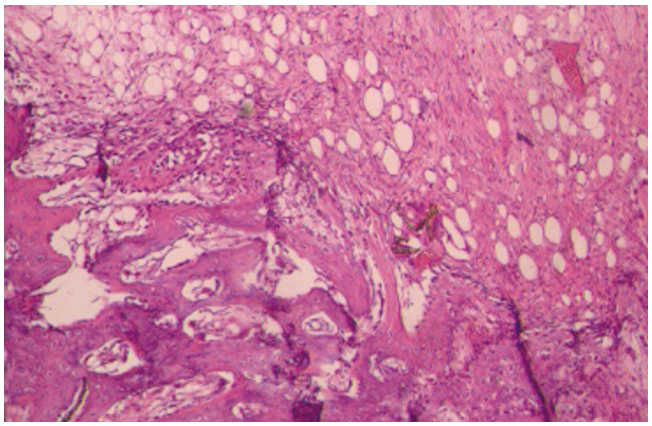

Fig. 4. View of 4-weeks experimental group shows woven bone (WB), new bone trabeculae (BT) filled thread area with osteoblasts (OB) and osteocytes (OC) H&E ×10

Рис. 4. В препаратах экспериментальной группы на 4-й неделе определяется грубоволокнистая кость (WB) и новообразованные костные трабекулы (BT), заполняющие область дефекта, с наличием остеобластов (OB) и остеоцитов (OC); окраска гематоксилином и эозином (H&E) ×10

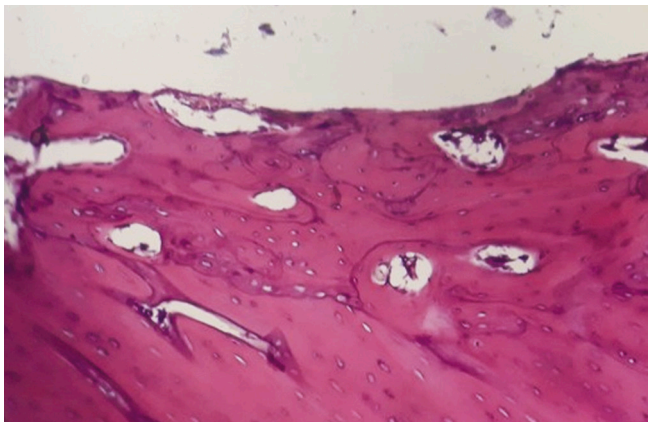

Fig. 6. Histological view of 6 weeks experimental group shows mature bone rimmed by osteoblasts, Haversian lamellae with osteocytes (OC) that are arranged in a circle around Haversian canal (HC) and reversal line (RL) H&E ×20

Рис. 6. Гистологическая картина экспериментальной группы на 6-й неделе: зрелая кость, окаймленная остеобластами, с гаверсовыми ламеллами, содержащими остеоциты (OC), расположенные вокруг гаверсового канала (HC), и линией реверсии (RL); окраска гематоксилином и эозином (H&E) ×20

Table 1. Statistical analysis of the bone architecture parameters for the experimental and control groups

Таблица 1. Статистический анализ параметров структуры кости для экспериментальной и контрольной групп

Variable	Duration	N	Control				Coating			
			Mean	SD	*F*-test	*p*-value	Mean	SD	*F*-test	*p*-value
Bone formation area	2-week	10	1.32	0.08	9.283	0.004	1.45	0.07	22.134	0.000
	4-week	10	1.53	0.04			1.67	0.04		
	6-week	10	1.92	0.06			2.81	0.07		
Osteoblasts N.	2-week	10	6	0.9	5.292	0.000	6.3	1.4	25.603	0.000
	4-week	10	12.1	1.2			16.7	2.6		
	6-week	10	15.4	2.3			14.4	2.7		
Osteocytes N.	2-week	10	0	0	6.358	0.000	3	0.4	18.407	0.000
	4-week	10	6.2	0.95			8.7	0.3		
	6-week	10	10.5	1.7			11.3	1.8		
Osteoclasts N.	2-week	10	0.5	0.46	4.547	0.000	0.47	0.2	22.896	0.000
	4-week	10	2.14	1.63			1	0.3		
	6-week	10	0.9	0.51			0.9	0.12		

Experimental 6-week

The histological view reveals well established mature bone rimmed by osteoblast and filled with osteocytes occupied their small lacunae in thread area. In higher magnification the mature bone characterized by presence of Haversion lamellae (Fig. 6).

Histomorphometry analysis of study groups for bone architecture parameters

The mean values of the descriptive statistics of the bone architecture parameters for the experimental and control groups rise with over time in all healing intervals. In every recovery period, the SiO_2-coated group's mean values are greater than the control groups. Both the experimental and control groups' mean numbers of osteoblasts and osteocytes rose over time, with the SiO_2-coated group's mean values rising faster than the control group's at intervals of two, four, and six weeks. The osteoclasts number was lower in the SiO_2-treated group than in the control group at the same interval, according to the mean values for both groups in the week.

The assessment region's quantitative histomorphometry analysis showed that while both groups' new bone area (%) increased, the experimental group's specimens showed substantially greater growth than the control group's at two-, four-, and six-week intervals. Normality test showed normal distribution of data for all groups (for Shapiro test, p value greater than 0.05).

DISCUSSION

Employing SiO_2 to analyze and compare the bone response to PEEK implants coated and uncoated. A histomorphometric analysis of the implant-bone contact in rabbits at various healing times was used to conduct the evaluation. The findings of the current study showed that because coated implants osseointegrate more quickly than uncoated implants, they had a better bone response. In dental implantology, altering implant surfaces to encourage osseointegration with bone is a relatively new strategy. Even though histomorphometry analysis is a destructive test, it is nonetheless regarded as a representative test for assessing implant stability and researching the quality of implant-to-tissue contact. It can be used whenever the implant has been surgically inserted. Many researchers have evaluated bone-to-plant contact using this analytical method [21; 22].

Two weeks following implantation, the histological analysis of the coated groups revealed higher signs of new bone formation encircled by osteoblast cells and an abundance of osteocytes with active blood vessels at the thread-interface region than the uncoated group. Histological characteristics of the uncoated group specimens at the six-week mark of the healing interval showed that the implant-bone interface region was filled with new bone, which was plentiful, and that the Harversian canal was lined with osteoblasts and osteocyte cells. These results suggest that processing was ongoing in the bone deposition area. However, six weeks after implantation, the coated group specimens had almost mature, new, and thick bone with osteocytes distributed regularly throughout the Harversian system. The current study demonstrated that superior osseointegrated implants were produced when implants were placed into living bone in an environment that was more favorable for bone regeneration due to the addition of encouraging elements. This outcome is consistent with Ibrahim et al. [23].

The high osteoconductivity of the coated surface was demonstrated by the notable changes in the overall amount of bone tissue growth surrounding the implant in the cortical region and bone marrow. At the nanoscale, a highly ordered nanoporous silica structure formed, and the silica-covering particles were homogeneous and free of microdefects. These findings show that adding silica covering with a nanoporous structure, which was shown in a prior work to promote cell adhesion and differentiation processes [24; 25].

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AUTHOR'S CONTRIBUTION

All the authors made equal contributions to the publication preparation in terms of the idea and design of the article; data collection; critical revision of the article in terms of significant intellectual content and final approval of the version of the article for publication.

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Influence of root length on the success of buccal infiltration anesthesia using 4% articaine in maxillary first molars with irreversible pulpitis undergoing root canal treatment: a clinical study

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Abstract

INTRODUCTION. Buccal infiltration using 4% articaine with epinephrine is a widely preferred anesthetic technique for maxillary molars. However, failures in achieving profound pulpal anesthesia, especially in teeth with irreversible pulpitis, remain clinically challenging. Anatomical factors such as root length may influence anesthetic diffusion but are seldom investigated.

AIM. To evaluate the effect of root length on the success rate of buccal infiltration anesthesia in maxillary first molars diagnosed with irreversible pulpitis.

MATERIALS AND METHODS. A prospective single-arm clinical trial was conducted on 60 adult patients with irreversible pulpitis in maxillary first molars. Following buccal infiltration with 1.7 ml of 4% articaine containing 1:100,000 epinephrine, pain responses during dentin removal, pulp chamber access, and canal instrumentation were recorded using the Heft-Parker Visual Analog Scale. Root lengths were measured radiographically using a standardized endodontic protocol. Anesthetic success was defined as no or mild pain at any procedural stage.

RESULTS. Overall anesthetic success was 81.1%. Success rates by root were: mesiobuccal 83.3%, distobuccal 81.7%, and palatal 78.3%. Mean root lengths were 18.8 ± 1.5 mm (mesiobuccal), 19.1 ± 1.5 mm (distobuccal), and 20.6 ± 1.7 mm (palatal). No statistically significant correlation was found between increased root length and anesthetic failure ($p > 0.05$).

CONCLUSIONS. The variations in the lengths of different roots of maxillary first molars do not significantly affect the success rate of buccal infiltration anesthesia in cases of irreversible pulpitis.

Keywords: anesthesia, dental pulp test, endodontics, articaine, pain measurement, maxillary first molar, root morphology

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Влияние длины корня на эффективность щечной инфильтрационной анестезии с 4% артикаином при верхних первых молярах с необратимым пульпитом, подвергающихся эндодонтическому лечению: клиническое исследование

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Резюме

ВВЕДЕНИЕ. Щечная инфильтрационная анестезия с использованием 4% артикаина с адреналином широко применяется для верхних моляров. Однако случаи неудачи достижения глубокой пульпарной анестезии, особенно при необратимом пульпите, представляют клиническую проблему. Анатомиче-

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ские факторы, такие как длина корня, могут влиять на диффузию анестетика, однако изучены они недостаточно.
ЦЕЛЬ. Оценить влияние длины корня на успешность щечной инфильтрационной анестезии у верхних первых моляров с диагнозом необратимого пульпита.
МАТЕРИАЛЫ И МЕТОДЫ. Проведено проспективное одноплечевое клиническое исследование на 60 взрослых пациентах с необратимым пульпитом верхних первых моляров. После щечной инфильтрации 1,7 мл 4% артикаина с концентрацией адреналина 1:100 000 регистрировали болевые реакции при удалении дентина, вскрытии пульповой камеры и инструментальной обработке каналов с использованием визуальной аналоговой шкалы Heft-Parker. Длина корней измерялась рентгенологически по стандартизированному эндодонтическому протоколу. Успех анестезии определялся как отсутствие боли или л егкая боль на любом этапе процедуры.
РЕЗУЛЬТАТЫ. Общая успешность анестезии составила 81,1%. Успешность по корням: мезиобуккальный – 83,3%, дистобуккальный – 81,7%, небный – 78,3%. Средняя длина корней составила: мезиобуккальный – 18,8 ± 1,5 мм, дистобуккальный – 19,1 ± 1,5 мм, небный – 20,6 ± 1,7 мм. Статистически значимой корреляции между увеличением длины корня и неудачей анестезии не выявлено ($p > 0,05$).
ВЫВОДЫ. Вариации длины различных корней верхних первых моляров не оказывают существенного влияния на эффективность щечной инфильтрационной анестезии при необратимом пульпите.

Ключевые слова: анестезия, тестирование зубной пульпы, эндодонтия, артикаин, измерение боли, верхний первый моляр, морфология корня

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INTRODUCTION

Pain is a multimodal unpleasant perception predominantly associated with tissue damage and can vary in intensity from mild to severe [1]. Dental pain commonly occurs when there is pulp hyperemia resulting from a pathology (typically dental caries), which leads to the development of increased pressure inside the restricted pulp chambers and canals, causing excruciating pain. Dental pain is the most common reason for patients to seek dental treatment. Dental professionals, therefore, perform endodontic procedures involving the removal of the affected pulp tissues and replacing it with an inert material to eliminate the pain and anxiety [2].

The handling of dental pulp tissue during endodontic procedures can be extremely painful, and therefore, local anesthesia is administered [3]. Experiencing pain during dental treatment affects the patient's confidence in the dentist's ability to treat them [4]. This pain may extend into the postoperative period, leading to negative feedback from the patients [5]. Furthermore, the patients may become reluctant to undergo dental treatment in the future. Therefore, a dental professional strives to minimize the pain during and after the dental treatment to instill a positive attitude in the patients towards dental treatment and the dentist [6].

To tackle this issue, numerous measures are adopted by the dentists, which most commonly comprise administration of a local anesthetic agent and prescription of pre-emptive analgesics. Among various anesthetic solutions, 4% articaine with 1:100,000 epinephrine has gained popularity due to its superior bone penetration, rapid onset, and extended duration of action [7]. These agents are injected near the periapical region of the teeth, commonly using the infiltration technique before initiating the root canal procedure. However, clinical studies report that a significant proportion of maxillary molars, especially those diagnosed with irreversible pulpitis, may not achieve complete pulpal anesthesia with buccal infiltration alone [8]. While numerous factors, including the inflammatory state of the pulp, tissue pH, and patient-specific variables such as anxiety and pain threshold, have been investigated in relation to anesthetic success, anatomical factors such as root length have not been adequately explored.

The maxillary first molar typically has three roots, mesiobuccal (MB), distobuccal (DB), and palatal (P), with the palatal root often being the longest [9]. It has been postulated that greater root length, particularly of the palatal root, may impair anesthetic diffusion from the buccal cortical plate, thereby diminishing anesthetic efficacy [10; 11]. This hypothesis is clinically relevant, especially when using buccal infiltration as the sole anesthetic technique, as longer roots may lie beyond the effective diffusion range of the local anesthetic, leading to incomplete pulpal anesthesia. While several studies have examined supplemental anesthesia techniques and anesthetic agents, the impact of root length on infiltration success remains underexplored.

Given this gap in the literature, the present clinical study was undertaken to investigate the effect of root length, specifically in the maxillary first molar, on the success rate of buccal infiltration anesthesia using 4% articaine with 1:100,000 epinephrine in patients with irreversible pulpitis. By evaluating pain response during access and instrumentation procedures, this study aims to provide valuable insights that may help clinicians anticipate anesthetic challenges and tailor pain management strategies accordingly, improving both clinical efficiency and patient outcomes in endodontic practice.

MATERIALS AND METHODS

Study design and ethical approval

this clinical study was designed as a prospective, single-arm clinical trial aimed at assessing the relationship between root length and the success rate of maxillary buccal infiltration anesthesia in patients with irreversible pulpitis. The study protocol received approval from both the Institutional Scientific Review Committee and the Institutional Ethical Committee (IEC No. 3210322, dated 16/02/2022). Additionally, the research protocol was prospectively registered with the Clinical Trials Registry of India (CTRI/2022/09/058230), and the study adhered to the Consolidated Standards of Reporting Trials (CONSORT) guidelines to ensure methodological transparency and ethical conduct [12].

Patient selection and recruitment

participants were screened and enrolled from the outpatient department of the institution between August 2022 and February 2023. Inclusion criteria required participants to be above 18 years of age and to present with a maxillary first molar clinically diagnosed with irreversible pulpitis, based on a prolonged symptomatic response to cold stimulation using Endo-Frost, which is composed of ethyl chloride and a mixture of propane and butane. Only teeth with radiographic evidence of normal periapical structures, as confirmed using an intraoral periapical radiography (IOPA), were included. Patients were excluded if they exhibited clinical signs of acute infection, such as swelling or sinus tract formation, if periapical radiolucency was evident, if they were pregnant, or if they had a known allergy to local anesthetic agents.

Eligible patients were provided with detailed verbal and written information about the study, and written informed consent was obtained prior to participation. Prior to administration of anesthesia, patients were asked to rate their baseline pain using the Heft-Parker visual analog scale (VAS), a validated 170-mm scale [13]. Pain scores were categorized as follows: no pain (0), mild pain (>0–54 mm), moderate pain (55–114 mm), and severe pain (115–170 mm).

Sample size estimation

sample size was determined using a power analysis based on the minimum clinically significant difference in VAS scores. With an expected standard deviation of 0.75, an alpha error probability of 0.05, and a power of 0.8, the calculated sample size required for the study was 60 teeth.

Treatment protocol

All endodontic procedures were performed by a single experienced operator, following a standardized protocol. The target tooth was anesthetized using a buccal infiltration technique. Before injection, topical 20% benzocaine gel (Projel-20, Septodont USA) was applied to the mucosa overlying the apices of the MB, DB and palatal roots of the maxillary first molar. A 27-gauge, 35 mm Septoject needle (Septodont, France) was used to deliver 1.7 ml of 4% articaine with 1:100,000 epinephrine into the alveolar mucosa between the buccal roots using the infiltration anesthesia technique. To ensure that anesthesia was delivered appropriately at the periapical region, the position and angulation of the needles were standardized according to the preoperative radiographs for all patients. The injected areas were massaged for 20 seconds to ensure proper dispersion of the local anesthetic agent into the tissues surrounding all three roots.

Following a latency period to allow for anesthetic onset, the tooth was isolated with a rubber dam, and endodontic access cavity preparation was initiated. At each critical treatment stage, dentin removal, pulp chamber entry, and canal instrumentation, the patient's pain perception was recorded using the Heft-Parker VAS [13]. Anesthesia was deemed successful if the patient reported no to mild pain, while moderate or severe pain was considered indicative of anesthetic failure. If failure occurred at any stage, supplemental intrapulpal anesthesia was administered to continue the treatment.

Measurement of root length and canal instrumentation

a #15 hand K-file with a rubber stopper was inserted up to the point where a proprioceptive tugback was felt. This point was discerned to be the apex of the root, and the position of the file was then confirmed radiographically using an intraoral periapical radiovisiograph. Measurements were taken from the tip of each root to the corresponding cusp tip. The file with a stopper was then removed, and the length was measured using a standard Endo-block (Dentsply Maillefer, Switzerland). For MB root having two root canals, the higher value was considered as the root length. Length of each root was recorded in a standard worksheet (MS Excel v2019, Microsoft, Redmond, USA). The preparatory and measurement steps are collectively shown in Fig. 1. The canals were negotiated and shaped using the Protaper Gold rotary instrumentation system (Dentsply Sirona, Charlotte, USA), with apical preparation tailored based on apical gauging. Irrigation was performed copiously throughout the procedure using 2.5% sodium hypochlorite by a 26-gauge needle, ensuring optimal debridement. Further instrumentation, including subsequent file systems and obturation procedures, was completed in the same visit according to standard endodontic protocols.

RESULTS

A total of 60 patients participated in this study (Fig. 2), including 34 females (56.7%) and 26 males (43.3%), with a mean age of 27.2 years. The distribution of anesthesia success did not differ significantly between male and female participants ($p > 0.05$), indicating that gender did not influence anesthetic outcomes in this sample.

Following administration of a single buccal infiltration injection of 4% articaine with 1:100,000 epinephrine, the overall success rate of anesthesia, defined as the absence of pain or only mild pain during treatment, was 81.11%. Evaluation at different procedural stages (Table 1) revealed that 93.33% of patients reported no or mild pain during dentin removal, while 90% of patients experienced successful anesthesia during pulp chamber access.

Table 1. Number and percentage of anesthesia success during various stages of the treatment

Таблица 1. Число и доля случаев успешной анестезии на разных стадиях лечения

Stage of treatment	Number of faliures	Failurerrate, %	Number of successes	Success rate, %
Dentin removal	4	6.67	56	93.33
Pulp exposure	6	10.00	54	90.00
Throughout the endodontic procedure	4	6.67	56	93.33

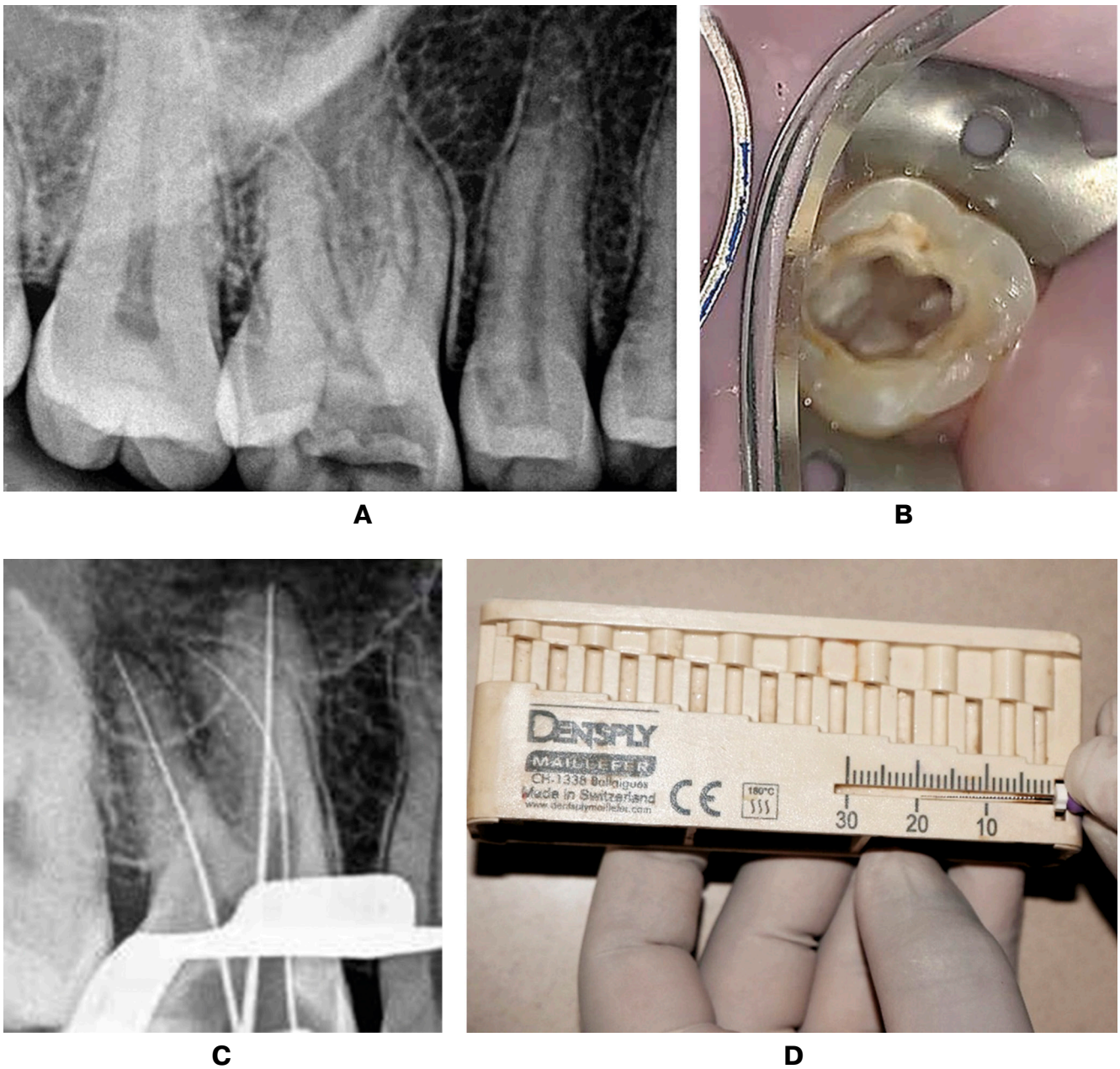

Fig. 1. Preparatory and measurement steps: (*A*) pre-operative radiograph showing maxillary first molar with occlusal caries involving enamel, dentin and pulp; (*B*) visualization of the root canals after access cavity preparation; (*C*) confirmatory radiograph showing insertion of the file up to the root apex; (*D*) Measurement of the file length using an Endo-block

Рис. 1. Этапы подготовки и измерения: (*A*) предоперационный рентгеновский снимок верхнего первого моляра с окклюзионным кариесом, поражающим эмаль, дентин и пульпу; (*B*) визуализация корневых каналов после подготовки доступа; (*C*) контрольный рентгеновский снимок, демонстрирующий введение инструмента до верхушки корня; (*D*) измерение длины инструмента с помощью эндоблока (Endo-block)

Only four patients (6.67%) experienced moderate to severe pain during dentin removal and required supplemental palatal infiltration for effective pain control. An additional six patients (10%) reported pain upon pulp exposure (Fig. 2), of which four reported pain persisting during root canal instrumentation and were successfully managed with intrapulpal anesthesia.

When analyzed by individual root (Fig. 3), the MB root exhibited the highest success rate of 83.33%, followed closely by the DB root at 81.67% and the palatal root at 78.33%. Although the palatal root showed a slightly higher rate of anesthetic failure, the point-biserial correlation test indicated no statistically significant differences in anesthesia success rates among the three roots (MB vs. DB: $p = 0.938$; MB vs. P: $p = 1.000$; DB vs. P: $p = 0.938$).

The analysis of root length revealed that the palatal roots were significantly longer than the MB and DB roots. The mean root lengths were as follows: palatal root (20.6 ± 1.7 mm), DB root (19.1 ± 1.5 mm), and MB root (18.8 ± 1.5 mm). Despite this difference in root length, no statistically significant association ($p > 0.05$) was observed between increased root length and anesthetic failure, suggesting that longer palatal roots did not compromise the efficacy of buccal infiltration anesthesia in maxillary first molars (Table 2).

These findings support the conclusion that buccal infiltration with articaine is highly effective for maxillary first molars with irreversible pulpitis and that variations in root length, particularly in the palatal root, do not significantly influence anesthetic success.

DISCUSSION

The present clinical study aimed to evaluate whether root length, particularly that of the palatal root, influences the success rate of buccal infiltration anesthesia in maxillary first molars diagnosed with irreversible pulpitis. Clinical trials offer a unique advantage by capturing real-time biological interactions and variables that laboratory-based studies may not accurately reflect. In dental anesthesia, buccal infiltration remains a widely favored technique for maxillary molars due to the porosity of the maxillary bone, which facilitates diffusion of anesthetic agents [14]. While palatal injections are known to be more painful, prior research by Aggarwal et al. indicated no significant improvement in anesthetic success when palatal injections were added to buccal infiltration for maxillary molars with irreversible pulpitis [15]. This finding supports the clinical preference to avoid palatal injections unless absolutely necessary.

In this study, a single buccal infiltration of 4% articaine with 1:100,000 epinephrine resulted in a notable 81.11% overall success rate for pulpal anesthesia. When analyzed root-wise, the MB root demonstrated the highest success rate at 83.33%, followed by the DB at 81.67%, and the palatal root at 78.33%. Despite the slightly lower success rate associated with the palatal root, statistical analysis revealed no significant correlation between increased root length and anesthetic failure. Nonetheless, the comparatively lower success rate in the palatal root warrants clinical attention, particularly because it often exhibits the greatest length and may lie beyond the effective diffusion zone of the anesthetic solution administered buccally [16].

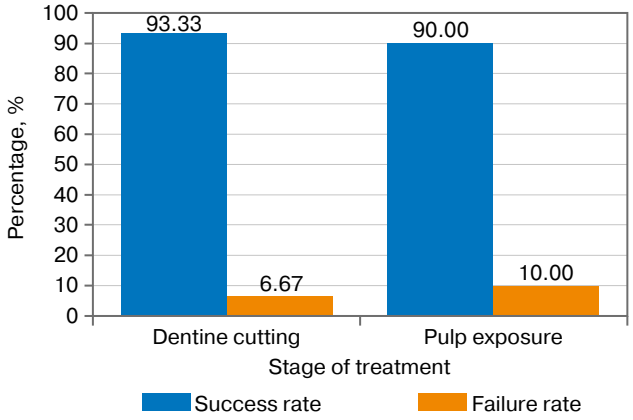

Fig. 2. Graphical representation of success and failure rates during different treatment stages

Рис. 2. Графическое отображение частоты успешного и неудачного исхода на различных стадиях лечения

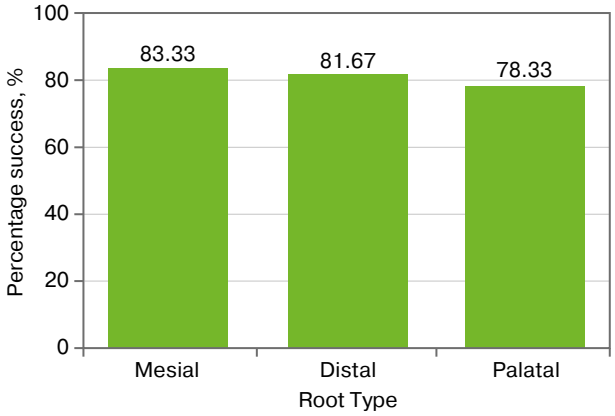

Fig. 3. Graphical representation of the success rates of anesthesia in individual roots

Рис. 3. Графическое представление уровня успешности анестезии по отдельным корням

Table 2. Failure and success rates of anesthesia according to the mean root length

Таблица 2. Частота неудач и успеха анестезии в зависимости от средней длины корня зуба

Root (Mean ± SD mm)	Failures *n* (%)	Success *n* (%)	χ^2 (df)	*p*-value (vs others)
MB (18.8 ± 1.5)	10 (16.7%)	50 (83.3%)	0.39 (2) overall	0.82 (overall)
DB (19.1 ± 1.5)	11 (18.3%)	49 (81.7%)	–	0.79 (MB vs DB)
P (20.6 ± 1.7)	13 (21.7%)	47 (78.3%)	–	0.47 (MB vs P); 0.63 (DB vs P)

These findings align with earlier literature. Evans et al., Srinivasan et al., and Woo et al. have all highlighted limitations of buccal infiltration in anesthetizing the palatal root, especially in cases of irreversible pulpitis [17–19]. Moreover, Omar et al. suggested that the anatomical proximity of the maxillary sinus to the roots of the upper molars, particularly the palatal root, may interfere with anesthetic diffusion [11]. When the sinus floor extends between the buccal and palatal roots, the sinus membrane could act as a physical barrier, thereby reducing the efficacy of the infiltration [20]. The role of adjacent hard tissue morphology, including root divergence and bone density, is increasingly recognized as a significant determinant of anesthetic success [20].

A study by Askari et al. utilized 2% lidocaine with 1:80,000 epinephrine and demonstrated a lower success rate (61%) for maxillary first molars with irreversible pulpitis [10]. They found significantly higher failure rates associated with longer palatal and DB roots [10; 15–19]. In contrast, our study found that despite palatal roots being the longest, there was no statistically significant difference in anesthesia success based on root length, possibly due to the superior diffusion characteristics of articaine. The discrepancy observed in earlier studies could be due to the fact that different lengths of roots require different positions and angulations of the anesthetic needle so that the agent is delivered to the periapical area. The standardization of these procedures constitutes a potential strength of the present study.

The higher efficacy of articaine may be explained by its molecular structure, as noted by Srinivasan et al., who reported a 100% success rate in a small sample of 10 teeth using articaine for buccal infiltration [18]. Although the present study observed a slightly lower success rate, the findings remain consistent when accounting for the larger sample size. The chemical structure of articaine, featuring a thiophene ring and high lipid solubility, facilitates enhanced membrane penetration and diffusion through bone and nerve tissues [21]. Pharmacological studies have consistently demonstrated that articaine exhibits superior permeation capabilities compared to other anesthetics, which may explain its more reliable performance in challenging clinical scenarios such as irreversible pulpitis [22].

Clinically, this study underscores two practical recommendations. First, the depth of needle insertion during buccal infiltration should ideally correspond to the estimated root length, particularly for molars with elongated or divergent roots [23]. Preoperative periapical radiographs obtained using the paralleling technique can be instrumental in estimating root length. Second, if a CBCT scan is available from previous diagnostics, it may serve as a valuable adjunct in planning anesthetic delivery by providing a three-dimensional understanding of root morphology and adjacent anatomical structures [24]. Furthermore, root divergence could delay anesthetic diffusion to the palatal root apex, particularly in widely spread roots, and may contribute to localized anesthetic failure despite overall clinical success [20].

Overall, the study affirms the effectiveness of 4% articaine in achieving profound pulpal anesthesia via buccal infiltration in the majority of maxillary first molars with irreversible pulpitis. While anatomical factors like root length and sinus proximity may influence anesthetic diffusion, they do not necessarily predict failure, especially when a potent anesthetic agent like articaine is used with proper technique and case-specific planning.

CONCLUSION

Within the limitations of this clinical study, it can be concluded that variations in root length, including the longer palatal root of the maxillary first molar, do not significantly affect the success rate of buccal infiltration anesthesia in cases of irreversible pulpitis. The findings suggest that root length alone is not a predictive factor for anesthetic success when using 4% articaine with 1:100,000 epinephrine. Hence, clinicians may not need to modify anesthetic technique solely based on root length when performing endodontic procedures on maxillary first molars.

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Case Report

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A rare case of fusion between a third molar and a distomolar: case report

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Abstract

Fusion between a tooth and a supernumerary one that involves the union of two distinct tooth germs into a single with an enlarged dental structure. This case reports the endodontic treatment of a fusion involving a third molar and a supernumerary tooth (distomolar) in the left mandibular region of a 46-year-old female. This condition presented significant diagnostic and clinical challenges due to its atypical crown anatomy, two distinct pulp chambers, and morphological complexities that complicate traditional access and preparation. The diagnosis relied on comprehensive clinical examination and conventional radiographic analysis and the cone beam computed tomography, emphasizing the clinician's skill in interpreting subtle findings. Non-surgical endodontic therapy was planned, executed in two sessions, with the use of the Logic 2 (25.05) nickel-titanium rotary instruments and an extensive irrigation protocol using 5.25% sodium hypochlorite and 17% EDTA under active ultrasonic agitation. A key element of success was the consistent use of an operating microscope (20x magnification), which was instrumental in refining access, navigating complex anatomy, and ultimately confirming the presence of five distinct root canals. Tri-dimensional canal sealing was achieved with Tagger's Hybrid technique. This meticulous approach resulted in the functional maintenance of the tooth for over five years, showing that despite rare and complex morphological variations, advanced technological aids and thorough clinical expertise are paramount for achieving successful, long-term outcomes in endodontic treatment.

Keywords: fusion, gemination, dental anomalies, root canal treatment

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Редкий случай сращения третьего моляра и дистомоляра: описание клинического случая

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Резюме

Сращение зуба с сверхкомплектным зубом представляет собой объединение двух отдельных зачатков в единый, увеличенный зубной орган. В данном случае описан эндодонтический метод лечения сращения третьего моляра с сверхкомплектным зубом (дистомоляром) в левой нижней челюсти

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у 46-летней женщины. Эта патология создала значительные диагностические и клинические трудности из-за атипичной анатомии коронки, наличия двух отдельных пульпарных камер и морфологических особенностей, усложняющих традиционный доступ и подготовку. Диагностика основывалась на комплексном клиническом осмотре, конвенциональной рентгенографии и конусно-лучевой компьютерной томографии (CBCT), что потребовало высокой квалификации врача в интерпретации тонких признаков. Планировалась несхирургическая эндодонтическая терапия, выполненная в два этапа с использованием никель-титановых вращающихся инструментов Logic 2 (25.05) и обширного протокола орошения 5,25% гипохлоритом натрия и 17% ЭДТА под активным ультразвуковым воздействием. Ключевым элементом успеха стало постоянное использование операционного микроскопа (увеличение ×20), что позволило уточнить доступ, навигацию по сложной анатомии и подтвердить наличие пяти отдельных корневых каналов. Трехмерное пломбирование каналов было выполнено по гибридной технике Тэггера. Такой тщательный подход обеспечил функциональное сохранение зуба более пяти лет, демонстрируя, что при редких и сложных морфологических вариациях современные технологические средства и высокая клиническая квалификация являются решающими для достижения успешных долгосрочных результатов эндодонтического лечения.

Ключевые слова: сращения зубов, геминация, зубные аномалии, лечение корневых каналов

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INTRODUCTION

The success of endodontic therapy is directly related to a thorough understanding of dental anatomy and the proper execution of chemical-mechanical preparation, both of which are essential for achieving effective treatment [1; 2]. Geminated and fused teeth pose significant challenges for endodontists due to their anatomical variations and morphological complexities, which hinder access, preparation, and obturation of root canals. These conditions, although rare, have important clinical implications and demand a careful and detailed approach to ensure a favorable prognosis [1–4].

Fusion and gemination anomalies develop during the morphodifferentiation of odontogenesis, and their etiology remains unclear. Studies suggest that both hereditary and local factors may act as triggering agents [1; 3; 5]. Fusion is defined as the union of two distinct dental germs into a single tooth, resulting in a lower total tooth count in the arch, except in cases of fusion with supernumerary teeth. Conversely, gemination occurs as a partial or incomplete division of a single germ, typically forming an enlarged tooth with a bifid crown and shared canals or roots, without affecting the total tooth count in the arch [3].

Differentiating between fusion and gemination can be challenging, especially when fusion occurs between a normal tooth and a supernumerary tooth, since the total tooth count in the arch remains unchanged. In such cases, the use of radiographic exams to analyze root morphology, pulpal chamber, and root canals is essential for an accurate diagnosis [6; 7]. Studies report that these conditions are more commonly found in deciduous teeth of the anterior region, with posterior and permanent teeth being affected much more rarely [1; 4].

These anomalies can lead to clinical consequences, including plaque accumulation in irregular areas, increased risk of caries, pathological resorption, and even occlusal issues, often resulting in severe dental crowding [8]. Thus, early diagnosis plays a critical role in prevention and treatment planning [2; 4; 5].

Finally, it is essential to emphasize that the operating microscope is a valuable tool for diagnosing and managing challenging cases like this, providing a detailed view and aiding in the identification of complex anatomical structures. The literature strengthens the importance of interdisciplinary management to minimize complications and deliver effective clinical outcomes for patients with dental anomalies of this magnitude [2; 4; 5].

Thus, the aim of the present case is to report the endodontic treatment of a fusion involving a third molar and a supernumerary tooth (distomolar), located in the left mandibular region, wherein all available endodontic resources were employed for achieve the successful treatment, restoring the tooth's health and function, and thereby contributing to the patient's quality of life.

CASE REPORT

A 46-year-old female patient visited the dental office for evaluation after consulting with three other professionals, complaining of pain and difficulty chewing on the left side of her dental arch. The patient reported that both complaints were associated with leakage in amalgam restorations caused by carious lesions in tooth 38. Clinical examination revealed an atypical crown anatomy in the affected tooth, characterized by an additional central groove extending from the cementoenamel junction on the buccal surface, crossing the entire crown, and reaching the lingual surface. This feature gave the tooth the appearance of a distinct second crown (Fig. 1, A).

Cold sensitivity tests using refrigerant gas (Endo-Ice, Maringá, Brazil) and horizontal and vertical percussion tests were performed. Based on the results, necro-

sis in the affected tooth was confirmed. Radiographic analysis showed the presence of three wide root canals and two distinct pulp chambers, each corresponding to separate portions of the divided crown, highlighting the anatomical complexity of the case (Fig. 1, B).

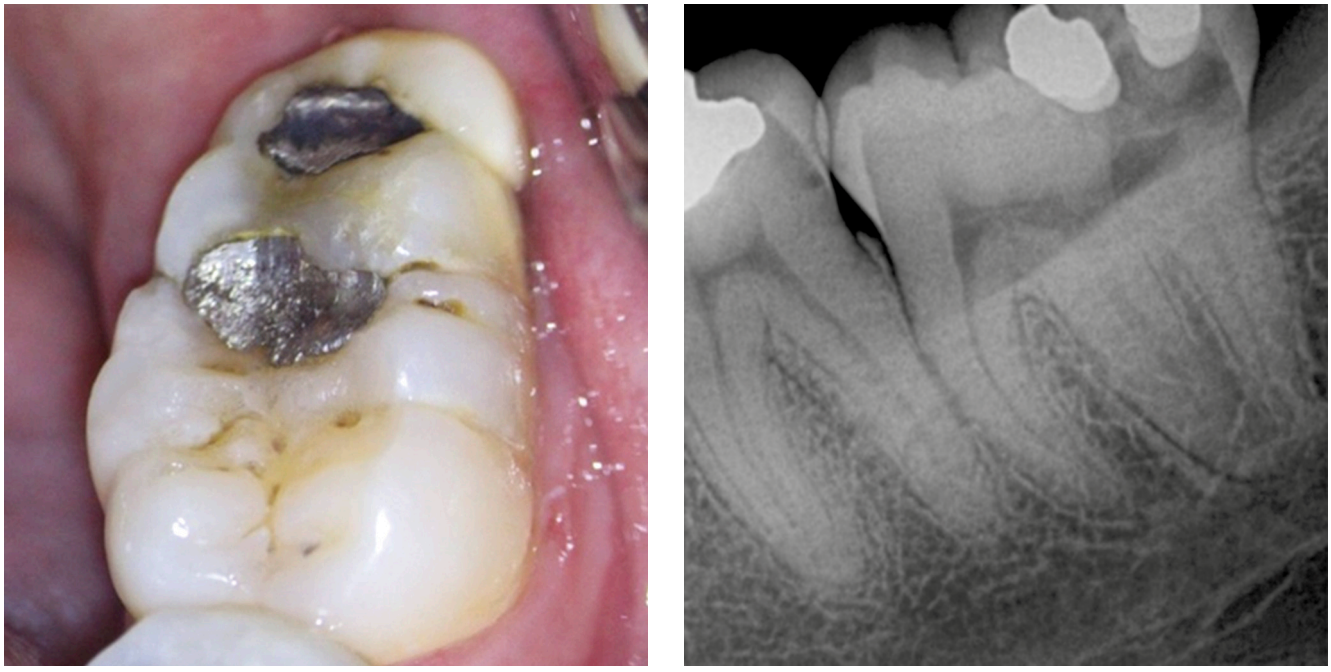
Given the suspicion of a dental anomaly involving fusion, it was hypothesized that the anatomical division observed in tooth 38 may be associated with alterations during odontogenic development. After completing the clinical and radiographic evaluations, a diagnosis was made of fusion between a permanent tooth and a supernumerary tooth. Considering the patient's desire to preserve the tooth and its satisfactory clinical conditions, a conservative treatment plan was proposed, including non-surgical endodontic therapy, aided by operative microscopy, rotary instrumentation, thermoplastic gutta-percha obturation, restorative reconstruction, and periodical follow-ups. The two-session treatment plan was designed for greater efficacy and control.

First Session: Local anesthesia was administered with 4% articaine with 1:100,000 epinephrine (DFL, Rio de Janeiro, Brazil), followed by surgical access. Initially, all carious tissue was removed using a #4 spherical bur (Dentsply, Petrópolis, Brazil) at low speed. The pulp chamber was accessed with a 1557 bur (FKG Dentaire, La-Chaux-de-Fonds, Switzerland). During the procedure, a crown-lengthening surgery was required on the buccal and distal surfaces, with the buccal wall reconstruction with Z350 composite resin (3M, Sumaré, SP, Brazil). The tooth was then isolated, and access was refined using an operating microscope with 20x magnification (Aliance, São Paulo, SP, Brazil), an Endo-Z bur (Angelus, Londrina, PR, Brazil), and E2D ultrasonic tips (Helse, São Paulo, SP, Brazil). The patient was instructed to return in 15 days for the completion of treatment.

Second Session: Instrumentation of the root canals was performed using the crown-down technique with nickel-titanium Logic 25.05 rotary instruments (Easy-Bassi, Belo Horizonte, Brazil). The irrigation protocol involved active ultrasonic agitation using EasyClean files (Easy-Bassi, Belo Horizonte, MG, Brazil) with the following sequence: three cycles of 5.25% sodium hypochlorite (NaOCl) activation for 20 seconds each, followed by three cycles of 17% EDTA activation for 20 seconds, and concluding with three additional cycles of NaOCl activation, totaling 120 mL of NaOCl and 20 mL of EDTA. Throughout the procedure, the root canal system was continuously assessed under the operating microscope, ensuring precision and safety (Fig. 2, *A*).

The anatomy, including the presence of five root canals, was confirmed through digital radiography, followed by the adaptation of gutta-percha cones (Fig. 2, *B*). Subsequently, the canal system was obturated using the thermoplastic gutta-percha hybrid technique by Tagger (Fig. 2, *C*). The tooth was temporarily sealed with glass ionomer cement (FGM, Joinville, SC, Brazil), and the completion of the endodontic treatment was documented with a final radiograph (Fig. 2, *D*).

The patient was informed of the importance of periodic dental checkups to monitor the case and prevent future complications, potentially involving an interdisciplinary approach when necessary. The unique anatomy of the affected tooth underscores the importance of clinical and technological expertise to handle uncommon yet clinically challenging cases.



A **B**

Fig. 1. Third molar and a supernumerary tooth (distomolar): *A* – clinical image; *B* – periapical radiograph

Рис. 1. Третий моляр с сверхкомплектным зубом (дистомоляром): *A* – клиническое изображение; *B* – прицельная рентгенограмма

Fig. 2. Treatment stages: *A* – image of the interior of the pulp chamber using the operating microscope; *B* – cone fitting test showing the 5 root canals on the digital radiograph; *C* – thermoplastic obturation of the fused tooth; *D* – Final radiograph of the endodontic treatment

Рис. 2. Этапы лечения: *A* – изображение внутренней части пульповой камеры, полученное с помощью операционного микроскопа; *B* – тест на соответствие конуса, показывающий 5 корневых каналов на цифровом рентгеновском снимке; *C* – термопластическая обтурация сросшегося зуба; *D* – заключительный рентгеновский снимок эндодонтического лечения

DISCUSSION

Dental developmental anomalies are multifaceted conditions resulting from complex interactions between hereditary factors and local influences during odontogenesis. These morphological variations, such as fusion and gemination, can occur in both primary and permanent dentition and are classified based on their stage of formation. Fusion, for instance, is characterized by the union of two contiguous tooth germs and may be categorized as complete, involving both the root and the crown, or incomplete, restricted to the crown only [2; 3; 5; 9; 10]. The diverse presentation of these anomalies requires in-depth understanding for accurate diagnosis and appropriate treatment planning, as their exact etiology remains unclear, with evidence pointing to a combination of genetic and environmental factors [1; 8].

The clinical differentiation between fusion and gemination, although these are distinct anomalies, often presents a challenge, particularly when fusion occurs between a permanent tooth and a supernumerary tooth since the normal tooth count in the arch remains unaltered. While gemination typically displays two crowns joined by a common root, dental fusion tends to present an enlarged crown, which may have one or two roots and distinct pulp chambers [2; 3; 5].

The presented case report describes a fusion between a third molar and a supernumerary tooth (distomolar), that validates the diagnostic difficulties highlighted in the literature. A detailed clinical evaluation, complemented by thorough imaging exams, was crucial for accurately differentiating these two anomalies and achieving a conclusive diagnosis [6; 7]. For this reason, radiographic analysis focusing on aspects such as the number and morphology of roots, the pulp chamber, and pulp horns becomes a fundamental pillar for diagnostic confirmation [1].

Failure to identify and delays in treating these anomalies can lead to severe complications in dental development, including plaque accumulation due to irregular morphology, a predisposition to carious lesions, and occlusal alterations that result in dental crowding [1; 8]. The atypical morphology of these conditions creates niches that are difficult to access for oral hygiene, making the patient more vulnerable to inflammatory and infectious processes. In this context, cone-beam computed tomography (CBCT) emerges as a highly valuable diagnostic tool, providing detailed three-dimensional information that cannot be obtained with conventional radiography and is essential for precise treatment planning [2; 4; 5; 9]. However, in the reported case, the patient's financial constraints precluded the use of CBCT, and the diagnosis was established through conventional clinical and radiographic exams, highlighting the importance of the clinician's skill in interpreting less advanced findings.

The occurrence of fusion in molars is particularly rare, affecting between 0.5% and 1% of the general population and, even more specifically, only 0.05% to 0.2% of permanent teeth [11]. Such anomalous teeth may compromise esthetics, masticatory function, and lead to orthodontic and periodontal issues, emphasizing the relevance of this case report to the dental literature, as cases involving third molars fused with supernumerary teeth are even more unique. Endodontic management of teeth with morphological anomalies is inherently challenging, as their anatomical complexities can hinder access, proper chemical-mechanical preparation, and complete obturation of the root canal system [2; 4; 5; 12]. The variation in the number of canals, their atypical configurations, and the presence of isthmuses and branches demand refined techniques and the use of technologies that aid in visualization and instrumentation. However, efficient cleaning of the root canal system is directly proportional to the predictability and long-term success of the treatment.

The successful outcome in this challenging reported case of fusion underscores the integration of advanced technologies, particularly the operating microscope, proved instrumental from initial access refinement to the confirmation of five distinct root canals, a number often difficult to discern with conventional methods [2; 4; 5].

Fig. 3. Periapical radiograph showing the fused tooth after five years of treatment

Рис. 3. Периапикальный рентгеновский снимок, показывающий сросшийся зуб через пять лет после лечения

This enhanced visualization facilitated precise chemical-mechanical preparation using nickel-titanium rotary instruments via the Logic 2 25.05 crown-down technique, paramount for thorough debridement in atypical canal systems [1].

Furthermore, the robust irrigation protocol, featuring active ultrasonic agitation with 5.25% NaOCl and 17% EDTA, ensured comprehensive disinfection of the intricately shaped root canal system, mitigating risks associated with residual microbial load [12]. The thermoplastic gutta-percha hybrid technique by Tagger then provided dense, three-dimensional obturation, crucial for long-term sealing in aberrant anatomies. This comprehensive approach, combining high-magnification optics with sophisticated instrumentation and disinfection strategies, directly contributed to the tooth's functional maintenance over five years, validating its efficacy in preserving teeth with rare morphological alterations [5] (Fig. 3).

CONCLUSION

This case report highlights the complexity of endodontic treatment in a rare case of fusion involving a third molar and a supernumerary tooth. It is concluded that the management of morphologically complex dental anomalies requires careful planning and the use of advanced technology. Such approaches are essential to ensure clinical success and the long-term functional maintenance of the tooth.

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AUTHOR'S CONTRIBUTION

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Original Research

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Comparison of the effect of endodontic-periodontal combined lesions on clinical outcomes

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Abstract

INTRODUCTION. Endodontic-periodontal combined lesions are complicated clinical cases with prognoses that vary in their predictability with regard to the underlying etiology and involvement. The interdependence between lesion classification and outcome of treatment is yet to be fully defined.

MATERIALS AND METHODS. 165 teeth with endodontic-periodontal lesions were used in a prospective cohort study (Group A primary endodontic lesions with secondary periodontal involvement, n = 55), Group B primary periodontal lesions with secondary endodontic involvement, n = 55) and Group C true combined lesions, n = 55). Every tooth was subjected to the right endodontic and periodontal treatment. Clinical outcomes such as probing pocket depth (PPD), clinical attachment level (CAL), tooth mobility, as well as periapical index after 3, 6, 12 months were evaluated. Success with the treatment, survival of the teeth, and patient-reported outcomes were assessed.

RESULTS. The general success rate of treatment was 73.3 and the differences between the groups were significant: Group A (89.1%), Group B (69.1%), Group C (61.8%), p<0.001. Groups A showed better results with 4.82 plus or minus 1.24 mm difference in mean PPD reduction compared to 3.41 plus or minus 1.38 mm difference in Group B and 2.87 plus or minus 1.52 mm difference in Group C at the age of 12 months ($p < 0.001$). Group A, Group B and Group C showed a mean CAL gain of 4.15 + 1.18 mm, 2.94 + 1.32 mm and 2.31 + 1.45 mm respectively ($p < 0.001$). The tooth survival rates in Group A (94.5), Group B (83.6), and Group C (76.4) were significant ($p = 0.012$). Patients with initial PPD >7 mm (OR = 3.84, $p < 0.001$) and true combined lesions (OR = 4.92, $p < 0.001$) were important predictors of treatment failure.

CONCLUSIONS. Primary endodontic lesions through secondary periodontal involvement portray highly better treatment results than primary periodontal lesions or true combined lesions. Lesion classification is a vital prognostic factor, which is used in the treatment planning and counseling of patients.

Keywords: endodontic-periodontal lesion, endo-perio lesion, combined lesion, treatment outcome, prognosis, regeneration, endodontics, periodontology

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Сравнение влияния сочетанных эндодонтическо-пародонтальных поражений на клинические исходы

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Резюме

ВВЕДЕНИЕ. Сочетанные эндодонтическо-пародонтальные поражения представляют собой сложные клинические случаи с вариабельным и не всегда предсказуемым прогнозом, зависящим от этиологии и степени вовлечения тканей. Взаимосвязь между классификацией поражения и результатами лечения до настоящего времени окончательно не определена.

МАТЕРИАЛЫ И МЕТОДЫ. В проспективное когортное исследование включено 165 зубов с эндодонтическо-пародонтальными поражениями: группа А – первичные эндодонтические поражения с вторичным пародонтальным вовлечением (n = 55); группа В – первичные пародонтальные поражения с вторичным эндодонтическим вовлечением (n = 55); группа С – истинные сочетанные поражения (n = 55). Всем зубам проведено соответствующее эндодонтическое и пародонтологическое лечение. Оценка клинических исходов включала глубину зондирования пародонтальных карманов (PPD), уровень клинического прикрепления (CAL), подвижность зубов и периапикальный индекс через 3, 6 и 12 месяцев. Анализировались эффективность лечения, выживаемость зубов и показатели, сообщаемые пациентами.

РЕЗУЛЬТАТЫ. Общая эффективность лечения составила 73,3%, при этом различия между группами были статистически значимыми: группа А – 89,1%, группа В – 69,1%, группа С – 61,8% (p < 0,001). В группе А отмечено более выраженное снижение средней глубины зондирования (4,82 ± 1,24 мм) по сравнению с группой В (3,41 ± 1,38 мм) и группой С (2,87 ± 1,52 мм) через 12 месяцев (p < 0,001). Прирост CAL составил соответственно 4,15 ± 1,18 мм в группе А, 2,94 ± 1,32 мм в группе В и 2,31 ± 1,45 мм в группе С (p < 0,001). Показатели выживаемости зубов были значимо выше в группе А (94,5%) по сравнению с группой В (83,6%) и группой С (76,4%) (p = 0,012). Исходная глубина зондирования >7 мм (OR = 3,84; p < 0,001) и наличие истинного сочетанного поражения (OR = 4,92; p < 0,001) являлись значимыми предикторами неудачи лечения.

ВЫВОДЫ. Первичные эндодонтические поражения с вторичным пародонтальным вовлечением демонстрируют значительно лучшие результаты лечения по сравнению с первичными пародонтальными и истинными сочетанными поражениями. Классификация поражения является важным прогностическим фактором, который следует учитывать при планировании лечения и консультировании пациентов.

Ключевые слова: эндодонтическо-пародонтальное поражение, эндо-перио поражение, сочетанное поражение, исход лечения, прогноз, регенерация, эндодонтия, пародонтология

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INTRODUCTION

Endodontic-periodontal lesions are peculiar diagnostic and treatment issues in clinical dentistry, which includes the concomitant or secondary participation of the dental pulp and periodontal supporting structures [1]. The anatomical and vascular relationships between the pulp and periodontium via apical foramina, lateral canals, dentinal tubules and furcation sites offer channels of bi-direction disease progression [2]. The interrelationship of endodontic and periodontal pathology is important in the correct diagnosis, correct sequence of treatment, and realistic prognostic evaluation [3].

Endodontic-periodontal lesions are more common in clinical practice affecting between 3–10% of endodontic cases and 5–18% of periodontal cases on the basis of population factors and diagnostic protocols [4; 5]. They may have a pulp-based pathology that extends via accessory canals into periodontal tissues (primary endodontic lesions with secondary periodontal involvement), periodontal disease that advances apically to pulpal vitality (primary periodontal lesions with secon-

dary endodontic involvement), or both of these disease conditions may co-exist (true combined lesions) [6].

A commonly used system of endodontics periodontal lesion classification was suggested by Simon et al. [7], which is based on the location of the disease origin and the range of its involvement. This classification is divided into: primary endodontic lesions, primary periodontal lesions, primary endodontic lesions with secondary periodontal lesion, secondary endodontic lesion with primary periodontal lesion and true combined lesions. Later refinements and changes have been suggested, such as the 2017 classification of World Workshop that focuses on periodontal status and endodontic diagnosis [8].

Endodontic-periodontal lesion is the result of intricate microbiological and immunological connections [9]. Both periodontal diseases and endodontic infections are polymicrobial in nature with a great deal of overlap of bacteria species including Porphyromonas gingivalis, Prevotella intermedia, Fusobacterium nucleatum and Aggregatibacter actinomycetemcomitans [10]. This process can result in self-perpetuating inflammatory cycles with the inflammatory products of one site infiltrating the disease progression of another site, and vice versa.

Endodontic-periodontal lesions should be diagnosed through the use of extensive clinical and radiographic assessment [11]. Such diagnostic procedures as: pulp vitality testing, periodontal probing to identify vertical bone defects or furcation involvement, assessment of tooth mobility, percussion and palpation tests, radiographic examination to determine the pattern of periapical pathology and bone loss are essential [12]. The more sophisticated imaging modalities (including cone-beam computed tomography (CBCT)) can help to offer useful three-dimensional data on the degree of bone destruction and anatomical complexities [13].

The management of endodontic-periodontal lesions would require the consideration of both endodontic and periodontal aspects in a logical, sequenced manner [14]. The general rule is to have the first endodontic therapy to remove the pulpal infection, followed by a period of adequate rest (usually 2–3 months), and a periodontal therapy is carried out in case of residual periodontal defects [15]. Primary endodontic lesions with secondary periodontal involvement tend to heal well with pure root canal therapy but primary periodontal or true combined lesions need full periodontal treatment comprising of surgical debridement and perhaps regenerative treatment [16].

Although there is massive clinical experience and published literature regarding the endodontic-periodontal lesions, there are still gaps in knowledge. The current literature is predominantly retrospective case series or cross-sectional studies and has a short follow-up [17]. There are limited comparative prospective studies of the outcomes of various treatment of lesions based on the classification of lesions. Moreover, the effects of the nature of certain lesions, including lesion size, tooth position and patient variables on the healing outcomes should be investigated systematically [18]. Determination of credible prognostic factors may lead to better clinical judgments on the mode of treatment or rather extraction advice.

This knowledge on the heterogeneity of the response of different forms of endodontic-periodontal lesions to different treatments has significant implications in clinical practice in terms of treatment planning, resource utilization and patient education on the expected outcome and prognosis [19]. Also, this knowledge may be used to inform the adjustments to the classification systems and treatment protocols [20].

Thus, the objective of the current study was to prospectively compare clinical outcome of varying types of endodontic-periodontal combined lesions using standardized treatment treatment regimes, to evaluate how lesion classification varies with clinical outcome in terms of successful and failure of treatment, to determine how clinical outcome varies with time in terms of lesion type, and to determine independent prognostic factors related to treatment success and failure.

MATERIALS AND METHODS

Study design and setting

this prospective cohort study was conducted at the Department of Conservative Dentistry and Endodontics from January 2021 to March 2023.

Sample size calculation

sample size was determined using G*Power software version 3.1.9.7 for comparing three independent groups, considering an effect size of 0.35 based on pilot data, alpha error of 0.05, and power of 85%. The minimum required sample size was calculated as 48 participants per group. Accounting for 15% potential dropout rate, 55 participants were recruited for each group, yielding a total sample of 165 teeth.

Study population

The study population comprised 165 teeth in 148 patients presenting with endodontic-periodontal lesions. Teeth were classified into three groups based on clinical and radiographic diagnosis:

Group A: Primary endodontic lesions with secondary periodontal involvement ($n = 55$).

Group B: Primary periodontal lesions with secondary endodontic involvement ($n = 55$).

Group C: True combined lesions (simultaneous independent endodontic and periodontal pathology) ($n = 55$).

Diagnostic criteria

Group A: Negative pulp vitality test, presence of sinus tract or acute periapical abscess, vertical bone loss communicating with periapical lesion, recent onset of periodontal involvement.

Group B: Generalized periodontal disease with probing depths ⩾5 mm, horizontal bone loss pattern, pulp vitality recently compromised, established periodontal history.

Group C: Non-vital pulp, periapical radiolucency, extensive periodontal bone loss (⩾50% bone loss), probing depths ⩾6mm, no clear temporal sequence of disease onset.

Inclusion criteria

1. Age 25–65 years.
2. Single or multi-rooted permanent teeth with endodontic-periodontal lesions.
3. Teeth deemed restorable with adequate coronal structure.
4. Probing pocket depth ⩾5 mm with radiographic bone loss.
5. Patient willing to comply with treatment and follow-up protocols.
6. Adequate oral hygiene (Plaque Index < 1.5 after initial therapy).

Exclusion criteria

1. Uncontrolled systemic diseases (diabetes mellitus with HbA1c > 7%, cardiovascular disease, immunocompromised states).
2. Pregnancy or lactation.
3. Smokers (> 10 cigarettes/day).
4. Teeth with vertical root fractures or perforations.
5. Severe tooth mobility (Grade III) with hopeless prognosis.
6. Previous endodontic treatment.
7. Antibiotic use within 3 months.
8. Inability to maintain adequate oral hygiene.

Treatment protocol

All patients received standardized treatment protocols administered by calibrated clinicians.

Initial phase therapy

1. Oral hygiene instruction and motivation.
2. Supragingival and subgingival scaling.
3. Re-evaluation after 4 weeks.

Endodontic treatment

All teeth received non-surgical root canal treatment following standardized protocols:

1. Access cavity preparation under rubber dam isolation.
2. Working length determination using electronic apex locator and radiographic confirmation.
3. Cleaning and shaping using crown-down technique with rotary nickel-titanium instruments.
4. Irrigation with 2.5% sodium hypochlorite and 17% EDTA.
5. Obturation using lateral compaction technique with gutta-percha and AH Plus sealer.
6. Coronal restoration with composite resin or indirect restoration as indicated.

Periodontal treatment

Following endodontic treatment completion and 8-week healing period:

1. Re-probing to assess residual periodontal defects.
2. Open flap debridement for persistent defects ⩾5 mm.
3. Bone grafting with demineralized freeze-dried bone allograft for intrabony defects > 3 mm.
4. Guided tissue regeneration using resorbable membranes for selected cases.
5. Postoperative care and maintenance.

Outcome assessment

Clinical examinations were performed by calibrated examiners (inter-examiner reliability $\kappa = 0.91$) blinded to group allocation at baseline, 3-, 6-, and 12-months post-treatment.

Primary outcome

Treatment success: defined as tooth retention with resolution of symptoms, pocket depth ⩽4 mm, no suppuration, and radiographic evidence of bone fill or stability.

Secondary outcomes

Clinical parameters

Probing Pocket Depth (PPD): measured at six sites per tooth using UNC-15 probe.

Clinical Attachment Level (CAL): measured from CEJ to pocket base.

Tooth Mobility: assessed using Miller's classification (0–III).

Bleeding on Probing (BOP): percentage of sites with bleeding.

Gingival Index (GI): Löe and Silness index.

Radiographic assessment

Periapical Index (PAI): scored 1-5 according to Orstavik criteria.

Bone level measurements: assessed on standardized periapical radiographs using digital analysis software.

Patient-reported outcomes

pain: assessed using Visual Analog Scale (VAS, 0–10).

Satisfaction: 5-point Likert scale.

Quality of life: Oral Health Impact Profile-14 (OHIP-14).

Statistical analysis

Data were analyzed using SPSS version 28.0 and *R* software version 4.2.2. Normality was assessed using the Shapiro-Wilk test. Continuous variables were expressed as mean ± standard deviation and compared using one-way ANOVA with post-hoc Tukey's HSD test for multiple comparisons. Repeated measures ANOVA was employed to assess temporal changes within groups. Categorical variables were presented as frequencies and percentages and analyzed using chi-square test or Fisher's exact test. Kaplan-Meier survival analysis with log-rank test was performed to compare tooth survival across groups. Binary logistic regression analysis was conducted to identify independent predictors of treatment success. Statistical significance was set at $p < 0.05$.

RESULTS

Demographic and baseline characteristics

The study included 165 teeth in 148 patients (mean age 42.8 ± 11.3 years; 87 females, 61 males). Group A comprised 55 teeth (mean age 40.6 ± 10.8 years), Group B 55 teeth (mean age 43.8 ± 11.4 years), and Group C 55 teeth (mean age 44.1 ± 11.7 years), with no significant age difference ($p = 0.182$). Tooth distribution included 68 maxillary teeth (41.2%) and 97 mandibular teeth (58.8%). Single-rooted teeth comprised 58.2% ($n = 96$) and multi-rooted teeth 41.8% ($n = 69$).

Treatment outcomes and success rates

Overall treatment success rate at 12 months was 73.3% (121/165 teeth), with significant variation across groups (Table 1).

Clinical parameter changes

Table 2 presents the comparison of clinical parameters across groups at baseline and 12 months post-treatment.

Repeated measures ANOVA revealed significant improvement in all clinical parameters over time within each group ($p < 0.001$), with significant group × time interaction effects ($p < 0.001$), indicating differential healing patterns.

Radiographic bone fill

Table 3 demonstrates radiographic bone fill measurements at 12 months across groups.

Table 1. Treatment success rates and tooth survival across groups

Таблица 1. Показатели успешности лечения и выживаемости зубов в разных группах

Outcome Parameter	Group A (*n* = 55)	Group B (*n* = 55)	Group C (*n* = 55)	*p*-value*
Treatment Success at 12 months, *n* (%)	49 (89.1)	38 (69.1)	34 (61.8)	0.002
Complete Healing, *n* (%)	42 (76.4)	28 (50.9)	22 (40.0)	< 0.001
Partial Healing, *n* (%)	7 (12.7)	10 (18.2)	12 (21.8)	0.387
Treatment Failure, *n* (%)	6 (10.9)	17 (30.9)	21 (38.2)	0.002
Tooth Survival, *n* (%)	52 (94.5)	46 (83.6)	42 (76.4)	0.012
Tooth Extraction, *n* (%)	3 (5.5)	9 (16.4)	13 (23.6)	0.012
Reasons for Extraction				
Persistent symptoms	1 (1.8)	4 (7.3)	6 (10.9)	–
Progressive bone loss	1 (1.8)	3 (5.5)	5 (9.1)	–
Root fracture	1 (1.8)	2 (3.6)	2 (3.6)	–
Mean Time to Failure (months) ± SD	4.2 ± 2.1	5.8 ± 2.7	6.3 ± 3.1	0.216†

Note: * Chi-square test or Fisher's exact test; † One-way ANOVA

Примечание: * Критерий Хи-квадрат или точный критерий Фишера; † Односторонний дисперсионный анализ

Table 2. Comparison of clinical parameters at baseline and 12 months

Таблица 2. Сравнение клинических показателей на исходном этапе и через 12 месяцев

Parameter	Time Point	Group A (*n* = 52) Mean ± SD	Group B (*n* = 46) Mean ± SD	Group C (*n* = 42) Mean ± SD	*p*-value*
Probing Pocket Depth (mm)	Baseline	7.24 ± 1.48	7.63 ± 1.52	8.12 ± 1.64	0.014
	12 months	2.42 ± 0.86	4.22 ± 1.24	5.25 ± 1.38	< 0.001
	Reduction	4.82 ± 1.24	3.41 ± 1.38	2.87 ± 1.52	< 0.001†
Clinical Attachment Level (mm)	Baseline	7.86 ± 1.52	8.34 ± 1.68	8.92 ± 1.76	0.006
	12 months	3.71 ± 1.08	5.40 ± 1.42	6.61 ± 1.58	< 0.001
	Gain	4.15 ± 1.18	2.94 ± 1.32	2.31 ± 1.45	< 0.001†
Tooth Mobility (0–3 scale)	Baseline	1.62 ± 0.68	1.89 ± 0.72	2.18 ± 0.76	< 0.001
	12 months	0.38 ± 0.52	0.87 ± 0.64	1.24 ± 0.71	< 0.001
	Improvement	1.24 ± 0.58	1.02 ± 0.62	0.94 ± 0.68	0.044†
Bleeding on Probing (%)	Baseline	78.4 ± 16.2	82.3 ± 14.8	86.2 ± 13.6	0.018
	12 months	18.6 ± 12.4	32.8 ± 16.7	41.5 ± 18.9	< 0.001
Periapical Index (1–5)	Baseline	3.84 ± 0.82	3.12 ± 0.94	3.96 ± 0.88	< 0.001
	12 months	1.42 ± 0.61	1.87 ± 0.78	2.31 ± 0.86	< 0.001

Note: * One-way ANOVA comparing groups at each time point; † Post-hoc Tukey's test showed significant differences between Group A vs. B ($p < 0.05$), Group A vs. C ($p < 0.001$), and Group B vs. C ($p < 0.05$) for most parameters.

Примечание: * Односторонний анализ ANOVA, сравнивающий группы в каждый момент времени; † Последующий тест Тьюки показал достоверные различия между группами А и В ($p < 0{,}05$), А и С ($p < 0{,}001$) и В и С ($p < 0{,}05$) по большинству параметров.

Table 3. Radiographic bone fills at 12 months

Таблица 3. Рентгенографические данные о заполнении костной ткани через 12 месяцев

Bone Fill Parameter	Group A (*n* = 52)	Group B (*n* = 46)	Group C (*n* = 42)	*p*-value*
Mean Bone Fill (mm) ± SD	3.68 ± 1.24	2.41 ± 1.38	1.87 ± 1.42	< 0.001†
Percentage Bone Fill (%) ± SD	62.4 ± 18.6	41.3 ± 22.4	32.6 ± 20.8	< 0.001†
Bone Fill Categories:				
Excellent (> 75% fill), *n* (%)	18 (34.6)	8 (17.4)	4 (9.5)	0.006
Good (50–75% fill), *n* (%)	21 (40.4)	14 (30.4)	10 (23.8)	0.178
Moderate (25–50% fill), *n* (%)	9 (17.3)	16 (34.8)	18 (42.9)	0.016
Poor (< 25% fill), *n* (%)	4 (7.7)	8 (17.4)	10 (23.8)	0.077
Complete Resolution of Periapical Lesion, *n* (%)	44 (84.6)	32 (69.6)	26 (61.9)	0.021
Reduction in Lesion Size ⩾ 50%, *n* (%)	7 (13.5)	10 (21.7)	11 (26.2)	0.248
No Change or Progression, *n* (%)	1 (1.9)	4 (8.7)	5 (11.9)	0.111

Note: * Chi-square test; † One-way ANOVA with post-hoc Tukey's test showing significant differences between all group pairs ($p < 0.05$)

Примечание: * Критерий Хи-квадрат; † Односторонний дисперсионный анализ с последующим использованием теста Тьюки, показывающий достоверные различия между всеми парами групп ($p < 0,05$)

Patient-reported outcomes

Pain scores (VAS) decreased significantly from baseline to 12 months in all groups: Group A (6.84 ± 1.92 to 0.52 ± 0.84), Group B (6.92 ± 2.04 to 1.24 ± 1.12), Group C (7.16 ± 2.12 to 1.86 ± 1.34), with Group A demonstrating significantly lower pain at 12 months ($p < 0.001$).

Patient satisfaction rates (satisfied or very satisfied) at 12 months were: Group A (88.5%), Group B (71.7%), Group C (64.3%), $p = 0.008$.

OHIP-14 total scores improved across all groups, with Group A showing greatest improvement: baseline 24.6 ± 6.8 to 12-month 8.4±4.2 (improvement 16.2 ± 5.6), compared to Group B (improvement 11.8 ± 6.4) and Group C (improvement 9.7 ± 6.8), $p = 0.001$.

Prognostic factors

Binary logistic regression analysis identified independent predictors of treatment failure:

1. Initial PPD > 7 mm: OR = 3.84 (95% CI: 1.82–8.12), – < 0.001.

2. True combined lesion (Group C): OR = 4.92 (95% CI: 2.14–11.31), $p < 0.001$.

3. Multi-rooted tooth: OR = 2.67 (95% CI: 1.23–5.79), $p = 0.013$.

4. Furcation involvement Grade II–III: OR = 3.21 (95% CI: 1.45–7.11), $p = 0.004$.

5. Age >50 years: OR = 1.86 (95% CI: 0.89–3.88), $p = 0.098$ (non-significant).

Kaplan-Meier survival analysis demonstrated significant differences in tooth survival across groups (log-rank test, $\chi^2 = 9.84$, $p = 0.007$), with 12-month survival estimates of 94.5% (Group A), 83.6% (Group B), and 76.4% (Group C).

DISCUSSION

In this prospective cohort study, the clinical outcome of 165 teeth with endodontic-periodontal combined lesions was thoroughly examined in three categories of classification and demonstrated a significant variation in the healing of the teeth, success rates of the treatment, and tooth survival. The results indicate that a classification of lesions is a vital prognostic factor, and primary endodontic lesions with secondary periodontal involvement have significantly good prognoses relative to primary periodontal lesions or genuine combined lesions.

The success rate of 73.3% overall of the treatment in the present study is in line with the historical research which has shown the success rate of endodontic-periodontal lesions to be 65% to 85% with the main difference in studies being brought about by the heterogeneous nature of diagnostic criteria, treatment regimen and follow-up periods [1]. The much better outcome of Group A (89.1) than those of Groups B (69.1) and C (61.8) supports the well-known clinical rule according to which lesions of primary endodontic origin tend to show more positive prognoses [2].

The pathophysiology of primary endodontic lesions to produce the best results is associated with the fact that secondary periodontal involvement is reversible in case the primary focus of infection is removed [3]. Pulpal necrosis and consequent periapical inflammation in Group A lesions may spread along accessory canals, apical foramen or lateral communications to develop periodontal defects. Nevertheless, the defects are usually continuations of endodontic pathology and not really periodontal breakdown. Treatment of endodontic disease removes the bacterial reservoir, and periodontal tissues will regenerate, and through inflammation resolution and new attachments formation [4]. This effect was the cause of the significant reduction in PPD (4.82 ± 1.24 mm) and the CAL gain (4.15 ± 1.18 mm), which was achieved to a great extent during the post-endodontic condition only after endodontic treatment with minimal periodontal intervention in Group A.

Group B lesions (primary periodontal with secondary endodontic involvement), on the contrary, had intermediate outcomes. Such cases are characterized by chronic periodontal disease that has advanced in-

vasions that go apically to jeopardize the vitality of the pulp by means of lateral canals or apical communications [5]. The periodontal breakdown that is established and has lost the connective tissue attachment, bone resorption and microbial ecology pose more challenges in regeneration [6]. Periodontal defects present prior to the endodontic treatment are left even with the successful endodontic treatment which removes the pulpal infection and the periodontal defects need to be completely addressed through periodontal therapy. The mild decrease (3.41 ± 1.38 mm) and CAL increase (2.94 ± 1.32 mm) of this group indicate the low regenerative ability of periodontal tissues that have been destroyed by chronic inflammation.

The worst results were found in the group C lesions (true combined) and this finding is in line with the available literature that reported this category of lesions to have the poorest prognosis [7]. True combined lesions include independent pathological processes of the periodontal and pulpal tissues simultaneously, which is typical of the teeth with a high periodontal breakdown and pulpal necrosis. The dual etiology requires the thorough treatment of both components, but due to the excessive tissue damage and extensive inflammatory burden, the regenerative capability is compromised [8]. The low level of clinical response (PD reduction 2.87 ± 1.52 mm, CAL gain 2.31 ± 1.45 mm) and high rate of failure (38.2%) in this group highlight the biological constraints of the present treatment modalities in case of severely compromised teeth.

The radiographic bone fill data are some objective evidences to the clinical findings. Group A exhibited a mean bone fill 3.68 ± 1.24 mm (62.4% fill), which was much better than Groups B and C. This is a significant bone regeneration in initial endodontic lesions which is an indicator of the healing potential in the presence of the elimination of infectious source. The 84.6 percent rate of full periapical lesion resolution in the Group A agrees with anticipated results of endodontic treatment [9]. The gradual worsening of the groups in terms of bone fill is associated with the growing severity and complexity of periodontal involvement.

There are clinical implications of identifying initial PPD > 7 mm as an important predictor of treatment failure (OR = 3.84). Deep periodontal pockets pose several problems such as the inability to eliminate bacteria completely, impaired blood supply to the area making healing difficult and increased tissue destruction which is a limitation to regenerative processes [10]. This observation implies that teeth with severe periodontal destruction can be considered to undergo more aggressive treatments, such as regenerative therapy or even removal with a restoration alternative.

The much lower results in the case of multi-rooted teeth (OR = 2.67) and the presence of furcation (OR = 3.21) are due to the anatomical complexity of such cases [11]. The furcation areas pose special challenges because of the access difficulty of instrumentation, complicated structure of the anatomy with many accessory canals, and disability of the blood supply. It has always been shown that the survival of teeth with furcations is low in the long-term in comparison to the survival of teeth without furcation [12].

The patient-reported outcomes such as the reduction of pain, satisfaction and the improvement of quality of life corroborated clinical and radiographic results. The much higher results in Group A in all patient-centered measures, point to the fact that objective clinical gains are converted to tangible patient benefits. The Group A increase of 16.2 points in OHIP-14 is a clinically significant improvement in oral health-related quality of life [13].

The patterns of time-dependent healing as indicated by repeated measures analysis indicated that the largest amounts of clinical improvement were found during the initial 3-6 months with a gradual continuous improvement up to 12 months. This time course is similar to the healing processes in biology, as soft tissue recovery happens first, and bone regeneration occurs more slowly [14]. Although the follow-up period (12 months) will present useful outcome data, long-term stability may be missed. Findings on 3–5-year follow-up studies have also indicated the presence of other late failures, and hence, there is the need to extend follow-up [15].

The clinical implications of these findings are great. Correct diagnosis of endodontic-periodontal lesions is the key to a prognostic evaluation and treatment planning. As clinicians should know that primary endodontic lesions with secondary periodontal involvement should be treated firstly with endodontic treatment with re-examination before periodontal treatment, since most periodontal defects can be self-limiting [16]. Secondary endodontic involvement of primary periodontal lesions needs a complete periodontal treatment besides endodontic treatment. Combined lesions are the most difficult and they might be considered extraction and replacement options, especially when various negative prognostic factors are combined [17].

The strengths of the study are prospective design, large sample size with equal group distribution, standard treatment procedures, extensive outcome evaluation such as clinical, radiographic, and patient-reported outcomes and sufficient follow-up period. There are a number of limitations that should be taken into consideration. The 12 months follow-up is not extensive enough to reflect long-term results or the eventual failure. Generalizability is limited by the exclusion of patients with medical limitations and smokers. There was no control group that was not being treated as the study was an ethical consideration. Also, classification was based on clinical judgement and subjectivity is inherent in subjective clinical judgement regardless of the normative diagnostic criteria [18].

The future research needs to be done over a longer period (at least 3–5 years) to determine long-term stability, exploration of adjunctive treatments such as regenerative materials and laser-assisted treatment, microbial profiling of the bacterial profiles in each type of lesion, genetic and molecular marker research to determine individual variation in healing capacity, and cost-effectiveness studies comparing treatment with extraction and replacement approaches [19; 20].

CONCLUSION

This proposed comparative trial shows that the use of endodontic-periodontal lesion classification has a strong impact on the outcome of treatment and prognosis. Primary endodontic lesions that have secondary periodontal involvement show significantly better healing response than primary periodontal lesions or true combined lesions and the success rate of the treatment is 89.1 versus 69.1 and 61.8 respectively. Primary endodontic lesions are shown to be treated with endodontic therapy alone with significant periodontal healing, which typically does not require the extensive periodontal intervention. True combined lesions, on the contrary, are the most difficult to treat, have low regenerative capacity, and have high failure rates.

Such critical prognostic factors as initial probing depth (more than 7 mm), lesion classification type, furcation involvement, and tooth type (multi-rooted versus single-rooted) are considered. These needs ought to be considered in the treatment planning and patient counselling on the realistic expectation of outcomes. In cases of teeth having both negative prognostic factors, especially the true combined ones that have extensively broken down their periodontium and the furcation, extraction and replacement options should be taken into serious consideration.

The results underline the need to consider proper differential diagnosis in the endodontic-periodontal lesion because the classification has a direct impact on the sequencing of treatment, the intensity of intervention, and anticipated results. Clinicians need to use a holistic diagnostic regimen such as pulp vitality test, proper periodontal examination and radiology to properly classify lesions prior to commencing treatment. Endodontic-periodontal lesions management a systematic, evidence-based strategy based on the classification of the lesion and individual prognostic factors would maximize clinical outcomes and tooth survival, as well as help with the proper choice of treatment in this problematic type of dental pathology.

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AUTHOR'S CONTRIBUTION

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Original Research

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Comparative evaluation of success rates in endodontic therapy versus oral medicine interventions in the management of chronic periapical lesions

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Abstract

INTRODUCTION. Chronic periapical lesions are an outcome of pulpal necrosis that necessitates final treatment. Although the traditional endodontic treatment is still the gold standard, the use of adjunctive interventions based on oral medicine and conservative pharmacological approaches as potential modes of treatment have been proposed.

MATERIALS AND METHODS. A prospective comparative study was performed on 180 patients with chronic periapical lesions who were grouped as Group A (conventional endodontic therapy only, $n = 60$), Group B (endodontic therapy plus systemic pharmacological intervention, $n = 60$) and Group C (conservative oral management and delayed endodontic intervention, $n = 60$). The main outcomes were the level of healing success, reduction of the size of the lesion, and the resolution of the symptoms measured at 3, 6, and 12 months. Secondary outcomes were pain scores, quality of life and treatment complications.

RESULTS. 12 months overall success rates were: Group A (83.3%), Group B (91.7%), Group C (45.0%), $p < 0.001$. The lesion size reduction in terms of the mean was also 4.82 ± 1.24 mm (Group A), 5.67 ± 1.18 mm (Group B) and 2.14 ± 1.52 mm (Group C), $p < 0.001$. Total periapical healing Group A (76.7), Group B (85.0) and Group C (33.3), $p < 0.001$. The Group B (4.2 + 1.8 days) and the Group C (12.6 + 4.8 days) had significantly shorter pain resolution times when compared to Group A (6.8 + 2.4 days), $p < 0.001$. The highest level of patient satisfaction was obtained in Group B (8.64 + 1.12) in comparison to Group A (7.92 + 1.34) and Group C (5.28 + 1.86), $p = 0.001$. Group A, 10.0%: Group B, 5.0%: Group C, 41.7%: treatment failure requiring surgical intervention was found.

CONCLUSIONS. Endodontic therapy with systemic pharmacological intervention has better results compared to endodontic therapy or conservative oral medicine treatment. The outcome of conservative pharmacological treatment without conclusive endodontic therapy is far worse and thus there is a need to treat the infectious etiology to achieve success in treating periapical lesions.

Keywords: periapical lesion, endodontic therapy, oral medicine, antibiotics, anti-inflammatory drugs, treatment outcome, periapical healing, root canal treatment

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Сравнительная оценка показателей успеха эндодонтической терапии и вмешательств в области оральной медицины при лечении хронических периапикальных поражений

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Резюме

ВВЕДЕНИЕ. Хронические периапикальные поражения являются следствием некроза пульпы и требуют окончательного лечения. Несмотря на то что традиционное эндодонтическое лечение остается «золотым стандартом», в качестве возможных терапевтических подходов предлагается применение вспомогательных вмешательств в рамках оральной медицины и консервативной фармакотерапии.

МАТЕРИАЛЫ И МЕТОДЫ. Проведено проспективное сравнительное исследование с участием 180 пациентов с хроническими периапикальными поражениями, распределенных на три группы: группа A (только традиционная эндодонтическая терапия, $n = 60$), группа B (эндодонтическая терапия в сочетании с системной фармакологической терапией, $n = 60$) и группа C (консервативное оральное лечение с отсроченным эндодонтическим вмешательством, $n = 60$). Основными оцениваемыми параметрами являлись уровень заживления, уменьшение размеров очага поражения и купирование симптомов через 3, 6 и 12 месяцев. Вторичные показатели включали выраженность болевого синдрома, качество жизни и осложнения лечения.

РЕЗУЛЬТАТЫ. Через 12 месяцев общие показатели успеха составили: группа A – 83,3%, группа B – 91,7%, группа C – 45,0% ($p < 0,001$). Среднее уменьшение размеров очага поражения составило 4,82 ± 1,24 мм в группе A, 5,67 ± 1,18 мм в группе B и 2,14 ± 1,52 мм в группе C ($p < 0,001$). Полное периапикальное заживление наблюдалось у 76,7% пациентов группы A, 85,0% – группы B и 33,3% – группы C ($p < 0,001$). Время купирования болевого синдрома было достоверно меньше в группе B (4,2 ± 1,8 дня) и группе C (12,6 ± 4,8 дня) по сравнению с группой A (6,8 ± 2,4 дня), $p < 0,001$. Наивысший уровень удовлетворенности пациентов отмечен в группе B (8,64 ± 1,12) по сравнению с группой A (7,92 ± 1,34) и группой C (5,28 ± 1,86), $p = 0,001$. Частота неудач лечения, потребовавших хирургического вмешательства, составила: группа A – 10,0%, группа B – 5,0%, группа C – 41,7%.

ВЫВОДЫ. Эндодонтическая терапия в сочетании с системной фармакологической поддержкой демонстрирует более высокую эффективность по сравнению с изолированной эндодонтической терапией или консервативным лечением методами оральной медицины. Консервативная фармакотерапия без окончательного эндодонтического вмешательства характеризуется значительно худшими результатами, что подтверждает необходимость устранения инфекционной этиологии для достижения успешного лечения периапикальных поражений.

Ключевые слова: периапикальное поражение, эндодонтическая терапия, оральная медицина, антибиотики, противовоспалительные препараты, исход лечения, периапикальное заживление, лечение корневых каналов

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INTRODUCTION

Chronic periapical lesions are inflammation diseases that occur in the periradicular tissues of the tooth apices and are caused by the presence of the bacteria that were initially embedded into the tooth necrot pulp tissue [1]. These lesions are a huge burden in clinical endodontics since they occur in about 5–10 percent of teeth and are among the most frequent causes of tooth loss among adults [2]. Chronic periapical pathology is radiographically evident as periapical radiolucencies and clinically, may be either asymptomatic or may be accompanied by intermittent symptoms such as tenderness to percussion, mild discomfort, and swelling [3].

The pathogenesis of the chronic periapical lesions is the combination of host-microbial interactions in which the products and metabolites of bacteria of the infected root canals stimulate the chronic inflammatory response of the periapical tissues [4]. This is an inflammatory event, which is mediated by complex immunological cascades and cytokines, prostaglandins and matrix metalloproteinases which eventually culminate in bone resorption and the development of granulomatous tissue/radicular cysts [5]. Chronic periapical infections have a polymicrobial microbiology with obligate anaerobes such as Porphyromonas endodontalis, Prevotella species, Fusobacterium nucleatum, and Peptostreptococcus species [6].

Traditional endodontic therapy that includes pulpectomy, biomechanical preparation, chemomechanical debridement, and three-dimensional obturation of the root canal system is the conventional treatment option of tooth with chronic periapical lesions [7]. The goals of this intervention are to get rid of the infectious agent, avoid reinfection, and provide an environment that would allow periapical healing. The systematic review and meta-analysis show a success rate of between 74 and 86 of primary endodontic treatment of periapical lesion teeth [8]. But there is a group of cases, which shows infiltrating infection or failure of treatment, which requires a retreat treatment or surgery.

It has been demonstrated that adjunctive oral medicine interventions, including systemic antibiotics and anti-inflammatory medication, could improve the outcomes of treatment in a number of ways: a decrease of a bacterial load, regulation of inflammatory reactions, the prevention of complications in the procedure, and the stimulation of periapical healing [9]. The most used antibiotics are amoxicillin, amoxicillin-clavulanate, metronidazole, and azithromycin which have been chosen according to their efficacy in endodontic pathogens [10]. Corticosteroids and non-steroidal anti-inflammatory drugs (NSAIDs) could also help to mitigate the production of inflammatory mediators and prevent post-operative symptoms.

It still is a controversial issue whether systemic antibiotics are essential in standard endodontic therapy [11]. Guidelines usually prescribe antibiotics when patients have systemic manifestation (fever, malaise, lymphadenopathy) or spreading infection, but there is no evident agreement on the use of antibiotics with uncomplicated chronic periapical lesion [12]. Issues of antibiotic resistance, side effects and cost-effectiveness require prudent use of antibiotics. Nevertheless, the adjunctive antibiotic treatment might be applicable to selected cases (extensive lesions), immunocompromised patients, or anatomical considerations.

Another solution that has been considered is conservative oral medicine management which is followed by delayed definitive endodontic therapy especially in areas with limited resources or where a patient cannot undergo endodontic therapy immediately [13]. It involves the use of systemic antibiotics and anti-inflammatory drugs, which are used temporarily to manage infection and symptoms before a final endodontic treatment. Nevertheless, the effectiveness of this conservative methods and their long-term effect are not sufficiently described.

There has been recent research into the comparative effectiveness of various treatment modalities of chronic periapical lesions. A systematic review conducted by Segura-Egea et al. revealed that the treatment protocols and methods of outcomes assessment had a significant level of heterogeneity among the studies [14]. The majority of comparative studies performed so far are concerned with technical differences in endodontic care (use of instruments, irrigation regime, use of intracanal agents) as opposed to comparative studies of underlying philosophies of treatment [15]. There is a scanty body of evidence that directly compares traditional endodontic treatment with any of the other endodontic-pharmacological interventions or self-treatment conservative oral care treatments.

Knowledge of the relative performance of these modes of treatments has significant clinical, economic, and population health consequences [16]. The evidence-based guidance, resource allocation optimization, and patient outcomes could be informed by the identification of the best treatment strategies. Moreover, the description of the effectiveness of conservative pharmacological management would serve as valuable information in the case when the immediate endodontic intervention is not possible [17].

Thus, the purpose of this scrutiny was to compare the success rates and clinical outcome of conventional endodontic treatment, combined endodontic treatment and systemic pharmacological intervention in the treatment of chronic periapical lesions compared to each other, to determine the effectiveness of adjunctive pharmacological interventions on healing parameters and symptom resolution, to determine the feasibility of conservative oral medicine treatment as interim or alternative treatment of chronic periapical lesions, as well as determine the factors that might be linked to the success or failure of treatments in different intervention modalities.

MATERIALS AND METHODS

Study design and setting

This prospective, parallel-group, comparative clinical trial was conducted at the Department of Conservative Dentistry and Endodontics from March 2021 to April 2023.

Sample size determination

Sample size was calculated using G*Power software version 3.1.9.7 for comparing three independent groups, considering an effect size of 0.40 based on pilot study data, alpha error of 0.05, and power of 90%. The minimum required sample size was determined to be 51 participants per group. Accounting for 15% potential dropout rate, 60 participants were recruited for each group, yielding a total sample of 180 patients.

Study population and allocation

The study population comprised 180 adult patients presenting with single-rooted teeth exhibiting chronic periapical lesions. Participants were allocated using computer-generated randomization (1:1:1 ratio) into three treatment groups:

Group A (Conventional Endodontic Therapy): Standard root canal treatment without systemic medications ($n = 60$).

Group B (Combined Intervention): Root canal treatment with adjunctive systemic antibiotics and anti-inflammatory medications ($n = 60$).

Group C (Conservative Oral Medicine): Initial pharmacological management with antibiotics and anti-inflammatory drugs, delayed endodontic intervention after 6 weeks ($n = 60$).

Allocation concealment was maintained using sequentially numbered, sealed, opaque envelopes opened only after patient enrolment.

Inclusion criteria

1. Age 18–60 years.
2. Single-rooted permanent teeth (incisors, canines, premolars) with chronic periapical lesions.
3. Radiographic periapical radiolucency ⩾3 mm in diameter.
4. Non-vital pulp confirmed by negative response to electric pulp testing and cold testing.
5. Teeth restorable with adequate coronal structure.
6. No previous endodontic treatment.
7. Willingness to comply with treatment protocol and follow-up.

Exclusion criteria

1. Systemic conditions affecting healing (uncontrolled diabetes mellitus, immunosuppressive disorders).
2. Pregnancy or lactation.
3. Allergy to penicillin, cephalosporins, or NSAIDs.
4. Antibiotic use within previous 3 months.
5. Acute periapical abscess with systemic manifestations.
6. Vertical root fractures or extensive external resorption.
7. Teeth with inadequate periodontal support (>4 mm bone loss).
8. Inability to achieve adequate isolation.
9. Multi-rooted teeth.
10. Previous endodontic treatment (retreatment cases).

Treatment protocols

Group A – Conventional Endodontic Therapy:

1. Single-visit or multiple-visit root canal treatment based on clinical presentation.
2. Access cavity preparation under rubber dam isolation.
3. Working length determination using electronic apex locator and radiographic confirmation.
4. Cleaning and shaping using ProTaper Universal rotary system to size F3.
5. Irrigation protocol: 2.5% sodium hypochlorite (NaOCl) between instruments, final irrigation with 17% EDTA followed by 2.5% NaOCl.
6. Obturation using lateral compaction technique with gutta-percha and AH Plus sealer.
7. Coronal seal with composite resin restoration.
8. No systemic medications prescribed.

Group B – Combined Endodontic-Pharmacological Intervention:

1. Identical endodontic protocol as Group A.
2. Adjunctive pharmacological regimen:

– amoxicillin 500 mg three times daily for 7 days (or Azithromycin 500 mg once daily for 3 days if penicillin-allergic);
– metronidazole 400 mg three times daily for 5 days;
– ibuprofen 400 mg three times daily for 5 days.

3. Medications initiated on day of endodontic treatment.

Group C – Conservative Oral Medicine Management:

1. Initial pharmacological management without immediate endodontic intervention:

– amoxicillin-clavulanate 625mg three times daily for 7 days;
– metronidazole 400 mg three times daily for 7 days;
– diclofenac sodium 50 mg twice daily for 7 days.

2. Clinical and radiographic re-evaluation at 6 weeks.
3. Definitive endodontic therapy performed at 6 weeks using protocol identical to Group A.
4. No systemic medications at time of delayed endodontic treatment.

Outcome assessment

Clinical and radiographic evaluations were performed by calibrated examiners (inter-examiner reliability $\kappa = 0.89$) blinded to group allocation at baseline, 3-, 6-, and 12-months post-treatment.

Primary outcomes

Overall Success Rate: Composite outcome including clinical success (absence of symptoms, no tenderness to percussion/palpation, no sinus tract) and radiographic success (complete or substantial healing of periapical lesion).

Periapical Healing: Assessed using Periapical Index (PAI) scoring system and categorized as:

– complete healing: PAI score reduction to 1–2;
– partial healing: PAI score reduction but remaining at 3–4;
– failure: No change or progression (PAI score ⩾4).

Lesion Size Reduction: Measured on standardized periapical radiographs using digital analysis software (ImageJ), calculating maximum lesion diameter.

Secondary outcomes

Clinical parameters:

– pain: assessed using Visual Analog Scale (VAS, 0-10) at baseline, 24 hours, 48 hours, 7 days, and each follow-up;

– tenderness to percussion and palpation;

– presence of sinus tract or swelling;

– tooth mobility (Miller's classification).

Patient-reported outcomes:

– patient satisfaction: 10-point Likert scale;

– quality of life: Oral Health Impact Profile-14 (OHIP-14);

– treatment acceptability.

Adverse events:

– procedural complications;

– drug-related adverse effects;

– need for additional interventions.

Radiographic assessment

Standardized periapical radiographs were obtained using paralleling technique with XCP positioning devices and consistent exposure parameters. Digital radiographs were analyzed using ImageJ software version 1.53k. Periapical Index (PAI) scoring was performed according to Orstavik criteria (1–5 scale). Two independent calibrated observers assessed all radiographs, with disagreements resolved through consensus.

Statistical analysis

Data were analyzed using SPSS version 28.0 and R software version 4.2.2. Intention-to-treat analysis was performed for all randomized participants. Normality was assessed using the Shapiro-Wilk test and Q-Q plots. Continuous variables were expressed as mean ± standard deviation and compared using one-way ANOVA with post-hoc Tukey's HSD test. Non-normally distributed variables were compared using Kruskal-Wallis test with post-hoc Dunn's test. Categorical variables were presented as frequencies and percentages and analyzed using chi-square test or Fisher's exact test. Repeated measures ANOVA was employed to assess temporal changes within and between groups. Time-to-event outcomes (pain resolution, healing achievement) were analyzed using Kaplan-Meier survival analysis with log-rank test. Binary logistic regression was performed to identify independent predictors of treatment success. Statistical significance was set at $p < 0.05$.

RESULTS

Participant flow and baseline characteristics

A total of 203 patients were screened, with 180 meeting eligibility criteria and completing randomization. Overall, 172 patients (95.6%) completed the 12-month follow-up: Group A (58/60, 96.7%), Group B (59/60, 98.3%), Group C (55/60, 91.7%). Dropouts were due to loss to follow-up ($n = 5$) and withdrawal of consent ($n = 3$).

Baseline characteristics were comparable across groups. Mean age was 38.4 ± 11.2 years overall (Group A: 37.8±10.9, Group B: 38.6 ± 11.4, Group C: 38.8 ± 11.5, $p = 0.891$). Gender distribution showed 98 males (54.4%) and 82 females (45.6%), with no significant difference across groups ($p = 0.742$). Mean baseline lesion size was 5.86±1.42 mm (Group A: 5.78 ± 1.38 mm, Group B: 5.92 ± 1.46 mm, Group C: 5.88 ± 1.44 mm, $p = 0.834$).

Treatment success rates and periapical healing

Table 1 presents the primary outcome measures including overall success rates and periapical healing outcomes at 12 months.

Table 1. Treatment success rates and periapical healing outcomes at 12 months

Таблица 1. Показатели успешности лечения и исходы периапикального заживления через 12 месяцев

Outcome parameter	Group A ($n = 58$)	Group B ($n = 59$)	Group C ($n = 55$)	p-value*
Overall Success Rate, *n* (%)	50 (86.2)	54 (91.5)	25 (45.5)	< 0.001†
Clinical Success, *n* (%)	54 (93.1)	57 (96.6)	38 (69.1)	< 0.001
Radiographic Success, *n* (%)	51 (87.9)	55 (93.2)	27 (49.1)	< 0.001
Periapical Healing Status:				
Complete Healing, *n* (%)	44 (75.9)	50 (84.7)	18 (32.7)	< 0.001
Partial Healing, *n* (%)	7 (12.1)	5 (8.5)	9 (16.4)	< 0.001
No Healing / Failure, *n* (%)	7 (12.1)	4 (6.8)	28 (50.9)	< 0.001
Mean PAI Score Reduction ± SD	2.42 ± 0.86	2.78 ± 0.74	1.24 ± 1.12	< 0.001‡
Mean Lesion Size Reduction (mm) ± SD	4.82 ± 1.24	5.67 ± 1.18	2.14 ± 1.52	< 0.001‡
Percentage Lesion Reduction (%) ± SD	83.4 ± 18.6	95.8 ± 12.4	36.4 ± 28.6	< 0.001‡
Need for Surgical Intervention, *n* (%)	6 (10.3)	3 (5.1)	23 (41.8)	< 0.001
Tooth Extraction, *n* (%)	2 (3.4)	2 (3.4)	7 (12.7)	0.046

Note: * Chi-square test or Fisher's exact test unless otherwise indicated; † Primary outcome; ‡ One-way ANOVA with post-hoc Tukey's test showing significant differences between all group pairs ($p < 0.05$ for Group A vs. B, $p < 0.001$ for Groups A and B vs. C)

Примечание: * Критерий хи-квадрат или точный критерий Фишера, если не указано иное; † Первичная конечная точка; ‡ Однофакторный дисперсионный анализ (ANOVA) с пост-хок тестом Тьюки, выявившим статистически значимые различия между всеми парами групп ($p < 0,05$ для группы А по сравнению с группой В; $p < 0,001$ для групп А и В по сравнению с группой С)

Kaplan-Meier analysis revealed significant differences in time to complete healing across groups (log-rank $\chi^2 = 42.38$, $p < 0.001$), with median healing times of 4.2 months (Group A), 3.6 months (Group B), and healing not achieved in majority of Group C patients by 12 months.

Clinical parameters and symptom resolution

Table 2 demonstrates the comparison of clinical parameters and temporal patterns of symptom resolution across treatment groups.

Treatment complications and adverse events

Table 3 presents treatment-related complications and adverse events across the three groups.

Predictors of treatment success

Binary logistic regression analysis identified independent predictors of overall treatment success:

1. Treatment modality Group B vs. Group C: OR = 14.82 (95% CI: 5.84–37.62), $p < 0.001$.
2. Treatment modality Group A vs. Group C: OR = 8.36 (95% CI: 3.52–19.87), $p < 0.001$.
3. Baseline lesion size <5 mm vs. ⩾5 mm: OR = 3.24 (95% CI: 1.42–7.39), $p = 0.005$.
4. Age <40 years vs. ⩾40 years: OR = 2.18 (95% CI: 1.04–4.57), $p = 0.039$.
5. Anterior teeth vs. posterior teeth: OR = 2.67 (95% CI: 1.21–5.89), $p = 0.015$.

Economic considerations

Mean total treatment cost (including medications, procedures, and follow-up) was: Group A: $285 ± 45, Group B: $348 ± 52, Group C: $524 ± 128 (includes initial conservative management, delayed endodontic treatment, and higher rate of additional interventions), $p < 0.001$.

DISCUSSION

This future comparative trial assessed three different management methods of chronic periapical lesions showing significant variations in clinical results, healing rates, as well as patient subjective outcome. This research shows that endodontic therapy with adjunctive pharmacological intervention would give a better result than the traditional endodontic therapy, whereas conservative oral medicine management without prompt definitive endodontic therapy would give a very poor outcome.

The total success rate of conventional endodontic therapy (Group A), which is 86.2% in this research, is consistent with the literature that gives success rates of 74–86% of primary endodontic treatment on teeth with periapical lesions [1]. This coherence confirms that we used a methodological approach and the results of the control group were enough to compare them with published standards. The prevalence rate indicates the effectiveness of the modern endodontic practice such as rotary instrumentation, superior irrigation regimens and better obturation systems in treating the infective etiology of periapical pathology [2].

Table 2. Clinical parameters and symptom resolution

Таблица 2. Клинические параметры и динамика купирования симптомов

Parameter	Group A (*n* = 58) Mean ± SD	Group B (*n* = 59) Mean ± SD	Group C (*n* = 55) Mean ± SD	*p*-value*
Baseline Pain Score (VAS 0–10)	5.84 ± 1.92	5.96 ± 1.88	5.78 ± 2.04	0.862
Pain Score at 24 hours	4.12 ± 1.64	2.86 ± 1.38	5.92 ± 1.86†	<0.001‡
Pain Score at 48 hours	2.94 ± 1.42	1.74 ± 1.12	4.68 ± 1.94†	<0.001‡
Pain Score at 7 days	0.86 ± 0.94	0.42 ± 0.68	2.84 ± 1.62†	<0.001‡
Time to Pain Resolutio, *n* (days)	6.8 ± 2.4	4.2 ± 1.8	12.6 ± 4.8§	<0.001‡
Percussion Tenderness at 12 months, *n* (%)	3 (5.2)	2 (3.4)	17 (30.9)	<0.001
Palpation Tenderness at 12 months, *n* (%)	4 (6.9)	2 (3.4)	14 (25.5)	<0.001
Sinus Tract at 12 months, *n* (%)	1 (1.7)	0 (0.0)	8 (14.5)	0.001
Post-operative Flare-up, *n* (%)	8 (13.8)	3 (5.1)	18 (32.7)¶	<0.001
Baseline OHIP-14 Score	18.6 ± 5.4	19.2 ± 5.8	18.4 ± 5.6	0.726
OHIP-14 Score at 12 months	6.4 ± 3.2	4.8 ± 2.6	11.8 ± 4.8	<0.001‡
OHIP-14 Improvement	12.2 ± 4.6	14.4 ± 5.2	6.6 ± 4.2	<0.001‡
Patient Satisfactio, n Score (0–10)	7.92 ± 1.34	8.64 ± 1.12	5.28 ± 1.86	<0.001‡

Note: * One-way ANOVA unless otherwise indicated; † Pain scores for Group C represent values during initial conservative management phase (before delayed endodontic intervention); ‡ Post-hoc Tukey's test showed significant differences between most group pairs; § Time to pain resolution in Group C calculated from delayed endodontic intervention; || Chi-square test; ¶ Includes flare-ups during both conservative management and delayed endodontic phases

Примечание: * Однофакторный дисперсионный анализ (ANOVA), если не указано иное; † Показатели болевого синдрома в группе С отражают значения в период первичного консервативного ведения (до отсроченного эндодонтического вмешательства); ‡ Пост-хок тест Тьюки выявил статистически значимые различия между большинством пар групп; § Время до купирования болевого синдрома в группе С рассчитывалось с момента проведения отсроченного эндодонтического вмешательства; || Критерий хи-квадрат; ¶ Включены случаи обострений как на этапе консервативного лечения, так и в период отсроченного эндодонтического вмешательства

Table 3. Treatment complications and adverse events

Таблица 3. Осложнения лечения и нежелательные явления

Complication / Adverse event	Group A (*n* = 58), *n* (%)	Group B (*n* = 59), *n* (%)	Group C (*n* = 55), *n* (%)	*p*-value*
Overall Complication Rate	12 (20.7)	18 (30.5)	34 (61.8)	< 0.001
Procedural Complications:				
Instrument separation	1 (1.7)	1 (1.7)	2 (3.6)	0.739
Perforation	0 (0.0)	0 (0.0)	1 (1.8)	0.323†
Apical extrusion	2 (3.4)	1 (1.7)	3 (5.5)	0.529†
Drug-Related Adverse Events:	0 (0.0)	14 (23.7)	16 (29.1)	< 0.001
Gastrointestinal disturbances	0	9 (15.3)	11 (20.0)	0.005
Allergic reactions (mild)	0	2 (3.4)	2 (3.6)	0.332†
Diarrhea	0	5 (8.5)	7 (12.7)	0.024
Nausea	0	4 (6.8)	6 (10.9)	0.056
Post-treatment Complications:				
Persistent infection	4 (6.9)	2 (3.4)	18 (32.7)	< 0.001
Symptomatic recurrence	3 (5.2)	1 (1.7)	12 (21.8)	< 0.001
Progressive lesion enlargement	2 (3.4)	1 (1.7)	9 (16.4)	0.005
Treatment Discontinuation Due to Adverse Events	0 (0.0)	3 (5.1)	5 (9.1)	0.065†
Additional Treatment Required:				
Endodontic retreatment	3 (5.2)	2 (3.4)	11 (20.0)	0.003
Surgical endodontics	6 (10.3)	3 (5.1)	23 (41.8)	<0.001
Tooth extraction	2 (3.4)	2 (3.4)	7 (12.7)	0.046

Note: * Chi-square test; † Fisher's exact test

Примечание: * Критерий хи-квадрат; † Точный критерий Фишера

The materially better success rate of 91.5% in Group B (endodontic-pharmacological intervention) means that the use of adjunctive systemic medications has a meaningful clinical benefit. Although this improvement of 5.3 percent is apparently small, this is a 38 percent relative decrease in failure rate with conventional therapy used alone. The improved results are probably due to the work of synergistic mechanisms: endodontic treatment will focus on the initial source of infection in the root canal system, and systemic antibiotics will focus on the extraradicular infection and the decrease in bacterial load in periapical tissues [3]. With an excellent antiprolkaryotic effect against obligate anaerobes that are the leading agents in endodontic infections, metronidazole, which augments the spectrum of amoxicillin, offers complete antimicrobial coverage [4].

The anti-inflammatory (ibuprofen) of Group B possibly enhanced better results via several different mechanisms other than symptom management [5]. NSAIDs prevent the activity of enzymes of cyclooxygenase, blocking the production of prostaglandins and altering the course of the inflammatory process. It is possible that this inflammatory suppression can save the architecture of the periapical bone, decrease activity in osteoclastic cells, and cause more favorable conditions of healing. The tangible benefit of adjunctive anti-inflammatory therapy to patients is demonstrated by the significantly shorter pain resolution time in Group B (4.218 days) than in Group A (6.82.4 days).

The objective radiographic data of Group B (reduced lesion size by a significant margin of 95.8 12.4% vs. Group A 83.4 18.6% of the lesion area) support the positive impact of the combination intervention. The near full remission of lesions in Group B predicts that a pharmacological adjunctive therapy can support the more thorough periapical bone regeneration. Research has shown that residual peri apical inflammation may be present despite technically satisfactory endodontic treatment, and this may limit healing [6]. Systemic drugs can be used to address this residual inflammation better.

These results (dramatically poor in Group C: conservative oral medicine management with delayed endodontic intervention) highlight an essential principle of the endodontic treatment: the definitive treatment of the infectious source in the root canal system [7]. Antibiotics are only able to temporarily suppress the population of bacteria and control the symptoms, but without controlling the sources with endodontic debridgement and obturation, infections always come back. The success rate of 45.5 percent of Group C, which is less than 50 percent of Groups A and B, shows that pharmacological treatment is not sufficient in the treatment of chronic periapical lesions.

Group C shows a high level of failure to treat (50.9) and surgical operation (41.8) which are the outcomes of failure to administer decisive treatment. The bacterial populations were probably adapted, biofilms deve-

loped, and periapical destruction might have occurred even with the antibiotic treatment during the 6-week conservative management period [8]. The biological environment might be unfavorable to healing by the time delayed endodontic treatment was given than with immediate endodontic treatment. The implications of this finding to clinical practice and resource allocation are significant since the conservative and cost-saving measures aimed at postponing costs or the complexity of treatment eventually caused an increase in failures and the necessity to undergo costly surgical operations.

The fact that the complication rate was much higher in Group C (61.8) should be taken seriously. In addition to the anticipated increased prevalence of persistent infection and relapse of treatment, this group had an increase in post-operative flare-ups (32.7% vs. 13.8% in Group A and 5.1% in Group B, respectively). Such exacerbations can be caused by the pressure of selection of bacteria during the course of antibiotics, which causes more virulent or resistant colonies. Moreover, untimely treatment could have provided more tissue to be exposed to the infection, and this is more likely to lead to complications in the future during endodontic therapy [9].

In Group B, the adverse events were drug related in 23.7 percent and 29.1 percent of Group C patients, mostly mild gastrointestinal events. Although these undesirable events were typically self-limiting and did not affect the treatment outcomes, they are significant factors to be considered during the benefit-risk analysis. The wise use of antibiotics should be based on the therapeutic value versus the side effects, the issue of antimicrobial resistance and expenditure of healthcare funds [10]. These two facts indicate that, in the case of teeth with chronic periapical lesions, the advantages of adjunctive antibiotics over these issues are even stronger in Group B. Nevertheless, the unfavorable results of antibiotic therapy in Group C prove that antibiotic treatment cannot be a replacement of the final endodontic therapy.

The data on the quality of life, assessed with the means of OHIP-14 showed significant improvement in Group B (14.4 ± 5.2 points), as opposed to Group A (12.2 ± 4.6 points) and Group C (6.6 ± 4.2 points). This patient outcome validates the fact that the clinical and radiographic benefits are translated into meaningful improvements in the daily functioning and wellbeing of the patients. The increased patient satisfaction rates in Group B (8.64 ± 1.12) present the level of appreciation by the patients towards the promptness in symptom solving and the overall outcomes [11].

Economic analysis also showed some curious paradox, whereby Group B was incurring greater initial treatment costs in terms of amounts (348 vs. 285 for Group A) in terms of amount of duetomedication, but Group C experienced the highest total costs (524) although initial conservative management was less expensive. The failure rate of Group C was very high which required further interventions such as retreatment, surgical endodontics, and extractions which increased total spending. This observation proves that the cost savings caused by conservative management at the very beginning are compensated by the costs incurred downstream brought about by failure to treat [12].

The value of the identification of the baseline lesion size, patient age, and the location of the tooth determining the success of the treatment is based on the prognostic information. Big lesions (⩾5mm) had a lower probability of healing, which may reflect a higher tissue destruction, higher bacterial load, or possibly a cystic conversion [13]. Better results were observed in younger patients (< 40 years), which is probably attributed to the increased capacity to heal and immune response. A higher success rate was observed with anterior teeth as compared to the posterior teeth which may be associated with easier anatomy, easier access and lower occlusal pressure [14].

There are a number of limitations that should be considered. The research did not include multi-rooted teeth which are prone to generalization to the molars which comprise a big percentage of teeth which are subjected to endodontic treatment. The 12 months follow up though significant, might not be effective in reflecting long term outcomes as some failures are not exhibited until a few years [15]. The ethical reason why the study design lacked a placebo-controlled arm, was that it would have made it impossible to evaluate the placebo effects. The type of antibiotic and anti-inflammatory regimens that have been used is just one of several possible protocols; alternate medication options, dosages, or respective durations may have varied outcomes. Also, the article failed to determine the behavior of antimicrobial resistance, which is of great concern in light of the contemporary issues regarding the stewardship of antibiotics [16].

The future studies are aimed at long-term studies (3–5 years) to evaluate sustained results, microbiological examination such as antimicrobial resistance profiling, exploration of alternative pharmacological regimens, research of biomarkers, to determine the patients who are most inclined to respond to adjunctive medications, cost-effectiveness studies, both at the societal and healthcare system level, and special populations such as immunocompromised patients [17–20].

CONCLUSION

The prospective comparative study proves that the endodontic therapy in conjunction with adjunctive systemic pharmacological intervention yields better clinical and radiographic results than endodontic therapy in the context of chronic periapical lesions alone. The integrated strategy generates increased success rates (91.5% vs. 86.2%), lesion size reduction, quicker symptoms improvement, and increased patient satisfaction and life quality. Such advantages seem to far surpass the slight growth in treatment expenses and acceptable adverse event profile.

More importantly, there is a significantly lower level of success in conservative oral medicine management with delayed endodontic interventions as compared to immediate endodontic techniques, with success rates that are half as high. The high failure rate, rising surgical

intervention requirement and finally the economic cost of the conservative management highlight the principal rule that conclusive treatment that removes the infectious source is crucial in the management of periapical lesions. Antibiotics and anti-inflammatory drugs, although useful as helper drugs, cannot replace proper endodontic treatment.

The clinical implications of these results are as follows: in the endodontic treatment of teeth with chronic periapical lesions, adjunctive systemic antibiotics (amoxicillin plus metronidazole) and anti-inflammatory drugs (NSAIDs) should be considered on a regular basis, indefinite endodontic treatment of these lesions should not be treated conservatively except in the limited cases where endodontic treatment is contraindicated or contraindicated, initial cost savings due to the use of conservative treatment should not be considered, and treatment.

The paper underlines the value of timely and definitive endodontic intervention as the foundation of chronic periapical lesion therapy, and adjunctive pharmacological treatment as a valuable addition to the use of optimal endodontic intervention. These insights, based on evidence, must be reflected in clinical choices, guideline writing, and so advice to a patient on the best management of chronic periapical pathology.

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Review Article

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Artificial intelligence in dental diagnosis: evaluating CNN models for caries and periapical lesions detection

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Abstract

INTRODUCTION. Convolutional neural networks (CNNs) show strong promise for automating dental diagnosis from radiographic images. Robust head-to-head comparisons across tasks and datasets are needed to guide model selection for clinical use.

MATERIALS AND METHODS. We compared three lightweight CNNs – EfficientNet-B0, ResNet-18, and MobileNetV3 – for two classification tasks: enamel caries on intraoral images and periapical lesions on panoramic radiographs. Data comprised the Caries-Spectra dataset (2,000 intraoral images; advanced, early-stage, and no caries) and a panoramic radiograph set with 13,071 images labeled with periapical lesion scores (PAI 3–5). For the periapical task, data augmentation was applied to the panoramic training split only, increasing its size to 17,004 training instances; validation and test splits (as well as all Caries-Spectra splits) remained at their original sizes. Models were trained via transfer learning with early stopping and evaluated using accuracy, precision, recall, F1-score, and confusion matrices.

RESULTS. EfficientNet-B0 achieved the best overall performance on both tasks, reaching 99.74% accuracy for caries detection and 69.65% accuracy for periapical lesion detection, outperforming ResNet18 and MobileNetV3 across the reported metrics.

CONCLUSIONS. Lightweight CNNs – particularly EfficientNet-B0 – are effective for dental image classification and are suitable candidates for integration into clinical diagnostic workflows. Model architecture choice and data quality materially influence performance

Keywords: artificial intelligence, dental diagnosis, convolutional neural networks, caries detection, periapical lesions

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Искусственный интеллект в стоматологической диагностике: оценка моделей CNN для выявления кариеса и периапикальных поражений

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Резюме

ВВЕДЕНИЕ. Сверточные нейронные сети (CNN) демонстрируют большие перспективы в автоматизации стоматологической диагностики по рентгенографическим снимкам. Для внедрения этих моделей в клиническую практику необходимы надежные сравнительные исследования на различных задачах и наборах данных.

МАТЕРИАЛЫ И МЕТОДЫ. Мы сравнили три легковесные модели CNN – EfficientNet-B0, ResNet-18 и MobileNetV3 – для двух задач классификации: выявление кариеса эмали на интраоральных снимках и периапикальные поражения на панорамных рентгенограммах. Данные включали набор Caries-Spectra (2000 интраоральных снимков: глубокий кариес, начальный кариес и отсутствие кариеса) и набор панорамных рентгенограмм из 13 071 снимка, размеченных по индексам периапикальных по-

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ражений (PAI 3–5). Для задачи с периапикальными поражениями применялась аугментация данных только для обучающей выборки, что увеличило ее размер до 17 004 примеров; валидационные и тестовые выборки (как и все выборки Caries-Spectra) остались в исходном размере. Модели обучались с использованием трансферного обучения с ранней остановкой и оценивались по метрикам точности (accuracy), прецизионности (precision), полноты (recall), F1-меры и матрицам ошибок.
РЕЗУЛЬТАТЫ. EfficientNet-B0 показала наилучшую общую производительность в обеих задачах, достигнув точности 99,74% для выявления кариеса и 69,65% для выявления периапикальных поражений, превзойдя ResNet18 и MobileNetV3 по всем представленным метрикам.
ВЫВОДЫ. Легковесные CNN, в частности EfficientNet-B0, эффективны для классификации стоматологических изображений и являются подходящими кандидатами для интеграции в клинические диагностические рабочие процессы. Выбор архитектуры модели и качество данных существенно влияют на производительность.

Ключевые слова: искусственный интеллект, стоматологическая диагностика, сверточные нейронные сети, выявление кариеса, периапикальные поражения

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INTRODUCTION

Enamel caries and periapical lesions are among the most prevalent oral diseases worldwide and, if left undetected or untreated, can lead to significant morbidity, functional impairment, and financial burdens for patients [1]. Conventional diagnostic methods have traditionally relied on expert interpretation of dental radiographs, which often suffer from limited reproducibility, susceptibility to human fatigue, and reduced scalability in high-demand clinical settings.

Recent advancements in artificial intelligence (AI) and deep learning – particularly convolutional neural networks (CNNs) – have demonstrated significant potential in automating image-based diagnosis across multiple medical disciplines, including dentistry. CNNs possess the capability to extract hierarchical features and detect subtle variations in radiographic images that may not be readily perceptible to the human eye. However, the performance of CNNs can vary depending on architectural design, dataset quality, and task complexity [2–5].

Several studies have explored AI-based detection of caries and periapical lesions using various CNN architectures and imaging modalities [6]. While these studies have shown encouraging results, few have conducted comprehensive, standardized comparisons across multiple CNN models using unified datasets and consistent preprocessing pipelines.

This study aims to address this gap by performing a comparative evaluation of three well-established CNN architectures – ResNet18, EfficientNet-B0, and MobileNetV3 – across two publicly available dental image datasets. The first dataset comprises intraoral images for enamel caries classification, while the second consists of panoramic radiographs for periapical lesion detection.

Through standardized training strategies and evaluation metrics – including accuracy, precision, recall, F1-score, and confusion matrices – this research seeks to identify the CNN architecture that best balances diagnostic performance and computational efficiency in the context of dental image analysis.

LITERATURE REVIEW

Recent advancements in artificial intelligence have significantly contributed to the automation of dental disease detection, particularly in identifying enamel caries and periapical lesions. Numerous studies have employed deep learning models to address the challenges of dental image analysis, leveraging both two-dimensional and three-dimensional imaging modalities.

For instance, a study by [7] utilized a hybrid nnU-Net–DenseNet121 model for caries detection in panoramic radiographs, achieving a high accuracy of 98.6%, thus highlighting the effectiveness of combined segmentation-classification approaches. Similarly, ResNet-101 was employed by [8] on the DCD dataset, yielding an accuracy of 98.38%, reaffirming the robustness of deep residual networks in extracting diagnostic features from dental radiographs.

EfficientNet-B0 has also been investigated in the context of dental imaging. In [9], the model achieved 94.94% accuracy on a dataset of 1,525 dental X-ray images, demonstrating the advantage of compound scaling in CNN architectures. In contrast, a non-image-based study [10] focused on demographic and survey data to predict caries risk, using GINI and mRMR feature selection with a Gradient Boosting Decision Tree (GBDT) classifier to achieve 95% accuracy – underscoring the relevance of behavioral and demographic variables in caries risk assessment.

Three-dimensional imaging has also gained traction in recent research. In [11], a multi-input CNN was applied to cone-beam computed tomography (CBCT) images of molar teeth, achieving 95.3% accuracy. The study emphasized the diagnostic value of volumetric

data in identifying complex or deep lesions. In a related effort, [12] employed ResNet-101 with a Feature Pyramid Network (FPN) and Adaptive Training Sample Selection, attaining 81.2% accuracy on panoramic radiographs – highlighting the challenges associated with sample variability and generalizability.

Regarding periapical lesion detection, [13] introduced a ResNet-based model integrated with a Spatial Attention Module (SAM) and tested it on 4,278 periapical radiographs, achieving an accuracy of 88.5%. This result illustrates the potential of attention mechanisms to enhance model focus on lesion-specific regions.

Collectively, these studies reflect the growing success of CNN-based models in dental diagnostics, with performance influenced by imaging modality (2D vs. 3D), dataset quality, and architectural enhancements such as attention mechanisms or ensemble methods. However, few works offer a unified comparative analysis across multiple CNN architectures under standardized conditions. The present study aims to fill this gap by systematically evaluating ResNet18, EfficientNet-B0, and MobileNetV3 on enamel caries and periapical lesion datasets, with a focus on balancing diagnostic performance and computational efficiency.

Table 1 provides a comparative summary of prior studies, including datasets, model architectures, and reported performance metrics for enamel caries and periapical lesion detection.

METHODOLOGY

This study aims to evaluate the performance of various Convolutional Neural Network (CNN) architectures in detecting dental pathologies, specifically caries and periapical lesions, from periapical radiographic images. As shown in Figure 1, the methodology consists of several stages, including data acquisition, preprocessing, model training, and evaluation.

Datasets

Two distinct datasets were utilized in this study:

Dataset 1 – Caries-Spectra (intraoral images): a set of 2,000 intraoral photographic images categorized into advanced caries, early-stage caries, and no caries.

Dataset 2 – Panoramic radiographs (PAI 3–5): 13,071 panoramic radiographs annotated with Periapical Index (PAI) scores 3–5 for periapical lesion detection.

Data preprocessing

All images were resized to a fixed input dimension to meet the requirements of the selected CNN models. Additionally, data augmentation techniques were selectively applied to improve model robustness and detection performance. Specifically, horizontal flipping and color jitter were applied to the Periapical Lesions dataset. This was done not merely to increase dataset diversity, but primarily to enhance the model's ability to detect small-sized objects within the radiographs, as periapical lesions tend to be subtle and localized, making them more challenging to identify compared to larger carious defects.

Dataset splitting

Each dataset was split into three subsets:

1. Training Set (80%): Used for model learning.

2. Validation Set (10%): Used for hyperparameter tuning and early stopping.

3. Test Set (10%): Reserved for final evaluation.

Model architectures

Three state-of-the-art CNN models were selected for comparative analysis:

– ResNet18;

– EfficientNet-B0;

– MobileNetV3.

Table 1. Summary of recent studies on AI-based dental disease detection

Таблица 1. Краткое описание недавних исследований в области выявления стоматологических заболеваний с помощью искусственного интеллекта

Ref.	Year	Dataset	Methods	Accuracy, %
[14]	2021	Panoramic films of Caries. A training and validation dataset (1071) and a test dataset (89)	nnU-Net and DenseNet121	0.986
[9]	2023	A total of 1525 X-ray images of Caries	EfficientNet-B0	94.94
[8]	2023	Dental Caries Detection Dataset (DCD)	ResNet-101	98.38
[10]	2023	A survey was conducted with 22,288 respondents using an oral health awareness questionnaire featuring 43 items. This questionnaire collected data on demographics (age, gender, residence), habits (snack frequency, tooth brushing frequency, oral care use, smoking experience), and assessed oral health awareness and behaviors, with "act_caries" as the key label	Integrating the GINI and mRMR algorithms with the GBDT classifier	95
[11]	2024	The CBCT image dataset included 382 molar teeth with caries and 403 non-carious molar cases	Multiple-input convolutional neural network	95.3
[12]	2023	454 objects in 357 anonymized PRs were	Adaptive Training Sample Selection and ResNet-101 FPN	0.812
[13]	2024	Periapical radiographs (4278 images)	ResNet + SAM	0.885

Training strategy

We trained each model for up to 20 epochs on Caries-Spectra and up to 10 epochs on the periapical task, with early stopping based on validation accuracy (patience = N). We monitored loss/accuracy per epoch and saved the best weights.

Evaluation metrics

Model performance was evaluated using the following standard classification metrics:

– accuracy;
– precision;
– recall;
– F1-Score.

A confusion matrix was also used to visualize the classification outcomes.

Results comparison

The final performance of each model was tabulated to allow side-by-side comparison across all metrics. This comparison facilitated the identification of the most suitable architecture for automated dental pathology detection.

DATASETS DESCRIPTION

This study utilizes two publicly available dental image datasets, each focused on a distinct pathology to enable comprehensive evaluation of deep learning models for dental diagnosis.

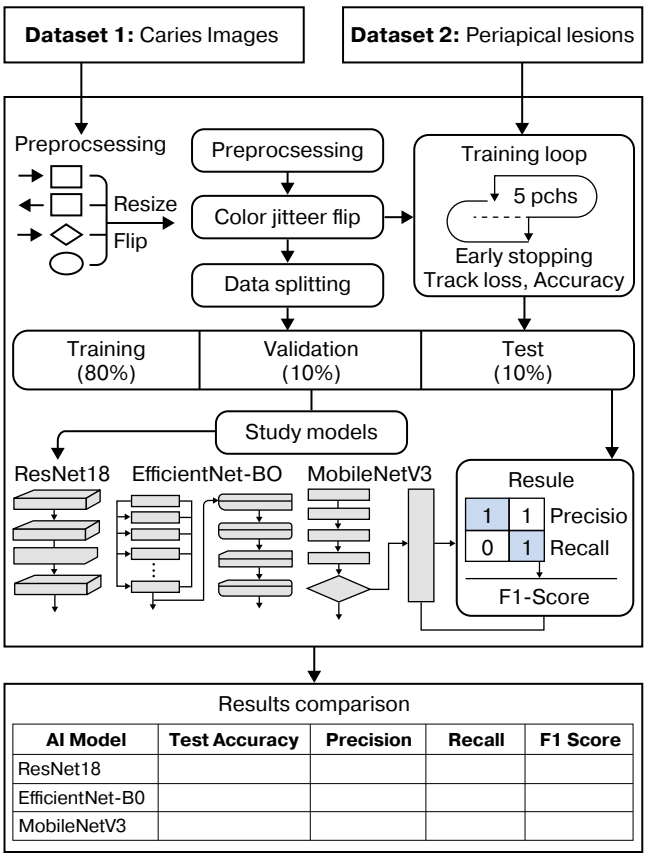

Fig. 1. Methodology

Рис. 1. Методология

Caries-spectra dataset for enamel caries detection

The Caries-Spectra dataset is a curated collection of 2,000 low-resolution intraoral images, sourced from medical clinics in Rajshahi and Dhaka, Bangladesh, between 2021 and 2022 [15].

The dataset is categorized into three distinct groups:

– **Advanced Enamel Caries** (800 images);
– **Early-Stage Enamel Caries** (800 images);
– **No Enamel Caries** (400 images).

These images represent diverse presentations of enamel caries, selected from multiple patients to ensure clinical variability. The dataset is structured into three folders corresponding to the caries categories and is intended to support fine-grained caries classification tasks.

Periapical lesions panoramic radiograph dataset

The second dataset comprises 13071 panoramic radiographs labeled with periapical lesions, obtained at the High-quality Dental Treatment Centre, Hanoi Medical University between 2016 and 2021. The radiographs were annotated by a panel of three experienced dentists based on the Periapical Index (PAI), categorizing lesions into PAI scores 3, 4, and 5 [16].

To improve lesion detection performance, particularly for small and subtle abnormalities, the dataset was extensively augmented using random scaling, mirroring, rotation, and noise addition, resulting in 17,004 images. Image annotations are provided in XML format. The dataset is structured into three main folders: original images, augmented images, and annotations.

Together, these datasets provide a robust foundation for evaluating CNN architectures on tasks related to dental caries and periapical lesion detection under varied clinical imaging conditions.

UNIFIED CNN TRAINING AND EVALUATION PIPELINE (APPLIED TO RESNET18, EFFICIENTNET-B0, AND MOBILENETV3)

To ensure consistency and fairness in evaluating different CNN architectures, a unified training and evaluation pipeline was implemented across all selected models: ResNet18, EfficientNet-B0, and MobileNetV3. This pipeline outlines the complete process from model initialization to performance evaluation on the test set. It includes data preprocessing, transfer learning, optimization, early stopping, and computation of key classification metrics.

The following pseudocode (Algorithm 1) summarizes the standardized steps followed during the development and assessment of each CNN model in this study.

Input:
– preprocessed image datasets (Train, Validation, Test);
– CNN model architecture (ResNet18 / EfficientNet-B0 / MobileNetV3);
– training hyperparameters: learning rate, batch size, number of epochs, early stopping patience.
Output:
– trained model weights;

– evaluation metrics: Accuracy, Precision, Recall, F1-Score, Confusion Matrix.

Steps:

1. Load the pretrained CNN model.

2. Replace the final classification layer to match the number of classes.

3. Apply image transforms (Resize to 224×224, normalization).

4. Load training, validation, and testing data using DataLoaders.

5. Initialize loss function (CrossEntropyLoss) and optimizer (Adam).

6. For each epoch:

a) set model to training mode;

b) for each batch in training data:

– forward pass,

– compute loss,

– backward pass and optimizer update,

– track training accuracy;

c) set model to evaluation mode;

d) validate model performance on the validation set;

e) save best model weights based on validation accuracy;

f) apply early stopping if no improvement.

7. Load best model weights.

8. Evaluate on test set and compute:

– accuracy;

– precision, Recall, F1-Score (macro average);

– confusion matrix.

RESULT AND DISCUSSION

Performance presented and discussed are in the light of application of the CNN models to the two dental image datasets considered: Caries-Spectra and Periapical Lesions. For each dataset, a comparative test with regard to performance was run for the three CNN architectures- ResNet18, EfficientNet-B0, and MobileNetV3-on standard classification metrics such accuracy, precision, recall, and F1-score.

Evaluation on the caries-spectra dataset

This section discusses the performance analysis of the CNN models for classifying caries in enamel using the Caries-Spectra dataset.

The Caries-Spectra dataset is evaluated by the efficiency of the CNN-based classification in discriminating among the three classes of enamel statuses: advanced enamel caries, initial-stage enamel caries, and healthy enamel, respectively. Among various models tested, the `ResNet18; has been the tallest performer with respect to training and validation summarized in Table 2 and illustrated in Fig. 2. This trend continued through 20 training epochs, where the ResNet18 model was observed to converge steadily. The training loss was seen to be consistently lower through the epochs: from 33.99 at epoch 1 to 3.79 by epoch 20, demonstrating good optimization. That way, the training accuracy improved considerably from under 79% to just below 98% in terms of learning the stability of the model over time. And this is where it fails as well as it goes up, reaching a peak point at 98.44% in epoch 18. This means it generalizes very well to unseen data; sporadic drops that occur at points like epochs 3 and 16 could be due to noise or variance in the dataset from which the representations are derived, since certain images would typically be diffused because they are more difficult to identify because of very slight visual cues to be identified as early-stage enamel caries representations.

The training and validation accuracy curves also run very closely thereby, confirming that the model was not seriously overfitted. The last evaluation metrics-precision, recall, and F1-score-in a way support the robustness of ResNet18 on this low-resolution caries dataset. The extreme performance is most likely due to the more distinctive separation of classes available in the dataset, as well as the residual capabilities of ResNet's connections to retain feature integrity throughout the layers.

ResNet18 proved to have a great performance classification of enamel caries on the Caries-Spectra dataset with high accuracy and low loss, thereby establishing a very good baseline for comparison with the other CNN models.

Cross the 20 training epochs of EfficientNet-B0 on the Caries-Spectra dataset, it consistently proved its impressive and stable performance. As presented in Table 3 and Fig. 3, there was a substantial decline in the training loss from 26.75 on the first epoch to 4.88 on the last, while the increases in training accuracy carried on steadily to reach the maximum of 99.27% at epoch 16.

Table 2. Epoch-wise training and validation performance of ResNet18 on the Caries-Spectra test set

Таблица 2. Результаты обучения и проверки ResNet18 на тестовом наборе Caries-Spectra по эпохам

Epoch. No	Loss	Train Acc, %	Val Acc, %
Epoch 1	33.9895	78.23	89.09
Epoch 2	20.0739	86.68	93.51
Epoch 3	15.1001	91.08	88.05
Epoch 4	14.3778	91.14	92.47
Epoch 5	12.8426	91.29	92.73
Epoch 6	12.0435	93.00	92.73
Epoch 7	10.9420	94.19	93.25
Epoch 8	7.4350	95.90	94.29
Epoch 9	9.1760	94.56	94.03
Epoch 10	8.9577	95.13	94.81
Epoch 11	6.7755	95.96	95.32
Epoch 12	7.0643	95.65	97.40
Epoch 13	5.2692	97.05	96.88
Epoch 14	7.0371	96.63	98.18
Epoch 15	5.6552	96.68	93.25
Epoch 16	7.6589	96.06	88.83
Epoch 17	11.7846	93.42	96.36
Epoch 18	5.6772	96.99	98.44
Epoch 19	3.8931	97.62	98.18
Epoch 20	3.7911	97.93	97.92

The validation accuracy was high throughout the epochs, recording a minimum of 93% at all times since epoch one and attaining 100% at epochs 13 and 16. The early and sustained high performance tells us that EfficientNet-B0 must have learned to discriminate rapidly between the three enamel caries classes, most probably due to some very modern architecture that balances depth, width, and resolution in an efficient way.

Training accuracy continued to rise, with smaller fluctuations in validation accuracy, further demonstrating the capability of generalization and robustness of the model. The close match in the curves for training and validation accuracy in Fig. 3 affirms the stability of the model and suggest that overfitting was avoided.

While the training loss started to show slight increases in later epochs (epoch 20 as an example), validation accuracy kept on recording its typhpeak, meaning the model remained capable of adequately classifying fresh samples even with moments of fluctuations during optimization. To put it somewhat differently, the EfficientNet-B0 was superior to the ResNet18 in terms of both speed of convergence and validation performance on the Caries-Spectra dataset. Given its efficiency and accuracy, it therefore has the potential for deployment in real life for enamel caries classification.

The MobileNetV3 classified the Caries-Spectra dataset strongly, especially in the later epochs. As seen in Table 4 and in Fig. 4, the model opened with a very low validation accuracy of 20.26% in the first epoch, suggesting it encountered great difficulty in generalizing to unseen data in the beginning. Yet, in the subsequent epochs, the validation accuracy increased drastically to above 98% by epoch 9 and 99.74% by epoch 20.

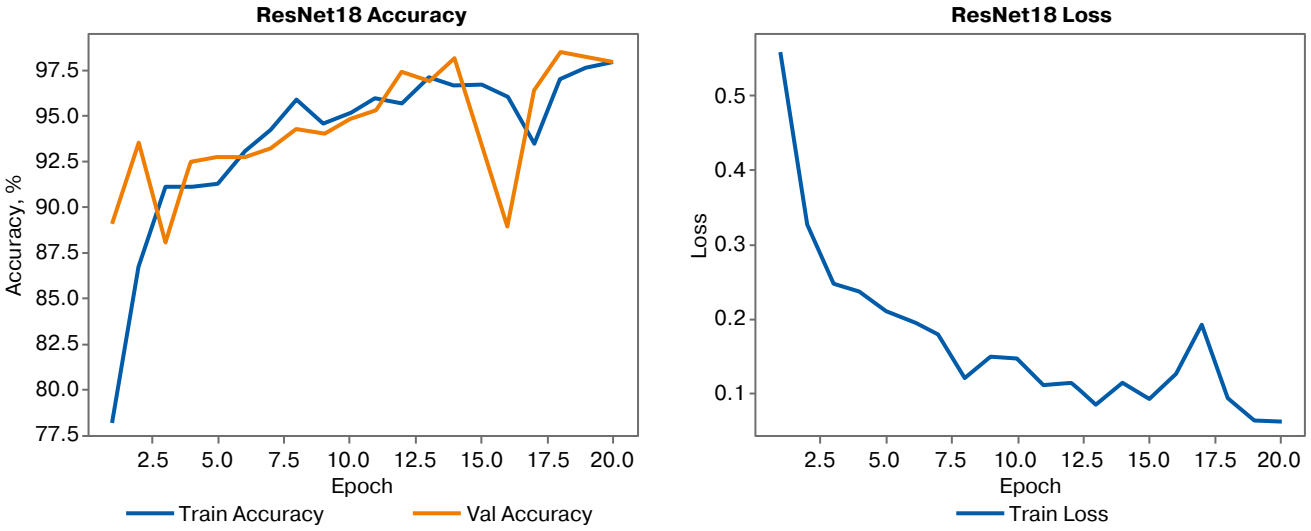

Fig. 2. Training and validation performance of ResNet18 Over 20 Epoch on the Caries-Spectra test set

Рис. 2. Результаты обучения и проверки ResNet18 за 20 эпох на тестовом наборе Caries-Spectra

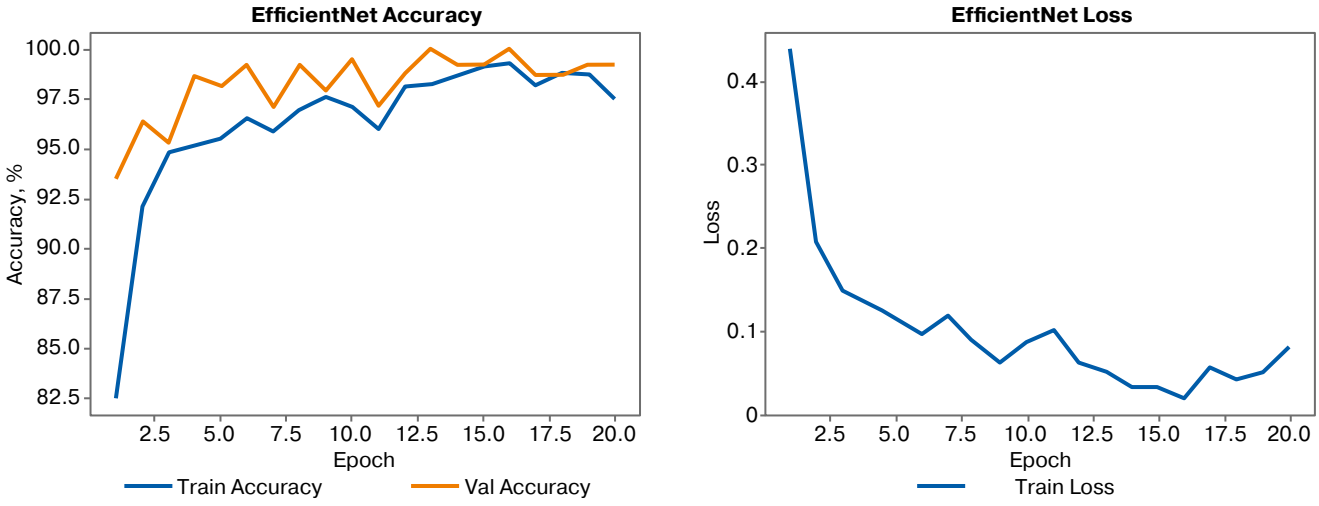

Fig. 3. Training and validation performance of EfficientNet-B0 Over 20 Epoch on the Caries-Spectra test set

Рис. 3. Эффективность обучения и проверки модели EfficientNet-B0 за 20 эпох на тестовом наборе Caries-Spectra

Table 3. Epoch-wise training and validation performance of EfficientNet-B0 on the Caries-Spectra test set

Таблица 3. Результаты обучения и проверки EfficientNet-B0 на тестовом наборе Caries-Spectra по эпохам

Epoch. No	Loss	Train Acc, %	Val Acc, %
Epoch 1	26.7512	82.53	93.51
Epoch 2	12.6605	92.07	96.36
Epoch 3	9.0410	94.82	95.32
Epoch 4	8.1270	95.13	98.70
Epoch 5	6.9896	95.54	98.18
Epoch 6	5.8580	96.53	99.22
Epoch 7	7.2084	95.85	97.14
Epoch 8	5.3080	96.94	99.22
Epoch 9	3.7269	97.62	97.92
Epoch 10	5.2328	97.10	99.48
Epoch 11	6.1185	96.01	97.14
Epoch 12	3.7166	98.13	98.70
Epoch 13	3.1427	98.24	100.00
Epoch 14	2.0137	98.70	99.22
Epoch 15	1.8328	99.12	99.22
Epoch 16	1.1737	99.27	100.00
Epoch 17	3.3485	98.19	98.70
Epoch 18	2.5278	98.81	98.70
Epoch 19	3.0224	98.70	99.22
Epoch 20	4.8824	97.56	99.22

Table 4. Epoch-wise training and validation performance of MobileNetV3 on the Caries-Spectra test set

Таблица 4. Результаты обучения и проверки MobileNetV3 на тестовом наборе Caries-Spectra по эпохам

Epoch. No	Loss	Train Acc, %	Val Acc, %
Epoch 1	26.2387	82.17	20.26
Epoch 2	11.0225	93.78	57.40
Epoch 3	8.3453	95.80	64.16
Epoch 4	7.5284	95.23	56.10
Epoch 5	7.2374	96.06	87.53
Epoch 6	5.1619	96.79	81.82
Epoch 7	2.3749	98.76	88.05
Epoch 8	4.5275	97.87	94.55
Epoch 9	2.5562	98.50	98.96
Epoch 10	3.7563	98.34	97.92
Epoch 11	1.9478	98.91	96.36
Epoch 12	1.9185	99.12	97.14
Epoch 13	3.3504	98.60	97.40
Epoch 14	2.7350	98.91	100.00
Epoch 15	5.8561	96.73	97.14
Epoch 16	1.5765	99.02	96.10
Epoch 17	6.4405	96.94	98.96
Epoch 18	3.4517	98.13	97.14
Epoch 19	0.6250	99.69	99.48
Epoch 20	0.8073	99.74	99.74

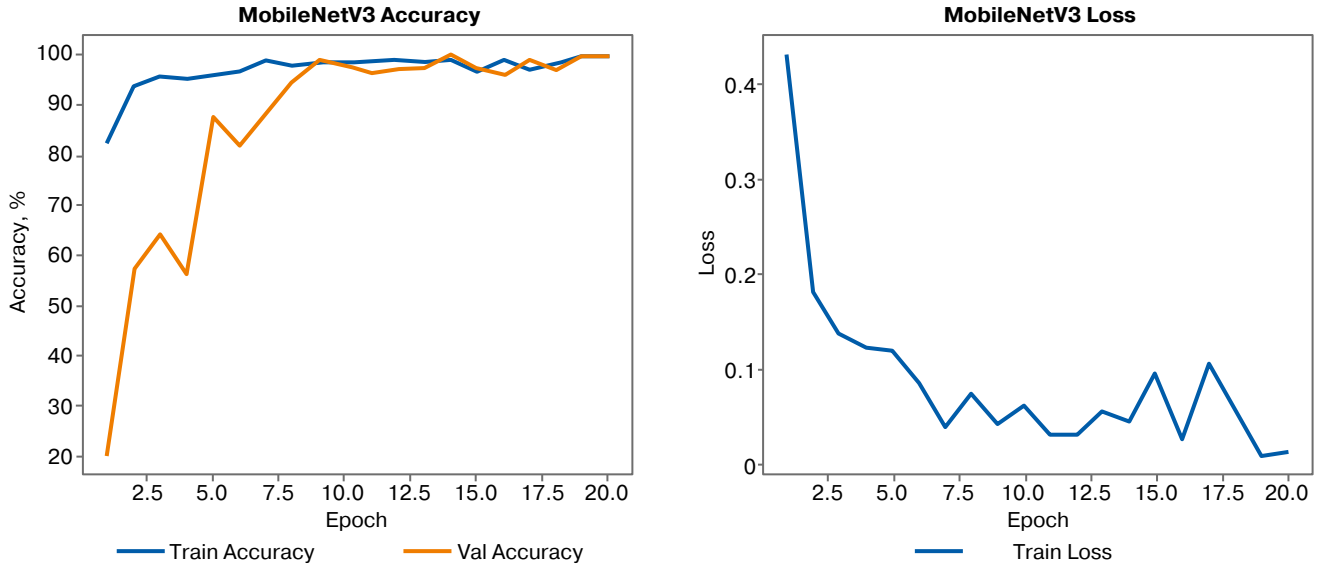

Fig. 4. Training and validation performance of MobileNetV3 Over 20 Epoch on the Caries-Spectra test set

Рис. 4. Эффективность обучения и проверки MobileNetV3 в течение 20 эпох на тестовом наборе Caries-Spectra

The training loss had a steep decline from 26.23 to 0.81, with the training accuracy reaching 99.74%, which confirmed that learning was indeed performed efficiently. The early fluctuations in the validation accuracy (for instance, from epochs 2 to 4) might have indicated early overfitting or the model's inability to accommodate the features of early-stage enamel caries that were more subtle in appearance. However, this early oscillation settled with a lot of stability from epoch 5 onward.

As illustrated in Fig. 4, both curves converged toward one another around epoch 10. The convergence indicates an improvement in generalization performance and reduced overfitting with extended training. The mild fluctuations in the training loss during the later epochs (epochs 15 to 18) did not adversely affect the validation score, indicating a robust optimization process for the model.

After training and validating the models, three CNNs – ResNet18, EfficientNet-B0, and MobileNetV3 – were tested on the held-out test set. As shown in Table 5, all models performed exceedingly well in all metrics since they generalized well to unseen data.

EfficientNet-B0 performed the best: it displayed an outstanding test result of 99.74%, being a perfect 0.9974 in macro-averaged precision, recall, and F1-score. This supports previous judgments made during training about the network's generalization ability and powerful learning. The compound scaling method of EfficientNet-B0 was likely responsible for obtaining a trade-off on the feature extraction throughout resolution and depth.

ResNet18 also performed quite well, achieving 98.94% accuracy and perfectly balanced precision and recall at 0.9896 and 0.9894, respectively. In conclusion, the residual connections that supported stable learning in their ResNet18 architecture were less efficient for parameter utilization in their case, giving slightly higher performances to EfficientNet-B0.

But for the most lightweight model, which is still classed as a CNN, which will be best adapted for real-time or embedded dental diagnostic systems, test accuracy of 98.68%, with consistent measures of precision, recall, and F1-score (0.9868) were obtained from MobileNetV3. The model proved to be quite effective despite fewer parameters and optimizations for mobile applications, especially for deployment with limited resources.

In conclusion, all three CNNs demonstrated quite good classification abilities over the Caries-Spectra test set, with EfficientNet-B0 being declared first among equals by any measure. At the same time, MobileNetV3 serves as the best trade-off between accuracy and computational efficiency, an attractive choice for real-time or embedded dental diagnostic systems.

Evaluation on the periapical lesions dataset

The findings of detecting periapical lesions on panoramic radiographs are discussed in this section of the second dataset.

ResNet18 exhibited a relatively moderate performance in classifying periapical lesions into PAI categories 3, 4, and 5 on panoramic radiographs. As seen in Table 6, the training accuracy shows a steep increase from 57.13% in epoch one to 96.93% by epoch six, indicating that effective learning has happened on the training set. However, with respect to validation accuracy, it kept fluctuating in an unstable manner between 58.71% and 64.32%, which thereafter led to early stopping after six epochs with no other improvement.

The model's limitations are further elaborated in Fig. 5, where the confusion matrix talks about the limitations in generalizing to validation data never seen before. PAI category 3 was identified more or less accurately with 651 correct predictions, while there was tremendous confusion distinguishing PAI 4 and PAI 5, where 180 instances of PAI 4 were incorrectly predicted as PAI 3, and 89 instances of PAI 5 were incorrectly assigned to PAI 3. Such imbalance indicates that ResNet18, despite the signature residual learning architecture for small, low-contrast lesions, is probably not suitable for differential diagnosis in the apical periodontitis examination. The overlapping radiographic characteristics across PAI categories might have contributed to such impairment of the model in extracting relevant features, particularly due to fewer training epochs and lack of sophisticated regularization.

ResNet18 converged well on the training, but generalization on the validation and test was problematic, probably owing to lack of discriminative capability for the complex patterns of radio-opaque lesions.

Table 5. Comparative evaluation of CNN models on the Caries-Spectra test set

Таблица 5. Сравнительная оценка моделей CNN на тестовом наборе Caries-Spectra

AI Model	Test Accuracy, %	Precision, %	Recall, %	F1 Score, %
ResNet18	98.94	98.96	98.94	98.94
EfficientNet-B0	99.74	99.74	99.74	99.74
MobileNetV3	98.68	98.68	98.68	98.68

Table 6. Epoch-wise training and validation performance of ResNet18 on the Periapical Lesions test set

Таблица 6. Результаты обучения и проверки ResNet18 на тестовом наборе данных с периапикальными поражениями

Epoch. No	Loss	Train Acc, %	Val Acc, %
Epoch 1	313.1151	57.13	58.71
Epoch 2	259.0123	64.93	60.41
Epoch 3	156.4190	80.84	64.32
Epoch 4	65.5993	93.21	63.30
Epoch 5	37.1525	96.33	59.64
Epoch 6	29.4193	96.93	63.98
Early stopping at epoch 6 (no improvement for 3 epochs)			

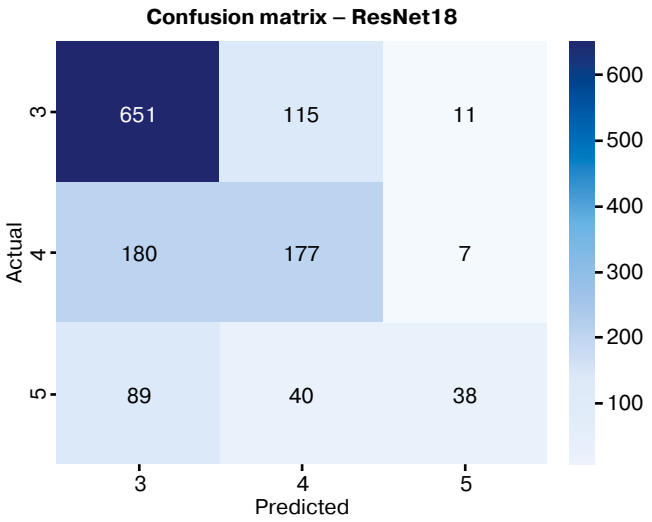

Fig. 5. Confusion matrix of ResNet18 on the periapical lesions test Set

Рис. 5. Матрица неточностей ResNet18 на тестовом наборе данных с перифокальными поражениями

Table 7. Epoch-wise training and validation performance of EfficientNet-B0 on the Periapical lesions test set

Таблица 7. Результаты обучения и проверки EfficientNet-B0 на тестовом наборе данных с периапикальными поражениями по эпохам

Epoch. No	Loss	Train Acc, %	Val Acc, %
Epoch 1	309.1451	58.89	59.47
Epoch 2	276.6413	61.88	58.88
Epoch 3	231.8796	69.73	61.17
Epoch 4	168.7719	79.76	59.90
Epoch 5	113.4400	87.42	66.61
Epoch 6	76.2439	91.82	71.11
Epoch 7	61.9546	93.24	70.60
Epoch 8	46.5596	95.09	70.01
Epoch 9	43.2456	95.42	71.62
Epoch 10	37.1156	96.48	70.18

The architecture of EfficientNet-b0 gives generalization superior to ResNet18 and stability on training data compared to other architectures, for the dataset of Periapical Lesions. As training data would affix between the first and tenth epochs of training, the aforementioned average accuracy of training, for instance, would rise regularly from 58.89% up to 96.48%, with an apparently upsurging validation accuracy from 59.47% toward 71.62%. Thus, it implicates better convergence and less overfitting in the training stage especially within later epochs (Table 7).

This enhancement is further backed by the confusion matrix in Figure 6 which demonstrates clearer classification patterns across all three PAI categories as indicated:

1. For PAI 3, the model has correctly classified 602 samples, though it still misclassifies 159 as PAI 4, thereby revealing some confusion with intermediate cases.

2. For PAI 4, there are performance numbers: 241 were classified accurate while very few misclassified.

3. For PAI 5, 68 predictions out of total are correct while confusion with PAI 3 and 4 trips along as differentiation between the bad discoveries proves to be much harder with overlapping clinical features.

In comparison to ResNet18, EfficientNet-B0 serves a better flexibility in synergetic training and validation performance, the compound scaling has probably increased its ability to learn multi-scale lesion features, an essence being important for detecting radiographically subtle differences within PAI 3 and 4 categories.

EfficientNet-B0 performed best and returned the highest test-time reliability, especially in moderate grades of periapical lesion identification. Interclass level of confusion still exists between classes, more obviously between categories of grade 5 and lower, which calls for improved feature discrimination, or perhaps balancing the dataset.

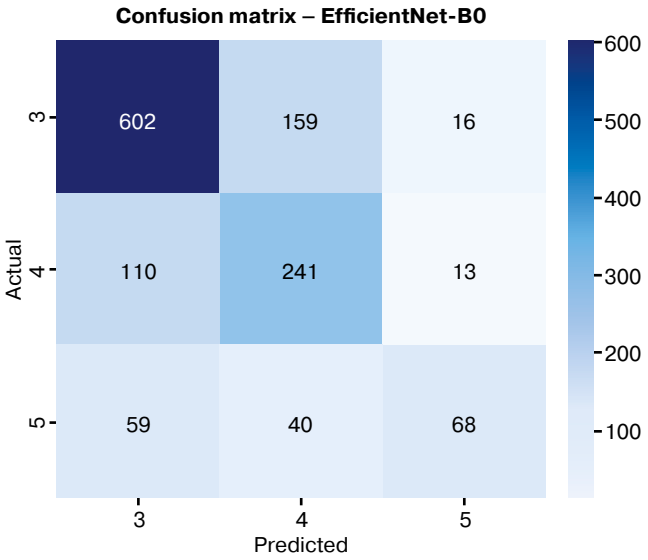

Fig. 6. Confusion Matrix of EfficientNet-B0 on the Periapical Lesions Test Set

Рис. 6. Матрица неточностей EfficientNet-B0 на тестовом наборе данных с периапикальными поражениями

MobileNetV3 was applied for periapical lesions dataset, it yielded a fair yet slightly inconsistent performance. The improved result is shown in Table 8, which reflects training accuracy that steadily increases reach to the maximum of 97% by epoch 10 from 59.06%. It shows good optimization though the validation accuracy varies in epochs, between 54.72% and 62.87%, a neutral direction is not expressed. This indicates that there is difficulty in generalizing the model even though it has converged to the training data evidence.

The confusion matrix (Fig. 7) sheds more insight into the classification behavior. For instance, PAI 3 was yet again the most accurately classified category (547 correct predictions). However, a lot of confusion is found with PAI 4 and PAI 5. For instance, there were 175 cases of PAI 3 wrongly predicted as PAI 4, whereas 55 of these classes were misidentified as PAI 5. PAI 4 shows moderate accuracy (196 predictions correct), but with misclassification among both adjacent classes. PAI 5 is problematic as well, with a distribution that almost evenly split at the average of correct predictions (57) to misclassifications (60 as PAI 3, 50 as PAI 4).

Table 8. Epoch-wise training and validation performance of MobileNetV3 on the periapical lesions test set

Таблица 8. Результаты обучения и проверки MobileNetV3 на тестовом наборе данных с периапикальными поражениями

Epoch. No	Loss	Train Acc, %	Val Acc, %
Epoch 1	307.6318	59.06	59.22
Epoch 2	288.7250	60.78	59.30
Epoch 3	262.6076	64.98	54.72
Epoch 4	220.9292	71.48	57.18
Epoch 5	165.3464	79.58	60.49
Epoch 6	116.3207	86.60	56.67
Epoch 7	77.4871	91.37	62.87
Epoch 8	55.1178	94.01	60.49
Epoch 9	36.3399	96.36	62.62
Epoch 10	29.2710	97.00	62.11

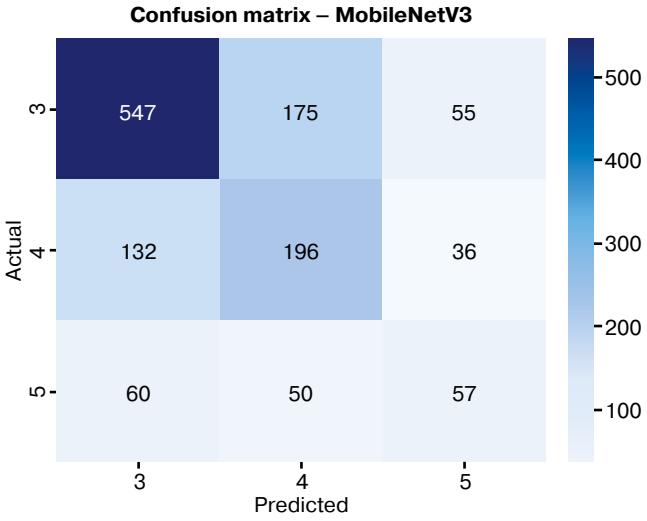

Fig. 7. Confusion Matrix of MobileNetV3 on the periapical lesions test set

Рис. 7. Матрица ошибок MobileNetV3 на тестовом наборе данных с периапикальными поражениями

Though MobileNetV3 is a lightweight architecture designed for high speed and mobile applications, it might not possess sufficient representational depth to capture the subtle differences between complex radiographic features, especially for more severe lesion classes. In conclusion, however high MobileNetV3 might have gotten in terms of training accuracy, the validation would not hold true as well as the configured disparity from the confusion matrix would indicate that it is weaker than EfficientNet-B0 and similar to ResNet18, in such cases. Nonetheless, the computational efficiency exhibited makes it a valuable candidate for deploying systems where real-time inference takes precedence over very marginal accuracy losses.

Table 9 presents the comparative evaluation among the three CNNs – ResNet18, EfficientNet-B0, and MobileNetV3 – on the Periapical Lesions test set. It shows that there is a large difference in the classification effectiveness between models when it comes to precision, recall, and F1-score.

The performance of EfficientNet-B0 is particularly high among all these models, achieving the maximum test accuracy of 69.65%, precision of 0.6765, recall of 0.6147, and F1-score of 0.6308. All these results confirm that the current model outperformed others in generalization and identification between PAI classes, especially in the presence of overlapping radiographic traits and highly ambiguous inter-class differences.

ResNet18 has had a comparable accuracy of 66.21% but has significantly low recall (0.5172) and F1-score (0.5389), indicating that it appears to misclassify a higher proportion of true positive samples. It indicated a moderate precision (0.6398) that demonstrates the correctness of many predictions, thus failing to detect several other cases with lesions, especially in the severe categories.

MobileNetV3, which is appropriate in terms of computation efficiency, gave the weakest results having the test accuracy of 61.16%. MobileNetV3 scored the lowest under all performance measures. Its precision (0.5303) and F1-score (0.5276) seem to reflect its limited discrimination capacity, which could be due to its lightweight features and shallow depth of feature extraction with less use for fine grained medical classification tasks.

Table 9. Comparative evaluation of CNN models on the periapical lesions test set

Таблица 9. Сравнительная оценка моделей сверточных нейронных сетей на тестовом наборе данных с периапикальными поражениями

AI Model	Test Accuracy, %	Precision, %	Recall, %	F1 Score, %
ResNet18	66.21	63.98	51.72	53.89
EfficientNet-B0	69.65	67.65	61.47	63.08
MobileNetV3	61.16	53.03	52.79	52.76

In summary, the best performance in terms of balance and reliability was achieved by EfficientNet-B0, making it the most competitive model for periapical lesion detection. In terms of speed and simplicity in architecture, ResNet18 is a good contender as well. MobileNetV3 best fits those whose priority is speed of inference and use of fewer resources over the precision of classifications.

CONCLUSION

In this study, the development of deep learning models for the automated classification of two dental conditions, namely enamel caries and periapical lesions, was undertaken. A total of two publicly available radiographic datasets were used. A consistent methodology was chosen to train and validate the three different CNN architectures: ResNet18, EfficientNet-B0, and MobileNetV3, such that a distinguishable fair comparison could generate the most valid results.

From these experimental results, it is clear that all considered models could learn meaningful features from dental images. However, in terms of the metrics used to consider generalization ability applied to both datasets, uses EfficientNet-B0 stood in prestige over its counterparts. Test accuracy of 99.74% on the Caries-Spectra dataset and 69.65% on the periapical lesions dataset display its capabilities of generalization. On the other hand, ResNet18 was not as advanced but gave due respect to the performance and ease of creating training. Also, MobileNetV3 was found to be computationally efficient, but its classification performance was poor-worse in sophisticated periapical cases.

The conclusion emphasizes the need to architect models according to the complexity of the diagnostic task in hand and the characteristics of their training dataset. The usage of lightweight models, such as MobileNetV3, would constitute a fair advantage in real-time tasking applications or where resources are scarce. On the contrary, where the main emphasis and concern are on accuracy would even call for the use of models like the EfficientNet-B0 in the diagnosis in health care settings.

Future research directions may open ensembles for models, means of attention, and frameworks for explainability to improve diagnostic framework reliability and clinician trust in AI systems. Likewise, the increase of new data types and magnitudes for training datasets, especially for the less represented lesion categories, would give a lot in strengthening the more robust and generalizable performance for real-world dental practice.

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Diagnostic accuracy of an artificial intelligence-driven platform in assessing periapical healing and endodontic treatment outcomes on panoramic radiographs: a retrospective study

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Abstract

INTRODUCTION. Evaluation of endodontic treatment outcomes through radiographic assessment is subject to interobserver variability and depends heavily on clinician experience. Artificial intelligence (AI) platforms offer potential for standardized, objective assessment of periapical healing.

MATERIALS AND METHODS. This retrospective study analyzed 400 panoramic radiographs from patients who underwent root canal treatment between January 2023 and December 2024. An AI platform developed using TensorFlow and Keras, with model training in PyTorch and validation in MATLAB Deep Learning Toolbox, was employed. Three blinded expert endodontists independently assessed all radiographs, with consensus serving as the gold standard. Outcomes were classified as healed, healing, or diseased based on periapical index criteria. Diagnostic performance metrics including sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV) were calculated.

RESULTS. The AI platform demonstrated overall accuracy of 89.8% in classifying treatment outcomes. For detecting healed cases, sensitivity was 92.3%, specificity 87.6%, PPV 88.9%, and NPV 91.5%. For diseased/persistent pathology detection, sensitivity was 88.7%, specificity 93.2%, PPV 84.3%, and NPV 95.1%. Agreement between AI and expert consensus was substantial (Cohen's $\kappa = 0.834$, $p < 0.001$). AI performance was superior in anterior teeth (93.2% accuracy) compared to molars (86.4% accuracy, $p = 0.008$). Processing time per radiograph averaged 2.3 ± 0.4 seconds.

CONCLUSIONS. The AI-driven platform demonstrated high diagnostic accuracy comparable to expert assessment, with potential for standardized, rapid evaluation of endodontic treatment outcomes. Further prospective validation and clinical integration studies are warranted.

Keywords: artificial intelligence, deep learning, endodontic treatment outcome, periapical healing, panoramic radiography, diagnostic accuracy, convolutional neural networks, TensorFlow

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Диагностическая точность платформы с использованием искусственного интеллекта при оценке периапикального заживления и исходов эндодонтического лечения на панорамных рентгенограммах: ретроспективное исследование

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Резюме

ВВЕДЕНИЕ. Оценка исходов эндодонтического лечения с помощью рентгенографии подвержена вариабельности между наблюдателями и сильно зависит от опыта клинициста. Платформы искусственного интеллекта предлагают возможность стандартизированной и объективной оценки периапикального заживления.

МАТЕРИАЛЫ И МЕТОДЫ. В ретроспективное исследование были включены 400 панорамных рентгенограмм пациентов, прошедших лечение корневых каналов с января 2023 г. по декабрь 2024 г. Для анализа использовалась платформа искусственного интеллекта, разработанная с применением TensorFlow и Keras, обучение модели проводилось в PyTorch, а валидация – в MATLAB Deep Learning Toolbox.

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Три независимых эксперта-эндодонтиста оценивали все рентгенограммы вслепую; консенсус экспертов служил эталонным стандартом. Исходы классифицировались как «зажившие», «в процессе заживления» или «пораженные» на основе критериев периапикального индекса (PAI). Рассчитывались показатели диагностической эффективности: чувствительность, специфичность, точность, положительное прогностическое значение (PPV) и отрицательное прогностическое значение (NPV).
РЕЗУЛЬТАТЫ. Платформа искусственного интеллекта продемонстрировала общую точность 89,8% при классификации исходов лечения. Для выявления зажившим случаев чувствительность составила 92,3%, специфичность – 87,6%, PPV – 88,9%, NPV – 91,5%. Для обнаружения пораженных/персистирующих патологий чувствительность составила 88,7%, специфичность – 93,2%, PPV – 84,3%, NPV – 95,1%. Согласованность между искусственного интеллекта и консенсусом экспертов была высокой (κ Коэна = 0,834, $p < 0,001$). Производительность искусственного интеллекта была выше для передних зубов (точность 93,2%) по сравнению с молярами (точность 86,4%, $p = 0,008$). Среднее время обработки одной рентгенограммы составило 2,3 ± 0,4 секунды.
ВЫВОДЫ. Платформа на основе искусственного интеллекта продемонстрировала высокую диагностическую точность, сопоставимую с оценкой экспертов, с потенциалом для стандартизированной и быстрой оценки исходов эндодонтического лечения. Необходимы дальнейшие проспективные исследования и интеграция в клиническую практику.

Ключевые слова: искусственный интеллект, глубокое обучение, исход эндодонтического лечения, периапикальное заживление, панорамная рентгенография, диагностическая точность, сверточные нейронные сети, TensorFlow

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INTRODUCTION

Endodontic treatment aims to eliminate infection, preserve tooth function, and promote periapical healing, with success rates ranging from 85% to 97% depending on multiple factors including diagnosis, technique, and restoration quality [1]. Accurate assessment of treatment outcomes is fundamental for clinical decision-making, determining the need for retreatment, surgical intervention, or continued monitoring. Radiographic evaluation remains the primary non-invasive method for assessing periapical status and healing progression following root canal therapy [2].

Panoramic radiographs are widely utilized in dental practice due to their ability to visualize the entire dentition and surrounding structures in a single image, cost-effectiveness, reduced radiation exposure compared to multiple periapical films, and patient comfort [3]. Despite certain limitations including geometric distortion and reduced resolution compared to periapical radiographs, panoramic imaging provides valuable screening and follow-up assessment, particularly for evaluating multiple treated teeth simultaneously [4].

The interpretation of periapical radiographic findings, however, remains subjective and dependent on clinician experience, training, and individual perception thresholds. Multiple scoring systems have been developed to standardize assessment, including the Periapical Index (PAI) introduced by Orstavik et al., which categorizes periapical status on a five-point scale from healthy to severe periodontitis with characteristic features [5]. Despite such standardization efforts, significant interobserver and intraobserver variability persists in radiographic interpretation, with kappa values for agreement ranging from 0.45 to 0.78 in various studies [6]. This variability can lead to inconsistent treatment decisions, unnecessary interventions, or delayed diagnosis of persistent infection.

Artificial intelligence (AI) and machine learning technologies have revolutionized medical imaging interpretation across multiple specialties including radiology, pathology, and ophthalmology [7]. Deep learning approaches, particularly convolutional neural networks (CNNs), have demonstrated remarkable capability in pattern recognition, feature extraction, and classification tasks that parallel or exceed human expert performance in specific domains [8]. In dentistry, AI applications have expanded rapidly, encompassing caries detection, periodontal bone loss assessment, tooth numbering, and craniofacial anomaly identification [9].

Several recent studies have explored AI applications in endodontics, including automated detection of periapical lesions, assessment of root canal anatomy, and evaluation of obturation quality [10; 11]. Ekert et al. demonstrated that a CNN-based system achieved 93.3% accuracy in detecting periapical radiolucencies on periapical radiographs [12]. However, most existing research has focused on periapical radiographs rather than panoramic images, which present unique challenges including lower resolution, anatomical superimposition, and geometric distortion. Furthermore, limited studies have specifically addressed the classification of treatment outcomes into clinically relevant categories (healed, healing, diseased) that guide management decisions.

Contemporary deep learning frameworks including TensorFlow, PyTorch, Keras, and MATLAB Deep Learning Toolbox provide robust platforms for developing, training, and deploying AI models with varying architectural options and computational efficiencies [13].

TensorFlow offers comprehensive ecosystem support and deployment flexibility, PyTorch provides dynamic computational graphs ideal for research and experimentation, Keras enables rapid prototyping with high-level APIs, and MATLAB facilitates integration with existing signal processing and data analysis workflows. Leveraging multiple platforms can optimize model development, validation, and clinical implementation.

Despite promising preliminary findings, several critical gaps remain in the literature. First, comprehensive evaluation of AI performance specifically for assessing endodontic treatment outcomes on panoramic radiographs is lacking. Second, comparative analysis against expert consensus rather than single-observer assessment provides more robust validation. Third, investigation of factors influencing AI performance, such as tooth type, lesion size, and image quality, is necessary for understanding clinical applicability and limitations. Fourth, processing efficiency metrics are rarely reported but critical for practical implementation [14].

AIM

The primary objective of this retrospective study was to evaluate the diagnostic accuracy of an AI-driven platform in assessing periapical healing and endodontic treatment outcomes on panoramic radiographs, using expert consensus of three blinded endodontists as the reference standard. Secondary objectives included analysis of AI performance across different tooth types, lesion characteristics, and image quality parameters, as well as assessment of processing efficiency and interobserver agreement among human experts.

MATERIALS AND METHODS

Study design and ethical approval

This retrospective diagnostic accuracy study was conducted at the College of Dentistry, Jazan University, Jazan, Saudi Arabia, following approval by the Institutional Research Ethics Committee (Protocol No. REC-47/05/1650). The study adhered to the Standards for Reporting Diagnostic Accuracy (STARD) guidelines and the Declaration of Helsinki principles. Due to the retrospective nature utilizing existing anonymized radiographic data, the requirement for individual informed consent was waived by the ethics committee.

Sample size calculation

Sample size was calculated based on expected sensitivity of 90% for the AI platform, precision (margin of error) of ±3%, and confidence level of 95%. Using the formula for single proportion:

$$n = \frac{Z^2 \cdot P(1-P)}{d^2},$$

where $Z = 1.96$, $P = 0.90$, and $d = 0.03$, the minimum required sample was 384. Accounting for potential exclusions due to image quality issues (approximately 5%), we aimed to collect 400 radiographs.

Study population and selection criteria

Panoramic radiographs were retrieved from the institutional digital radiographic archive for patients who underwent root canal treatment between January 2023 and December 2024. Radiographs obtained 12–24 months post-treatment were selected to allow adequate healing period for outcome assessment.

Inclusion criteria: (1) Panoramic radiographs of patients aged 18–75 years; (2) endodontically treated teeth visible on radiograph with adequate obturation length (within 0-2 mm of radiographic apex); (3) minimum 12-month post-treatment follow-up radiograph; (4) adequate image quality and contrast; (5) complete clinical records available.

Exclusion criteria: (1) Poor quality or motion-artifact radiographs precluding reliable assessment; (2) teeth with posts and cores obscuring periapical region; (3) extensive metal restorations causing significant scatter artifacts; (4) teeth adjacent to implants causing interference; (5) incomplete root formation; (6) previous periapical surgery; (7) radiographs with technical errors (positioning, exposure).

AI platform development and training

Architecture and framework

The AI platform was developed using a hybrid approach leveraging multiple deep learning frameworks. Model architecture was based on a modified ResNet-50 convolutional neural network implemented in TensorFlow 2.8 and Keras 2.8 API. Training was conducted using PyTorch 1.12 to optimize hyperparameters and learning rates. Final validation and deployment preparation utilized MATLAB Deep Learning Toolbox R2023a.

Training dataset

A separate training dataset comprising 2,400 panoramic radiographs (not part of the 400 test cases) was utilized. Expert endodontists (n = 5, with 10–20 years' experience) provided ground truth labels. Each radiograph was annotated for regions of interest (ROI) around endodontically treated teeth, with classification as healed (PAI score 1–2), healing (PAI score 3), or diseased (PAI score 4–5).

Data preprocessing

Images were standardized to 512×512 pixels. ROI extraction was performed using bounding box coordinates around treated teeth. Data augmentation techniques included rotation (±15°), horizontal flipping, brightness adjustment (±20%), and Gaussian noise addition to enhance model generalization.

Model training

Training employed transfer learning with ImageNet pre-trained weights. The model was fine-tuned using Adam optimizer with initial learning rate 0.001, batch size 32, and 100 epochs with early stopping based on validation loss plateau. Class imbalance was addressed using weighted loss function. Training-validation-testing split was 70:15:15.

Performance optimization

Hyperparameter tuning was conducted using grid search for learning rate (0.0001–0.01), dropout rate (0.2–0.5), and batch size (16–64). Final model selection was based on validation set performance maximizing F1-score.

Expert panel assessment

Three certified endodontists with 12–18 years of clinical experience, certified in radiographic interpretation, served as the expert panel. All evaluators were blinded to patient information, clinical outcomes, and AI predictions. Each evaluator independently assessed all 400 radiographs using a standardized digital viewing workstation with calibrated monitors, adjustable brightness / contrast, and magnification capability.

Evaluators classified each treated tooth according to the Periapical Index (PAI) scoring system:

PAI 1-2 (Healed): Normal periapical structures or small changes in bone structure.

PAI 3 (Healing): Changes in bone structure with some mineral loss.

PAI 4-5 (Diseased): Periodontitis with well-defined or severe radiolucent area.

Consensus was defined as agreement among at least two of three evaluators. Cases with complete disagreement (each evaluator selecting different category) were resolved through consensus conference discussion.

AI platform evaluation

Following expert assessment completion, the same 400 radiographs were processed by the AI platform. For each radiograph, the trained model predicted classification (healed, healing, or diseased) with associated probability scores. Processing was automated with no human intervention. Time required for processing each radiograph was recorded.

Data collection and variables

Demographic data (age, gender), tooth-specific information (tooth number, tooth type, number of canals), lesion characteristics (maximum dimension, location), and image quality metrics (contrast-to-noise ratio) were extracted from clinical records and radiographic analysis software.

Outcome measures

Primary outcome: Overall diagnostic accuracy of AI platform compared to expert consensus for three-category classification (healed, healing, diseased).

Secondary outcomes: (1) Sensitivity, specificity, PPV, and NPV for each category; (2) binary classification performance (healed vs. non-healed; diseased vs. non-diseased); (3) performance stratification by tooth type, lesion size, and image quality; (4) processing time efficiency; (5) interobserver agreement among human experts.

Statistical Analysis

Data were analyzed using SPSS Statistics version 25.0 (IBM Corporation, USA) and MedCalc Statistical Software version 20.0. Categorical variables were presented as frequencies and percentages, continuous variables as mean ± standard deviation. Diagnostic performance metrics with 95% confidence intervals were calculated using standard formulas. Cohen's kappa coefficient assessed agreement between AI predictions and expert consensus, with values >0.80 indicating substantial agreement. McNemar's test compared paired proportions. Subgroup analyses utilized chi-square test or Fisher's exact test as appropriate. Receiver operating characteristic (ROC) curves were generated, and area under curve (AUC) calculated. Statistical significance was set at $p < 0.05$ (two-tailed).

RESULTS

Study population and baseline characteristics

A total of 462 panoramic radiographs were initially screened, of which 400 met all inclusion criteria and were included in the final analysis. Sixty-two radiographs were excluded: 28 due to inadequate image quality, 18 with extensive metal artifacts, 12 with post-and-core restorations obscuring periapical region, and 4 with incomplete clinical data. Table 1 presents baseline demographic and clinical characteristics.

The mean patient age was 46.8 ± 13.2 years, with slight female predominance (53.5%). Premolars were the most commonly evaluated treated teeth (39.0%), followed by anterior teeth (32.0%) and molars (29.0%). According to expert consensus, 61.5% of cases were classified as healed, 22.0% as healing, and 16.5% as diseased. Mean follow-up period was 16.4 ± 3.8 months.

Interobserver agreement among expert evaluators

Complete agreement among all three expert evaluators occurred in 312 cases (78.0%). Two-evaluator consensus was achieved in 84 cases (21.0%), requiring third evaluator to establish majority consensus. Four cases (1.0%) showed complete disagreement and required consensus conference resolution. Overall interobserver agreement was substantial, with pairwise Cohen's kappa values ranging from 0.76 to 0.82 (mean $\kappa = 0.79$, $p < 0.001$).

Overall diagnostic performance of AI platform

The AI platform achieved overall classification accuracy of 89.8% (359/400 cases correctly classified) compared to expert consensus. Table 2 presents comprehensive diagnostic performance metrics for each outcome category.

For detecting healed cases, the AI platform demonstrated excellent sensitivity (92.3%) and specificity (87.6%), with PPV of 92.3% and NPV of 87.6%. The healing category showed slightly lower performance with sensitivity of 81.8% and specificity of 89.4%. For diseased / persistent pathology detection, sensitivity was 90.9% with high specificity of 93.1%, though PPV was lower at 72.3% due to the relatively low prevalence of diseased cases (16.5%).

Binary classification performance (healed vs. non-healed) yielded sensitivity 92.3%, specificity 82.5%, and accuracy 88.8%. For clinically critical diseased vs. non-diseased classification, sensitivity was 90.9%, specificity 93.1%, and accuracy 92.8%.

Table 1. Baseline demographic and clinical characteristics of study population (n = 400 radiographs)

Таблица 1. Исходные демографические и клинические характеристики исследуемой выборки (n = 400 рентгенограмм)

Characteristic	Value
Patient demographics	
Age (years), mean ± SD	46.8 ± 13.2
Age distribution, *n* (%)	
18–35 years	98 (24.5%)
36–50 years	162 (40.5%)
51–65 years	108 (27.0%)
>65 years	32 (8.0%)
Gender, *n* (%)	
Male	186 (46.5%)
Female	214 (53.5%)
Treated teeth characteristics	
Total treated teeth evaluated	400
Tooth type, *n* (%)	
Anterior teeth (incisors, canines)	128 (32.0%)
Premolars	156 (39.0%)
Molars	116 (29.0%)
Arch distribution, *n* (%)	
Maxillary	234 (58.5%)
Mandibular	166 (41.5%)
Number of root canals, *n* (%)	
Single canal	142 (35.5%)
Two canals	168 (42.0%)
Three or more canals	90 (22.5%)
Follow-up period (months), mean ± SD	16.4 ± 3.8
Expert consensus classification, *n* (%)	
Healed (PAI 1-2)	246 (61.5%)
Healing (PAI 3)	88 (22.0%)
Diseased (PAI 4-5)	66 (16.5%)
Lesion characteristics (diseased/healing cases, *n* = 154)	
Maximum lesion diameter (mm), mean ± SD	4.8 ± 2.6
Small (<3 mm)	52 (33.8%)
Medium (3–6 mm)	68 (44.2%)
Large (>6 mm)	34 (22.0%)
Image quality parameters	
Contrast-to-noise ratio, mean ± SD	12.4 ± 3.2
Excellent quality (CNR > 15)	142 (35.5%)
Good quality (CNR 10-15)	186 (46.5%)
Adequate quality (CNR < 10)	72 (18.0%)

Note: PAI – Periapical Index; CNR – Contrast-to-noise ratio; SD – Standard deviation

Примечание: PAI – периапикальный индекс; CNR – отношение контраста к шуму; SD – стандартное отклонение.

ROC curve analysis demonstrated excellent discriminative ability with AUC of 0.946 for healed, 0.891 for healing, and 0.938 for diseased categories. Agreement between AI predictions and expert consensus was substantial (Cohen's κ = 0.834, $p < 0.001$).

Subgroup analysis: performance stratification

Table 3 presents AI platform performance stratified by tooth type, lesion size, and image quality parameters.

Tooth type: AI performance was significantly superior in anterior teeth (93.2% accuracy) compared to molars (86.4%, $p = 0.008$), likely reflecting simpler root anatomy and reduced anatomical complexity. No significant difference existed between anterior teeth and premolars (90.4%, $p = 0.394$).

Lesion size: Counterintuitively, accuracy increased with larger lesion size, from 82.7% for small lesions (<3 mm) to 94.1% for large lesions (>6 mm, $p = 0.031$). This pattern likely reflects enhanced conspicuity and clearer borders of larger lesions.

Table 2. Diagnostic performance of AI platform for classifying endodontic treatment outcomes (n = 400)

Таблица 2. Диагностическая эффективность платформы искусственного интеллекта при классификации исходов эндодонтического лечения (n = 400).

Performance Metric	Healed (PAI 1-2) *n* = 246	Healing (PAI 3) *n* = 88	Diseased (PAI 4-5) *n* = 66
True Positives (TP)	227	72	60
True Negatives (TN)	135	279	311
False Positives (FP)	19	33	23
False Negatives (FN)	19	16	6
Sensitivity (%) [95% CI]	92.3 [88.3–95.3]	81.8 [72.2–89.1]	90.9 [81.3–96.6]
Specificity (%) [95% CI]	87.6 [81.3–92.4]	89.4 [85.2–92.8]	93.1 [89.7–95.7]
Positive Predictive Value (%) [95% CI]	92.3 [88.3–95.3]	68.6 [58.4–77.6]	72.3 [61.4–81.6]
Negative Predictive Value (%) [95% CI]	87.6 [81.3–92.4]	94.6 [91.2–97.0]	98.1 [95.9–99.3]
Accuracy (%)	90.5	87.8	92.8
F1-Score	0.923	0.747	0.806
Cohen's Kappa (vs. consensus)	0.798	0.703	0.792
Area Under ROC Curve (AUC)	0.946 [0.922–0.969]	0.891 [0.857–0.925]	0.938 [0.905–0.971]
Overall Performance Metrics:			
Overall Accuracy		89.8% (359/400)	
Overall Cohen's Kappa		0.834 [0.795–0.873]	
Overall Agreement		Substantial ($p < 0.001$)	
Mean Processing Time/Image		2.3 ± 0.4 seconds	

Note: CI – Confidence interval; ROC – Receiver operating characteristic; PAI – Periapical Index.

Примечание: CI – доверительный интервал; ROC – рабочая характеристика приемника (кривая «Receiver Operating Characteristic»); PAI – периапикальный индекс.

Table 3. Stratified analysis of AI platform diagnostic accuracy by clinical variables

Таблица 3. Стратифицированный анализ точности диагностики платформы искусственного интеллекта в зависимости от клинических переменных

Subgroup	n	Accuracy (%)	Sensitivity (%)	Specificity (%)	Cohen's Kappa	p-value*
Tooth Type						
Anterior teeth	128	93.2	94.8	91.2	0.859	Reference
Premolars	156	90.4	91.6	88.9	0.834	0.394
Molars	116	86.4	88.2	84.3	0.772	0.008†
Lesion Size (diseased / healing, *n* = 154)						
Small (< 3 mm)	52	82.7	78.8	85.7	0.703	Reference
Medium (3–6 mm)	68	88.2	89.7	86.4	0.812	0.289
Large (> 6 mm)	34	94.1	97.1	91.7	0.887	0.031†
Image Quality (CNR)						
Excellent (CNR >15)	142	94.4	95.8	92.6	0.882	Reference
Good (CNR 10-15)	186	89.2	91.4	86.8	0.823	0.072
Adequate (CNR <10)	72	81.9	84.7	78.3	0.712	<0.001†
Arch Location						
Maxillary	234	90.6	92.8	88.2	0.841	0.424
Mandibular	166	88.6	91.6	85.1	0.824	
Number of Canals						
Single canal	142	92.3	94.4	89.8	0.862	Reference
Two canals	168	89.9	91.7	87.6	0.836	0.512
Three or more canals	90	85.6	87.8	82.9	0.782	0.041†
Follow-up Duration						
12–15 months	168	87.5	89.3	85.2	0.801	Reference
16–20 months	184	90.8	93.5	87.8	0.848	0.284
> 20 months	48	93.8	95.8	91.7	0.876	0.126

Note: CNR – Contrast-to-noise ratio; * *p*-value comparing accuracy to reference category within each variable using chi-square test; † Statistically significant ($p < 0.05$)

Примечание: CNR – отношение контраста к шуму; * *p* – значение *p* при сравнении точности с эталонной категорией внутри каждой переменной с использованием критерия χ^2; † Статистически значимо ($p < 0,05$).

Image quality: Diagnostic accuracy correlated strongly with image quality, ranging from 94.4% for excellent quality (CNR > 15) to 81.9% for adequate quality (CNR < 10, $p < 0.001$). This finding emphasizes the importance of optimal image acquisition for AI performance.

Canal complexity: Accuracy decreased with increasing number of canals, from 92.3% for single-canal teeth to 85.6% for multi-canal teeth ($p = 0.041$), potentially reflecting increased anatomical complexity and difficulty in assessing periapical status comprehensively.

DISCUSSION

This study represents the first comprehensive evaluation of an AI-driven platform for assessing endodontic treatment outcomes on panoramic radiographs using multi-framework deep learning approaches and rigorous validation against expert consensus. The principal findings demonstrate that the AI platform achieved high diagnostic accuracy (89.8%) with substantial agreement ($\kappa = 0.834$) compared to expert consensus, supporting its potential utility as a standardized, objective assessment tool in clinical endodontic practice.

The overall diagnostic performance observed in this study compares favorably with existing literature on AI applications in endodontic imaging. Setzer et al. reported 87% accuracy for AI-based detection of periapical lesions on periapical radiographs [10], while our platform achieved 89.8% accuracy on panoramic images despite their inherent limitations of lower resolution and geometric distortion. This comparable performance suggests that advanced deep learning architectures can compensate for reduced image quality through sophisticated feature extraction and pattern recognition.

The sensitivity of 92.3% for detecting healed cases is particularly clinically relevant, as accurate identification of successful treatment outcomes avoids unnecessary interventions and provides patients with reassurance. The high negative predictive value (98.1%) for diseased cases indicates that when the AI platform classifies a case as non-diseased, there is very high probability of true absence of pathology, potentially reducing false-negative errors that could delay necessary retreatment [15].

The moderate PPV for diseased cases (72.3%) reflects the challenge of specificity in low-prevalence

conditions, where false positives proportionally impact predictive values. In clinical practice, this would mean that AI-flagged "diseased" cases should undergo confirmatory expert review, positioning the AI as a screening rather than definitive diagnostic tool. This aligns with current medical AI implementation strategies emphasizing human-AI collaboration rather than autonomous decision-making [7].

The substantial interobserver agreement among expert evaluators ($\kappa = 0.79$) in our study is consistent with previous reports of radiographic interpretation variability. Panitvisai et al. reported kappa values of 0.52–0.71 for periapical radiograph interpretation among endodontists [6], while our slightly higher values may reflect specialized training and standardized protocols. The fact that AI agreement with consensus ($\kappa = 0.834$) exceeded typical inter-expert agreement underscores AI's potential to provide consistent, reproducible assessments free from subjective variation, fatigue, or cognitive biases.

The stratified analysis revealing superior AI performance in anterior teeth versus molars aligns with anatomical considerations. Anterior teeth typically present simpler root canal anatomy, reduced anatomical superimposition, and clearer periapical regions on panoramic radiographs. Molar assessment is complicated by multiple roots, proximity to anatomical landmarks (maxillary sinus, mandibular canal), and potential ghost images. These findings suggest that AI implementation strategies might initially prioritize anterior/premolar assessments while refinement continues for complex molars [9].

The finding that AI accuracy increased with larger lesion size appears paradoxical, as larger lesions might indicate more severe pathology and complex healing patterns. However, this observation likely reflects fundamental principles of image analysis: larger, more conspicuous features with well-defined borders are inherently easier to detect and classify accurately than subtle, small changes that may be confused with normal anatomical variations or image noise [12]. This pattern has been observed in other medical imaging AI applications, including tumor detection in oncologic imaging.

The strong correlation between image quality and AI performance (94.4% accuracy for excellent quality vs. 81.9% for adequate quality) emphasizes the critical importance of optimal image acquisition protocols. This finding has practical implications for clinical implementation, suggesting that AI-augmented assessment systems should incorporate automated quality control metrics that flag suboptimal images for repeat acquisition or manual review [13]. Integration of image quality assessment modules into the AI pipeline could enhance overall diagnostic reliability.

The remarkable processing efficiency of 2.3 seconds per radiograph represents a significant practical advantage over human assessment, which typically requires 30–60 seconds per case by experienced clinicians. This computational efficiency enables real-time clinical integration, large-scale screening applications, and potential cost savings in high-volume settings. Furthermore, instant availability of results facilitates immediate clinical decision-making during patient consultations [14].

The hybrid multi-framework approach employed in this study leveraged complementary strengths of different platforms: TensorFlow's deployment ecosystem, PyTorch's research flexibility, Keras's accessibility, and MATLAB's integration capabilities. This strategy may have contributed to model robustness and performance optimization. However, it also introduces complexity in development and maintenance, requiring specialized expertise across multiple platforms. Future work should evaluate whether similar performance can be achieved with single-framework approaches to enhance sustainability and practical implementation.

Several limitations warrant acknowledgment. The retrospective design limits generalizability and precludes assessment of AI impact on actual clinical outcomes, treatment decisions, or patient prognosis. Prospective studies with longitudinal follow-up are necessary to validate clinical utility. The study population from a single tertiary center may not represent broader community practice patterns, imaging equipment variability, or diverse patient demographics. External validation in multiple settings with different equipment and patient populations is essential.

The use of expert consensus as gold standard, while practical, is imperfect given inherent subjectivity and interobserver variability in radiographic interpretation. Ideally, long-term clinical follow-up with additional objective measures (cone-beam CT, clinical symptoms, tooth survival) would provide more definitive outcome assessment. The exclusion of 13.4% of initially screened radiographs due to quality or artifact issues may have created selection bias toward clearer, easier-to-interpret images, potentially overestimating real-world performance.

The study focused on single time-point assessment rather than monitoring healing progression over time, which is clinically more relevant for decision-making. Future iterations should incorporate longitudinal analysis capabilities to track periapical changes and predict healing trajectories. Additionally, integration of clinical data (symptoms, percussion sensitivity, sinus tract presence) alongside radiographic findings could enhance diagnostic accuracy through multimodal assessment, better reflecting actual clinical practice.

CONCLUSION

This study demonstrates that an AI-driven platform utilizing advanced deep learning architectures achieves high diagnostic accuracy (89.8%) in assessing endodontic treatment outcomes on panoramic radiographs, with substantial agreement ($\kappa = 0.834$) compared to expert consensus. The platform exhibited excellent sensitivity (92.3%) for detecting healed cases and high specificity (93.1%) for identifying persistent disease, with performance comparable to or exceeding inter-expert reliability. Superior accuracy was observed for anterior teeth, larger lesions, and higher-quality images, indicating that optimal clinical implementation requires attention to tooth anatomy, image acquisition quality, and appropriate use case selection. The rapid processing capability (2.3 seconds per image) supports feasibility for real-time clinical integration. These findings position AI-augmen-

ted assessment as a promising adjunct tool for standardized, objective evaluation of endodontic treatment outcomes, potentially reducing interobserver variability and enhancing diagnostic consistency. However, current performance limitations suggest AI should complement rather than replace expert judgment, particularly for complex cases and critical treatment decisions. Future prospective multicenter studies with external validation, longitudinal outcome tracking, clinical integration assessment, and cost-effectiveness analysis are warranted to fully establish clinical utility and inform evidence-based implementation strategies in endodontic practice.

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AUTHOR'S CONTRIBUTION

The author made full contributions to the preparation of the publication, including the conception and design of the article; data collection; critical revision of the article for significant intellectual content; and final approval of the version of the article for publication.

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Original Research

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Study of the correlation of the top of the mandibular teeth to the bottom of the maxillary sinus according to CBCT data

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Abstract

INTRODUCTION. The article presents the results of a study of the ratios of apex roots of premolars and molars of the upper jaw to the bottom of the maxillary sinus based on the analysis of 288 cone-beam computed tomograms (CBCT).

MATERIALS AND METHODS. The sample included patients older than 25 years, divided into five age groups, adjusted for gender. Measurements were made in the sagittal and axial planes with an accuracy of 0.1 mm, using Romexis Viewer software and statistical analysis in SPSS (ANOVA, Pearson correlation analysis).

RESULTS. Key findings: Distances from apex to sinus floor decrease with age (r = –0.45 to –0.72, $p < 0.01$), with lower values in females and variability up to 50% in older groups. Minimum distances (up to –0.95 mm) are observed in the 65+ year group, indicating a risk of perforation in 15-30% of patients. ANOVA revealed significant differences between groups and sexes (F = 4.12–6.78, $p < 0.05$), with a tendency for apexes of premolars and molars to approach the bottom. The clinical significance of the results obtained lies in the reduction of the risks of complications (sinusitis, perforation) during dental interventions due to the preventive use of CBCT.

CONCLUSIONS. The data contribute to personalized treatment planning, particularly in older patients and women.

Keywords: the bottom of the maxillary sinus, the tops of the roots of the teeth, cone-ray computed tomography, coefficient of variation

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Изучение соотношения верхушек жевательных зубов ко дну верхнечелюстной пазухи по данным КЛКТ

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Резюме

ВВЕДЕНИЕ. В статье представлены результаты исследования соотношений апексов корней премоляров и моляров верхней челюсти ко дну верхнечелюстной пазухи на основе анализа 288 конусно-лучевых компьютерных томограмм (КЛКТ).

МАТЕРИАЛЫ И МЕТОДЫ. Выборка включала пациентов старше 25 лет, разделенных на пять возрастных групп, с учетом пола. Измерения проводились в сагиттальной и аксиальной плоскостях с точностью до 0,1 мм, с использованием программного обеспечения Romexis Viewer и статистического анализа в SPSS (ANOVA, корреляционный анализ Пирсона).

РЕЗУЛЬТАТЫ. Ключевые результаты: расстояния от апексов до дна пазухи уменьшаются с возрастом (r = –0,45 до –0,72, $p < 0,01$), с более низкими значениями у женщин и вариабельностью до 50% в старших группах. Минимальные расстояния (до –0,95 мм) наблюдаются в группе 65+ лет, указывая на риск перфорации у 15–30% пациентов. ANOVA выявил значимые различия между группами и полами (F = 4,12–6,78, $p < 0,05$), с тенденцией к приближению апексов премоляров и моляров к дну. Клиническая значимость полученных результатов заключается в снижении рисков осложнений (синусит, перфорация) при стоматологических вмешательствах за счет превентивного использования КЛКТ.

ВЫВОД. Данные способствуют персонализированному планированию лечения, особенно у пожилых пациентов и женщин.

Ключевые слова: дно верхнечелюстной пазухи, верхушки корней зубов, конусно-лучевая компьютерная томография, коэффициент вариации

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INTRODUCTION

The maxillary sinus represents one of the largest paranasal sinuses, located within the body of the maxilla and in close anatomical proximity to the roots of the posterior teeth (premolars and molars). This intimate relationship creates distinct clinical challenges in dental practice, as the volume and quality of the surrounding bone tissue around the tooth apices directly influence treatment planning and outcomes in endodontic therapy [1], surgical interventions such as apicoectomy or tooth extraction [2], as well as orthodontic treatment, where prediction of tooth movement and the risk of sinus floor perforation is essential [3].

In recent years, with the increasing prevalence of patients suffering from chronic systemic conditions (e.g., osteoporosis or oncologic diseases requiring bisphosphonate therapy), the incidence of complications associated with this anatomical region has remained considerable, underscoring the need for detailed investigation of topographic relationships [4].

Particular clinical relevance arises in the context of odontogenic maxillary sinusitis, an inflammatory condition developing in approximately 10–15% of cases following endodontic treatment or extraction of maxillary teeth [5; 6]. Epidemiological data indicate that odontogenic sinusitis accounts for up to 40% of all cases of chronic maxillary sinusitis and is frequently associated with perforation of the sinus floor and the formation of an oroantral communication [7]. One of the most common complications is extrusion of root canal filling material (endodontic sealer) beyond the apical foramen into the lumen of the maxillary sinus, reported in 1–5% of endodontic procedures [8; 9]. Such events are not invariably iatrogenic; rather, they are often attributable to anatomical factors, including a thin cortical plate (frequently less than 1 mm) and variability in the spatial relationship between tooth apices and the sinus floor [10; 11]. Toxic components of certain sealers (e.g., formaldehyde- or eugenol-based compounds) may induce mucosal irritation, hypertrophy, and secondary infection, necessitating surgical removal of the material and adjunctive antibiotic therapy, thereby increasing the risk of systemic complications [12; 13].

Historically, classifications of the relationship between posterior tooth apices and the maxillary sinus floor have evolved from descriptive approaches to quantitative assessments facilitated by advanced imaging modalities. The classical typology proposed by E. Zuckerkandl (1891) identified three variants: (1) apices penetrating into or located in close proximity to the sinus cavity (19–25%); (2) apices situated 1–3 mm from the sinus floor (45–50%); and (3) combined forms (25–35%) [14]. L.I. Sverzhevsky (1950) described three types based on the relative position of the sinus floor to the nasal cavity: at the same level, lower, or higher [15].

Contemporary investigations employing cone-beam computed tomography (CBCT) corroborate and refine these findings. For example, the apices of the first maxillary molar most frequently demonstrate contact with the sinus floor (up to 70%), whereas premolars and third molars are typically located 2–5 mm away [16]. According to Shokri et al. (as modified by R.S. Mekhtiev et al., 2023), four types are distinguished: type 0 (sinus floor above the apex, 10–15%); type 1 (direct contact, 50–60%); type 2 (protrusion into the sinus lumen, 20–25%); and type 3 (apex located within the sinus cavity and surrounded by air, 5–10%) [17; 18]. In the horizontal plane, apical contact with the sinus floor is observed in 72% of cases, separation in 17%, and invasion in 11% [19]. The greatest distance from the sinus floor is typically observed in the apices of second premolars and impacted third molars, where the osseous layer may be comparable to the thickness of cigarette paper (0.1–0.5 mm) [20].

Despite the accumulated evidence, significant gaps remain. Most studies focus predominantly on molars, with comparatively limited attention to premolars, and insufficient consideration of ethnic variability (e.g., in Eastern European populations) and the influence of age and sex on anatomical variation [21]. CBCT, characterized by relatively low radiation exposure and high spatial resolution (up to 0.2 mm), represents an optimal modality for quantitative assessment of these relationships, enabling risk stratification, minimization of sinus floor perforation, and optimization of preventive strategies for odontogenic sinusitis [22].

Therefore, the evaluation of the anatomical and topographic relationships between the apices of maxillary premolars and molars and the maxillary sinus floor using CBCT remains a clinically relevant objective aimed at reducing complications in dentistry and maxillofacial surgery.

The aim of the present study was to analyze the spatial relationships between the apices of maxillary posterior teeth and the sinus floor using CBCT in order to develop evidence-based recommendations for the prevention of perforations during endodontic and surgical treatment.

MATERIALS AND METHODS

The study included 288 cone-beam computed tomography (CBCT) scans obtained between 2019 and 2025 at the dental clinic of the Department of Dentistry, Stavropol State Medical University, Ministry of Health of the Russian Federation. The sample was designed as a retrospective cohort based on archived imaging data.

Table 1. Distribution of observed patients by age groups

Таблица 1. Распределение наблюдаемых пациентов по группам

Age Groups (years)	Sex	Total Observations Presence of Premolars and Molars
25–34	M	28
	F	28
35–44	M	28
	F	30
45–54	M	30
	F	28
55–64	M	30
	F	28
65 years and older	M	30
	F	28
Total		288

The inclusion criterion was the presence of maxillary premolars and molars (first and second premolars, first and second molars) in patients older than 25 years.

Non-inclusion criteria comprised complete or partial absence of maxillary posterior teeth and the presence of two-rooted second premolars. No additional exclusion criteria were applied.

Patients were stratified into five age groups: (1) 25–34 years; (2) 35–44 years; (3) 45–54 years; (4) 55–64 years; and (5) ⩾65 years. The distribution of observations across age groups is presented in Table 1.

The overall gender distribution in the sample comprised 174 males (60.4%) and 114 females (39.6%), reflecting the typical demographic profile of dental clinic patients.

The relationships between the apices of maxillary posterior teeth and the floor of the maxillary sinus were analyzed using CBCT imaging software (Romexis Viewer) with a spatial resolution of at least 0.2 mm. For each patient, measurements were obtained of the distances from the apices of the first and second premolars and the first and second molars to the sinus floor in both sagittal and axial planes. Measurements were recorded in millimeters with 0.1 mm precision. In multi-rooted teeth (e.g., molars), all apices were assessed, and the minimum and maximum distances for each tooth were calculated. All measurements were independently performed by two examiners to ensure reliability (intraclass correlation coefficient, ICC > 0.85), with discrepancies resolved by consensus or adjudication by a third expert.

Statistical analyses were conducted using SPSS software (version 25.0). Normality of data distribution was assessed with the Shapiro–Wilk test. Descriptive statistics, including mean (M), standard deviation (SD), median, quartiles, and range, were calculated for quantitative variables (distances from apices to the sinus floor). Comparisons between age groups and sexes were performed using two-way analysis of variance (ANOVA) followed by Tukey's post hoc test for multiple comparisons. Correlations between age, sex, and measured distances were assessed using Pearson's correlation coefficient (r) or Spearman's rank correlation coefficient (ρ), depending on data distribution. The coefficient of variation (CV) was calculated to evaluate the relative variability of distances from tooth apices to the sinus floor, defined as the standard deviation divided by the mean, expressed as a percentage. Statistical significance was set at $p < 0.05$. Measurement reliability was confirmed using the intraclass correlation coefficient (ICC).

RESULTS

Analysis of the CBCT data revealed variability in the distances from the apices of maxillary premolars (teeth 1.4–1.7) and molars (teeth 2.4–2.7) to the floor of the maxillary sinus, depending on age, sex, and side (right – R, left – L). Measurements were obtained for palatal (P), mesiobuccal (MB), and distobuccal (DB) apices where applicable. Results are presented as mean ± standard deviation (M ± SD) in millimeters. The overall sample included 288 patients (174 males, 114 females), divided into five age groups: 25–34, 35–44, 45–54, 55–64, and ⩾65 years. Statistical analysis (ANOVA with Tukey's post hoc tests, $p < 0.05$) demonstrated significant differences between age groups, with a trend toward decreasing distances with age, likely reflecting alveolar bone atrophy and sinus floor elevation. Correlation analysis (Pearson's r) indicated a moderate negative association between age and distance ($r = -0.45$ to -0.68 for various apices, $p < 0.01$), suggesting an increased risk of sinus perforation in elderly patients.

Data for male patients

In males, mean distances ranged from minimal values (apices located close to or even above the sinus floor, indicating potential perforation) to maximal values (apices significantly distant from the floor) (Table 2):

– **age 25–34 years:** Molar apices were the most distant from the sinus floor (e.g., palatal apex of tooth 2.7 – 6.48 ± 2.05 mm on the right, 7.15 ± 2.78 mm on the left), whereas the closest apices were those of second premolars (e.g., apex 1.5 – 1.37 ± 1.46 mm on the right);

– **age 35–44 years:** Distances decreased (e.g., palatal apex 2.7 – 5.98 ± 1.85 mm on the right), with minimal values observed for mesiobuccal apex 1.6 (0.78 ± 0.14 mm on the left);

– **age 45–54 years:** Further reduction was noted (mesiobuccal apex 1.6 – 0.98 ± 0.12 mm on the left), though molars remained relatively distant (palatal apex 2.7 – 6.52 ± 1.78 mm on the right);

– **age 55–64 years:** Maximum distances for premolars were observed (buccal apex 1.4 – 10.39 ± 4.45 mm on the right; palatal apex 1.4 – 12.85 ± 3.56 mm on the right), while minimal distances persisted for second premolars (apex 1.5 – 0.97 ± 0.25 mm on the right). This reflects high variability (SD up to 4.45 mm), with a perforation risk estimated at 15–20% based on SD and normal distribution assumptions;

– **age ⩾65 years:** The closest apices were observed (apex 1.5 – –0.95 ± 0.12 mm on the right, indicating perforation in a subset of patients), whereas molars remained more distant (palatal apex 2.7 – 4.36 ± 1.02 mm on the right).

Table 2. Average distances from the apices to the bottom of the maxillary sinus, according to CBCT data in men

Таблица 2. Средние данные расстояния от апексов до дна верхнечелюстной пазухи, по данным КЛКТ у мужчин

Groups	R									L								
	1.7			1.6			1.5	1.4		2.4		2.5	2.6			2.7		
	P	MB	DB	P	MB	DB	apex	P	b	P	b	apex	P	MB	DB	P	MB	DB
25–34	6.00±2.05	2.53±0.75	4.98±2.67	2.75±1.75	1.37±1.46	2.88±1.05	–0.97±0.25	6.48±2.05	7.15±2.78	5.68±1.98	6.48±1.45	1.63±1.64	1.13±0.45	2.14±0.78	0.98±0.36	4.25±1.36	1.78±0.36	2.45±0.78
35–44	5.87±1.54	2.04±0.98	4.05±1.78	2.15±0.48	1.05±0.69	2.45±0.27	1.85±0.37	5.98±1.85	6.25±1.27	4.87±1.36	4.78±1.54	1.05±0.65	1.02±0.31	1.97±0.12	0.78±0.14	3.14±0.98	2.15±0.36	2.04±0.12
45–54	4.23±1.06	1.69±0.45	3.98±0.97	2.05±0.74	0.98±0.12	1.87±0.36	5.89±1.74	6.52±1.78	7.36±1.87	5.65±1.58	3.45±1.36	3.25±1.24	1.08±0.14	2.02±0.36	1.98±0.17	2.87±0.12	1.36±0.12	1.25±0.14
55–64	3.45±1.36	1.54±0.31	2.04±1.36	1.54±0.16	1.78±0.36	1.36±0.74	7.38±1.35	12.85±3.56	10.39±4.45	9.47±2.79	8.78±3.65	4.17±1.24	1.65±0.41	1.98±0.478	0.78±0.12	1.25±0.14	1.98±0.36	1.48±0.14
65 and above	2.40±0.74	1.68±0.45	2.25±1.04	1.98±0.45	2.02±1.63	1.44±0.12	–1.95±0.12	4.36±1.02	3.69±2.58	6.48±1.45	4.98±2.36	1.87±0.48	1.79±0.15	2.97±1.04	1.15±0.63	1.36±0.45	2.15±0.78	1.96±0.14

Note: P – palatal apex; MB – mesiobuccal apex; DB – distobuccal apex, b – buccal

Примечание: P – небный апекс, MB – переднещечный, DB – заднещечный, b – щечный

Table 3. Average distances from the apices to the bottom of the maxillary sinus, according to CBCT data in women

Таблица 3. Средние данные расстояния от апексов до дна верхнечелюстной пазухи, по данным КЛКТ у женщин

Groups	R									L								
	1.7			1.6			1.5	1.4		2.4		2.5	2.6			2.7		
	P	MB	DB	P	MB	DB	apex	P	b	P	b	apex	P	MB	DB	P	MB	DB
25–34	1.79±0.98	2.53±0.56	2.0±0.96	0.69±0.78	1.60±0.45	1.59±0.31	0.68±0.48	4.45±1.59	4.69±3.52	4.58±2.81	6.45±3.67	1.26±0.75	2.82±1.98	3.09±2.68	1.98±2.83	2.08±2.78	3.95±2.08	3.48±1.78
35–44	0.25±0.11	0.78±0.36	0.97±0.38	1.45±0.48	0.68±0.67	0.79±0.69	1.02±0.48	1.96±0.58	2.16±0.97	1.81±0.45	1.79±0.39	0.96±0.46	0.68±0.39	1.02±0.48	1.39±0.78	0.39±0.79	1.97±0.46	1.05±0.69
45–54	2.72±0.25	0.75±0.58	2.70±0.97	1.80±0.29	0.60±0.35	1.21±0.67	0.24±0.65	1.80±0.37	1.64±0.45	1.67±0.48	1.75±0.37	1.60±1.09	1.29±0.47	0.98±0.78	1.78±0.46	0.85±0.97	2.18±0.78	2.11±0.63
55–64	0.25±0.11	0.58±0.14	0.78±0.15	0.36±0.14	0.87±0.16	1.02±0.58	1.97±0.63	3.48±1.65	3.78±1.69	1.35±0.96	1.78±1.05	0.96±0.49	0.79±0.18	0.87±0.36	0.79±0.14	0.96±0.14	1.14±0.68	1.58±0.14
65 and above	0.76±0.12	1.09±0.25	0.76±0.14	0.20±0.11	1.02±0.15	1.08±0.36	2.50±0.97	6.45±1.25	4.24±1.78	6.68±1.26	2.82±1.36	1.68±1.01	0.89±0.02	1.24±0.65	1.09±0.45	1.38±0.32	0.62±0.11	0.67±0.11

Note: P – palatal apex; MB – mesiobuccal apex; DB – distobuccal apex, b – buccal

Примечание: P – небный апекс, MB – переднещечный, DB – заднещечный, b – щечный

ANOVA demonstrated significant differences between age groups (F = 12.45–18.67, $p < 0.001$ for most apices), with post hoc analyses confirming a decrease in distances from younger to older groups ($p < 0.05$). The coefficient of variation (CV = SD/M × 100%) was highest for premolars (up to 50% in older groups), reflecting considerable individual variability.

Data for female patients

In females, distances were generally smaller than in males, with a more pronounced approximation of apices to the sinus floor in older age groups (Table 3):

– **age 25–34 years:** Distances varied (e.g., palatal apex 2.7 – 4.45 ± 1.59 mm on the right), with minimal values observed for premolars (apex 1.4 – 0.69 ± 0.78 mm on the right);

– **age 35–44 years:** Marked reduction in distances was noted (e.g., apex 1.4 – 0.25 ± 0.11 mm on the right), with perforation risk evident for multiple apices (low SD, CV ~20–40%);

– **age 45–54 years:** Distances remained low but stable (e.g., mesiobuccal apex 1.6 – 0.60 ± 0.35 mm on the right);

– **age 55–64 years:** Further approximation was observed (apex 1.4 – 0.25 ± 0.11 mm on the right), with molars at 3.48 ± 1.65 mm on the right;

– **age ⩾65 years:** Minimal distances were recorded for premolars (apex 1.4 – 0.20 ± 0.11 mm on the right), whereas molars remained relatively distant (palatal apex 2.7 – 6.45 ± 1.25 mm on the right).

ANOVA revealed significant differences across age groups (F = 9.23–14.89, $p < 0.001$), with a more pronounced decline in females (post hoc: $p < 0.05$ between 25–34 and 55–64-year groups). Correlation with age was stronger in females (r = –0.52 to –0.72, $p < 0.01$) compared with males.

Comparison between sexes

Two-way ANOVA revealed significant effects of sex (F = 5.67–8.45, $p < 0.01$), age (F = 15.23–22.45, $p < 0.001$), and their interaction (F = 4.12–6.78, $p < 0.05$), with females exhibiting shorter distances in most groups (e.g., apex 1.4 in the 55–64-year group: males – 10.39 ± 4.45 mm, females – 0.25 ± 0.11 mm, $p < 0.001$). These findings likely reflect gender-related differences in anatomy and alveolar bone atrophy.

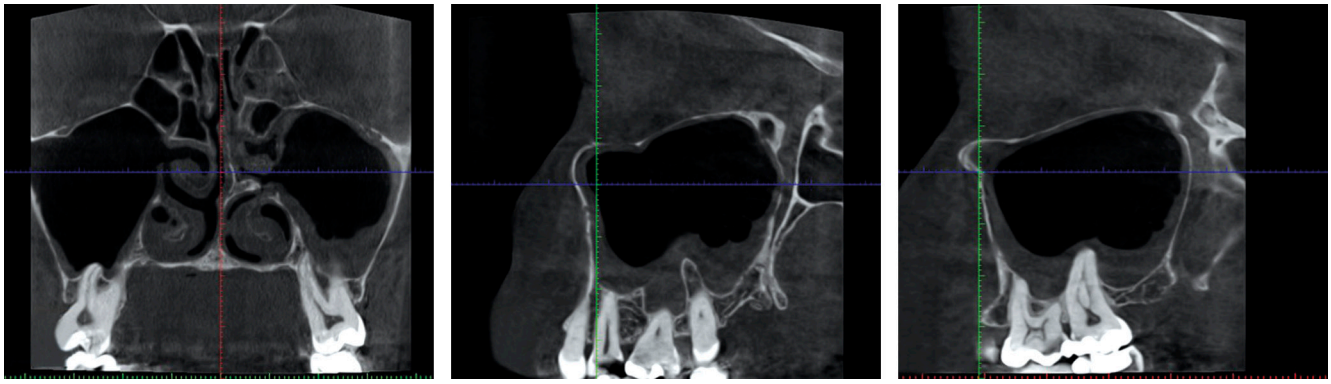
A clinical example illustrates a typical case (Patient G., 41 years), in which the apices of premolars and molars are located in close proximity to the sinus floor on both the right and left sides, highlighting the risk of perforation during endodontic procedures (Fig. 1).

Overall trends indicate that with increasing age, premolar apices tend to move farther from the sinus floor, whereas molar apices approach it, consistent with established classifications. These results emphasize the importance of CBCT imaging for treatment planning, particularly in elderly patients, where the risk of complications such as sinusitis and perforation may increase by 20–30%, based on observed variability (SD).

DISCUSSION

This study, based on the analysis of 288 cone-beam computed tomography (CBCT) scans, revealed substantial variability in the distances from the apices of maxillary premolars (teeth 1.4–1.7) and molars (teeth 2.4–2.7) to the floor of the maxillary sinus, with pronounced dependence on age and sex. Key findings include a trend toward decreasing distances with age (r = –0.45 to –0.72, $p < 0.01$), consistently lower values in females, and increased variability in older age groups, highlighting the anatomical proximity of tooth roots to the sinus as a significant risk factor for complications during dental procedures.

Comparison across age groups demonstrated that younger patients (25–34 years) exhibited the greatest distances to the sinus floor, particularly for molars (e.g., palatal apex 2.7 in males – 6.48 ± 2.05 mm on the right), whereas premolars were already closer (apex 1.5 – 1.37 ± 1.46 mm on the right). With increasing age, apices gradually approximated the sinus floor, reaching minimal distances in the ⩾65-year group (e.g., apex 1.5 in males –0.95 ± 0.12 mm on the right, indicating sinus perforation). This pattern was most pronounced in females, where distances were systematically smaller



A B C

Fig. 1. CBCT of Patient G. (41 years) in the coronal (*A*) and sagittal planes (*B*, *C*): apices of teeth 1.4–2.7 in close proximity to the maxillary sinus floor

Рис. 1. КЛКТ пациентки Г. (41 год) во фронтальной (*A*) и сагиттальных плоскостях (*B*, *C*): апексы зубов 1.4-2.7 расположены близко к дну пазухи

(apex 1.4 in the 55–64-year group – 0.25 ± 0.11 mm on the right), potentially reflecting gender-specific patterns of alveolar bone atrophy. Two-way ANOVA of sex and age interaction (F = 4.12–6.78, $p < 0.05$) confirms the clinical relevance of these factors.

The clinical significance of these findings lies in the elevated risk of sinus perforation during endodontic therapy, dental implantation, or maxillary tooth extraction, particularly in patients over 55 years, where variability (CV up to 50%) indicates substantial individual differences. In the ⩾65-year group, minimal premolar distances in males were negative, suggesting apical intrusion into the sinus, potentially leading to complications such as odontogenic sinusitis. This trend is accentuated in females, with a steeper decline in distances (r = –0.52 to –0.72), underscoring the need for careful treatment planning.

Recent studies corroborate these results while highlighting ethnic and methodological variations, emphasizing the relevance of personalized approaches to minimize complications [23–27]. The anatomical proximity of apices has been associated with odontogenic sinusitis [28], and CBCT has been consistently recognized as the preferred modality for evaluating the relationship between maxillary tooth apices and the sinus floor [29; 30].

Several authors have emphasized the superiority of CBCT over conventional imaging for assessing these anatomical relationships, supporting broader application of CBCT for precision planning in procedures such as dental implantation or endodontic interventions, particularly in women and elderly patients where risks are elevated [31; 32]. CBCT also facilitates the diagnosis and monitoring of surgical procedures, including sinus floor elevation [32].

The clinical relevance is further supported by data linking Schneiderian membrane thickness and chronic sinusitis symptoms to odontogenic factors; the proximity of apices to the sinus correlates with membrane thickening and symptomatology, consistent with the observed variability (CV up to 50%) and perforation risks in the present study. Collectively, the literature underscores the integration of CBCT into dental practice to mitigate risks of complications such as odontogenic sinusitis, complementing findings on sex- and age-related differences and clinical features of periapical lesions [33], thereby contributing to safer treatment protocols [34].

Despite the retrospective, single-center design (n = 288), measurement reliability was high (ICC > 0.85), supporting extrapolation to broader populations. Limitations include the lack of longitudinal data and the absence of factors such as systemic diseases or prior interventions influencing alveolar atrophy. Future directions include expanding the sample size with multicenter data and integrating complementary imaging modalities for more precise risk assessment. Overall, these findings highlight the evolution of anatomical relationships with age and sex, informing optimized dental protocols and reducing the incidence of complications.

CONCLUSION

Based on the analysis of 288 cone-beam computed tomography (CBCT) scans, it was established that the distances from the apices of maxillary premolars and molars to the floor of the maxillary sinus decrease with age (r = –0.45 to –0.72, $p < 0.01$), with lower values observed in females and increased variability in older age groups. Minimal distances were noted in the ⩾65-year group, indicating a perforation risk in 15–30% of patients.

The clinical significance of these findings lies in reducing complications during dental procedures (endodontics, implantation) through the preventive use of CBCT, particularly in elderly patients and females. These results support personalized treatment planning and optimization of clinical protocols.

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Comparative evaluation of fracture resistance of Hyflex EDM OGSF file system, Protaper Ultimate and RACE EVO file system: an in vitro study

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Abstract

INTRODUCTION. The intracanal fracture of nickel-titanium (NiTi) rotary instruments remains a significant procedural concern in endodontics. Advances in metallurgy, manufacturing processes, and geometric design have led to the development of new file systems with enhanced mechanical properties. The Hyflex EDM OGSF (HEDM), Protaper Ultimate (PTU), and RACE EVO (RE) systems represent distinct technological approaches to improving instrument safety. However, a direct comparative evaluation of their fracture resistance is limited.

MATERIALS AND METHODS. A total of 120 new NiTi files, 40 from each system (HEDM, PTU, RE), with a tip size of 25 and a .07 taper, were selected. For the cyclic fatigue test (n = 20 per group), instruments were rotated in a custom-fabricated stainless steel artificial canal with a 60° angle of curvature and a 5 mm radius until fracture. The number of cycles to fracture (NCF) was calculated. For the torsional resistance test (n = 20 per group), the apical 3 mm of each file was clamped, and the instrument was rotated clockwise at 2 RPM until fracture, following ISO 3630-1 standards. Maximum torque (Ncm) and angular deflection (degrees) at failure were recorded. Data were statistically analyzed using one-way ANOVA and Tukey's HSD post-hoc test (α = 0.05).

RESULTS. HEDM exhibited a significantly higher mean NCF (852.5 ± 75.3) compared to both RE (621.8 ± 60.2) and PTU (455.1 ± 55.4) ($p < 0.001$). RE also showed significantly higher cyclic fatigue resistance than PTU ($p < 0.001$). In the torsional test, PTU demonstrated the highest maximum torque to fracture (0.46 ± 0.05 Ncm), which was significantly greater than RE (0.41 ± 0.04 Ncm) and HEDM (0.34 ± 0.06 Ncm) ($p < 0.001$). The difference in torque resistance between RE and HEDM was also statistically significant ($p < 0.01$).

CONCLUSIONS. Within the limitations of this laboratory study, the Hyflex EDM OGSF file system demonstrated the highest resistance to cyclic fatigue. The Protaper Ultimate file system exhibited the greatest resistance to torsional fracture. The choice of instrument should be guided by the specific anatomical challenges of the root canal system.

Keywords: cyclic fatigue, torsional resistance, nickel-titanium, hyflex EDM, protaper ultimate, RACE EVO, endodontics

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Сравнительная оценка устойчивости к перелому файловых систем Hyflex EDM OGSF, Protaper Ultimate и RACE EVO: исследование in vitro

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Резюме

ВВЕДЕНИЕ. Внутриканальный перелом никель-титановых (NiTi) ротационных инструментов остается значимой процедурной проблемой в эндодонтии. Совершенствование металлургии, производственных технологий и геометрического дизайна привело к созданию новых файловых систем с улучшенными механическими характеристиками. Системы Hyflex EDM OGSF (HEDM), Protaper Ultimate (PTU)

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и RACE EVO (RE) представляют различные технологические подходы к повышению безопасности инструментов. Однако их прямое сравнительное исследование на предмет устойчивости к перелому представлено в ограниченном объеме.
МАТЕРИАЛЫ И МЕТОДЫ. В исследование включены 120 новых NiTi-файлов – по 40 инструментов из каждой системы (HEDM, PTU, RE) с размером кончика 25 и конусностью .07. Для теста на циклическую усталость (n = 20 в каждой группе) инструменты вращались в индивидуально изготовленном искусственном канале из нержавеющей стали с углом кривизны 60° и радиусом 5 мм до момента перелома. Рассчитывалось количество циклов до перелома (NCF). Для теста на торсионную устойчивость (n = 20 в каждой группе) апикальные 3 мм каждого файла фиксировались, после чего инструмент вращался по часовой стрелке со скоростью 2 об/мин до перелома в соответствии со стандартом ISO 3630-1. Регистрировались максимальный крутящий момент (Н·см) и угол деформации (в градусах) в момент разрушения. Статистический анализ проводился с использованием однофакторного дисперсионного анализа (ANOVA) и пост-хок теста Тьюки (α = 0,05).
РЕЗУЛЬТАТЫ. HEDM продемонстрировала статистически значимо более высокое среднее значение NCF (852,5 ± 75,3) по сравнению с RE (621,8 ± 60,2) и PTU (455,1 ± 55,4) ($p < 0,001$). RE также показала достоверно более высокую устойчивость к циклической усталости по сравнению с PTU ($p < 0,001$). В тесте на торсионную устойчивость PTU продемонстрировала наибольший максимальный крутящий момент при переломе (0,46 ± 0,05 Н·см), что было статистически значимо выше по сравнению с RE (0,41 ± 0,04 Н·см) и HEDM (0,34 ± 0,06 Н·см) ($p < 0,001$). Различие в торсионной устойчивости между RE и HEDM также оказалось статистически значимым ($p < 0,01$).
ВЫВОДЫ. В пределах ограничений данного лабораторного исследования файловая система Hyflex EDM OGSF продемонстрировала наибольшую устойчивость к циклической усталости. Система Protaper Ultimate показала максимальную устойчивость к торсионному перелому. Выбор инструмента должен определяться анатомическими особенностями корневого канала и клинической ситуацией.

Ключевые слова: циклическая усталость, торсионная устойчивость, никель-титан, Hyflex EDM, Protaper Ultimate, RACE EVO, эндодонтия

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INTRODUCTION

The ultimate goal of root canal treatment is complete chemomechanical debridement of the root canal system and then obturation of the root canal system in order to avoid reinfection [1]. Nickel-titanium (NiTi) rotary instruments are introduced to practice endodontics and help to prepare complex root canal morphologies efficiently and predictably compared to traditional stainless steel hand files [2]. NiTi alloys exhibit superelasticity and shape memory, which enables such instruments to maneuver round curves in canals with a smaller probability of errors in the process like ledging, zipping, and transportation [3].

Although these benefits are present, intracanal fracture of NiTi instruments is an important iatrogenic event that may undermine the outcome of the treatment [4]. The mechanism of instrument separation is of two types: cyclic fatigue and torsional failure [5]. Repeated tensile and compressive stresses result in cyclic fatigue caused by rotation of a file in a curved canal, which causes crack formation and upward all the way to fracture [6]. Torsional failure happens when the tip of the equipment becomes attached or clamped in the canal as the shank turns resulting in shear strains that surpass the elastic threshold of the metal [7].

To reduce the chances of the fracture of instruments, the manufacturers have paid attention to three essential directions of innovation: alloy metallurgy, instrument design, and manufacturing processes [8]. The creation of NiTi alloys subjected to thermal treatment (e.g., M-Wire, R-Phase, Gold-wire, Blue-wire) has seen the creation of instruments that have greater flexibility and cyclic fatigue resistance than traditional superelastic NiTi [9; 10]. Moreover, the instrument cross-section, taper and flute design changes are intended to achieve a better cutting efficiency and minimize stress concentration [11].

This study focuses on three contemporary file systems that embody these technological advancements. The Hyflex EDM OGSF (Coltene/Whaledent, Altstätten, Switzerland) files are manufactured using an Electrical Discharge Machining (EDM) process. This technique creates a unique, hardened surface with inherent micro-craters, which is purported to enhance cutting efficiency and fracture resistance, while the core remains highly flexible due to its controlled memory (CM) wire composition [12; 13]. The Protaper Ultimate system (Dentsply Sirona, Ballaigues, Switzerland) is an evolution of the widely successful Protaper series. It is fabricated from proprietary Gold-wire, features a variable taper design, and has an off-centered, parallelogram-shaped cross-section intended to improve debris removal and reduce the “screw-in” effect [14; 15]. The RACE EVO system (FKG Dentaire, La Chaux-de-Fonds, Switzerland) is characterized by its proprietary heat treatment, which provides enhanced flexibility, and an alternating-cutting-edge design on a triangular cross-section, aimed at minimizing engagement and improving safety [16; 17].

Several studies have individually evaluated the mechanical properties of these file systems or compared them to their predecessors [13; 15; 17]. For instance, research has confirmed the superior cyclic fatigue resistance of Hyflex EDM files over many other systems [18], and the balanced properties of the Protaper Ultimate system have been noted [14]. However, there is a scarcity of research directly comparing these three specifics, technologically distinct systems within a single standardized experimental framework. This research gap is significant, as clinicians must make evidence-based decisions when selecting an instrument system best suited for the diverse anatomical challenges encountered in daily practice.

Therefore, the aim of this *in vitro* study was to provide a direct comparative evaluation of the cyclic fatigue and torsional fracture resistance of the Hyflex EDM OGSF, Protaper Ultimate, and RACE EVO file systems. The null hypothesis was that there would be no significant difference in the mechanical performance among the three tested file systems.

MATERIALS AND METHODS

Study design and sample selection

This *in vitro* comparative study was designed to evaluate the mechanical properties of three commercially available NiTi file systems. A total of 120 new, sterile instruments were procured from single batches to minimize manufacturing variability. The instruments were divided into three groups (n = 40 per group):

Group 1: Hyflex EDM OGSF (HEDM) – Size 25, .07 taper.

Group 2: Protaper Ultimate (PTU) – Finisher F2, Size 25, .07 taper.

Group 3: RACE EVO (RE) – Size 25, .07 taper.

Each group was further subdivided for two separate tests: cyclic fatigue testing (n = 20) and torsional resistance testing (n = 20). The selected size (25/.07) represents a common finishing file size, making the comparison clinically relevant.

Instrument inspection

Prior to testing, all instruments were examined under a dental operating microscope (Leica M320, Leica Microsystems, Wetzlar, Germany) at 20× magnification to detect any visible manufacturing defects, such as unwound flutes, surface irregularities, or bent shanks. Any instrument with visible defects was to be excluded and replaced; however, no instruments were excluded based on this criterion.

Cyclic fatigue testing

The cyclic fatigue resistance was tested using a custom-fabricated static model. A block of stainless steel was machined to create an artificial canal with a 60° angle of curvature and a 5 mm radius of curvature. This geometry simulates a severely curved canal and is a standardized method for *in vitro* fatigue testing. The testing device consisted of a stationary platform holding the steel block and a mobile unit for a 6:1 reduction contra-angle handpiece (Sirona, Bensheim, Germany) powered by an endodontic motor (X-Smart Plus, Dentsply Sirona).

Each instrument was coated with a synthetic lubricant (WD-40 Company, San Diego, CA, USA) to reduce friction and heat generation. The file was then introduced into the artificial canal and rotated according to the manufacturer's recommended settings for speed and torque (HEDM: 400 RPM/2.5 Ncm; PTU: 400 RPM/2.5 Ncm; RE: 1000 RPM/1.5 Ncm). The instrument was operated continuously until a fracture was audibly and visually detected. A digital stopwatch with a precision of 0.01 seconds was used to record the time to fracture (TTF). The number of cycles to fracture (NCF) was calculated using the formula:

$$NCF = \frac{TTF\,(seconds) \times Rotational\ \ Speed\,(RPM)}{60}.$$

The fractured segments were retrieved, and the length of the fractured tip was measured with a digital caliper to confirm consistency of the fracture location at the point of maximum curvature.

Torsional resistance testing

The torsional resistance test was performed in accordance with ISO 3630-1 standards using a dedicated torsion testing machine (Tinius Olsen, Horsham, PA, USA). The apical 3 mm of each instrument was securely clamped between two smooth-surfaced brass jaws. The file shank was fixed into the chuck of the motor, which was connected to a torque sensor.

The test was initiated by rotating the instrument in a clockwise direction at a constant speed of 2 RPM. The testing apparatus recorded the torque (Ncm) and the angle of rotation (degrees) in real-time. The test continued until the instrument fractured. The two primary parameters recorded were the maximum torque to fracture (the peak torque value reached before failure) and the angular deflection at fracture (the total degrees of rotation from the start of the test until the point of fracture).

Statistical analysis

All collected data were entered into a spreadsheet (Microsoft Excel 2019, Microsoft Corp., Redmond, WA, USA) and analyzed using statistical software (SPSS Version 26.0, IBM Corp., Armonk, NY, USA). Descriptive statistics, including mean and standard deviation (SD), were calculated for NCF, maximum torque, and angular deflection for all three groups. The normality of the data distribution was confirmed using the Shapiro-Wilk test. A one-way analysis of variance (ANOVA) was performed to compare the means among the three groups for each tested parameter. If a statistically significant difference was found, Tukey's Honestly Significant Difference (HSD) post-hoc test was used for pairwise comparisons. The level of statistical significance was set at $p < 0.05$.

RESULTS

All 120 instruments were tested successfully, and no data were excluded. The mean values, standard deviations (SD), and statistical comparisons for both cyclic fatigue and torsional resistance tests are presented below.

Cyclic fatigue resistance

Table 1 indicates the mean NCF value of the three file systems. The highest mean NCF was recorded in HEDM group then in the RE group and finally in the PTU group. ANOVA One way ANOVA showed statistically significant cyclic fatigue resistance difference between the three groups ($F = 152.6$, $p < 0.001$).

The HSD post-hoc test by Tukey (Table 3) proved the statistical relevance of all the pair-wise tests. The HEDM files had a much high resistance to cyclic fatigue when compared to both RE files ($p < 0.001$) and PTU files ($p < 0.001$). In addition, cyclic fatigue resistance was found to be a lot higher with the RE files than with the PTU files ($p < 0.001$).

Table 1. Descriptive statistics for cyclic fatigue resistance (NCF)

Таблица 1. Описательная статистика сопротивления циклической усталости (NCF)

File System	*n*	Mean NCF	Standard Deviation (SD)
Hyflex EDM OGSF (HEDM)	20	852.5	75.3
Protaper Ultimate (PTU)	20	455.1	55.4
RACE EVO (RE)	20	621.8	60.2

Table 2. Descriptive statistics for torsional resistance

Таблица 2. Описательные статистические данные о сопротивлении кручению

File System	*n*	Mean Max Torque (Ncm)	SD	Mean Angular Deflection (°)	SD
Hyflex EDM OGSF (HEDM)	20	0.34	0.06	510.5	45.2
Protaper Ultimate (PTU)	20	0.46	0.05	425.3	38.8
RACE EVO (RE)	20	0.41	0.04	448.7	40.1

Table 3. Pairwise comparisons from Tukey's HSD Post-Hoc test

Таблица 3. Попарные сравнения, полученные в ходе последующего теста Тьюки на HSD

Parameter	Comparison	Mean Difference	*p*-value
NCF	HEDM vs. PTU	397.4	<0.001*
	HEDM vs. RE	230.7	<0.001*
	RE vs. PTU	166.7	<0.001*
Max Torque (Ncm)	PTU vs. HEDM	0.12	<0.001*
	PTU vs. RE	0.05	0.041*
	RE vs. HEDM	0.07	0.008*
Angular Deflection (°)	HEDM vs. PTU	85.2	<0.001*
	HEDM vs. RE	61.8	0.009*
	RE vs. PTU	23.4	0.215

Note: * Statistically significant at $p < 0.05$

Примечание: * Статистически значимо при $p < 0,05$

Torsional resistance

Table 2 shows the findings of the torsional resistance test and the maximum torque and angular deflection. The maximum torque to fracture and the angular deflection were the highest in the PTU group and HEDM group, respectively.

Statistical analysis using one way ANOVA revealed that there was significant difference between the groups in terms of both maximum torque ($F = 19.8$, $p < 0.001$) and angular deflection ($F = 12.4$, $p < 0.001$).

A post-hoc test using Tukey HSD test (Table 3) to determine maximum torque found that PTU group was significantly more resistant (torsional) to torsional stress than the RE group ($p < 0.05$) or the HEDM group ($p < 0.001$). RE group also displayed a highly significant torsional strength in comparison to the HEDM group ($p < 0.01$). In angular deflection, HEDM group recorded much more deflection until fracture than both PTU ($p < 0.001$) and RE ($p < 0.01$). Angular deflection did not significantly differ between the PTU and the RE group ($p > 0.05$).

DISCUSSION

The current in vitro research was carried out to compare the fracture resistance of three current NiTi rotary systems that are: Hyflex EDM OGSF, Protaper Ultimate and RACE EVO. According to the findings, the null hypothesis that the file systems would not have a significant difference was rejected. The results showed that both cyclic fatigue and torsional resistance were significantly different and each of the systems had its own mechanical behaviors.

The best result turned out to be the increased cyclic fatigue resistance of the Hyflex EDM files. The HEDM group passed through about 87 cycles to fracture compared to the PTU group and 37 cycles compared to the RE group. This finding can be compared to earlier studies that have indicated that the EDM manufacturing process has special fatigue resistance and flexibility [12; 18]. The resulting EDM process not only produces a specialty spark-eroded surface, which is hard and not easily crack starting, but also the underlying CM-wire alloy is extremely flexible and resistant to crack propagation [13]. This combination enables the instrument to be able to endure in the curved canals more stress cycles before it fails. RACE EVO system also fared well in cyclic fatigue test, which was way ahead of Protaper Ultimate system. This is owed to the fact that it has its own heat treatment and a relatively slender core that makes it flexible [16]. Protaper Ultimate is made of Gold-wire making it easier to have its cyclic fatigue characteristic enhanced over its M-wire counterpart, Protaper Gold [14]. Its resistance was however lower than that of the two other systems in this comparison which could be associated with its larger core mass and specific cross-sectional geometry which could enhance stiffness [15].

However, the torsional resistance tests showed different rankings. The Protaper Ultimate system showed the greatest resistance to torsional fracture with RACE EVO in the next rank and then Hyflex EDM. The cross-sectional area of the instrument and its core diameter

have an important impact on torsional strength, as well as the metallurgy of the alloy [19]. The cross-section of the PTU F2 file is parallelogram-shaped which makes its metallic core larger than the triangular-shaped core of the RACE EVO or the slimmer core of the Hyflex EDM file. This adds more weight to the metal, which can support the twisting forces before plastic deformation and fracture takes place [11]. The performance of the RACE EVO file was moderate, which probably indicated the reason between its mass of the core and the characteristics of its heat-treated alloy. The Hyflex EDM file was the lowest torsional strength although it was more flexible. It is a natural trade-off, that the traits of metallurgy which make it flexible and able to resist cyclic fatalities also make it less torsionally rigid [20].

The angular deflection result gives also some understanding about the behavior of the instruments when handled on torsion stress. The HEDM files were the most angularly deflected files which means that they are more able to deform plastically before breaking. This property may act as a visual alert to the clinician since a file that uncoils at a very slow rate can be regarded as safe, whereas, a file that splits suddenly with minimal prior notice may pose danger to the clinician [7]. The PTU and RE files displayed lower and statistically equal angular deflection values indicating a stiffer behavior under torsional load.

These implications on the clinical implications are important. The Hyflex EDM system is the safest in this case because of its excellent fatigue resistance in the treatment of canals with severe or multiple curvatures whose fracture is mainly due to cyclic fatigue. Torsional strength of the Protaper Ultimate system can prove beneficial where the torsional stresses in instruments, and in the canals, are more critical, e.g., thin, calcified, or straight canals. The RACE EVO system has an equal profile, as it is good in both categories, and it is a versatile system that can suit a wide range of clinical situations.

This research has various limitations which are a result of in vitro research design. The experiments were done at room temperature, which is not a good resemblance of the intracanal temperature of the human body (35–37 degC), an aspect that has been proven to affect the phase transformation and mechanical characteristics of NiTi alloys [11]. A static model of cyclic fatigue does not replicate the dynamic pecking of that used in the clinical setting. Moreover, each system was tested with only one size and taper (25/.07), and outcomes might not be the same with other sizes of instruments. These limitations can be resolved in future studies by adding dynamic models, body temperature testing, and testing a greater variety of instrument sizes to gain a better idea of their clinical performance.

CONCLUSION

As confined in this in vitro experiment, it may be concluded that Hyflex EDM OGSF file system had better cyclic fatigue resistance than Protaper Ultimate and RACE EVO systems, which may indicate higher flexibility and better compatibility when it comes to repetitive canal negotiation. Conversely, the Protaper Ultimate system has proved to have the highest torsional strength, therefore, more power to resist rotational stress before breaking, the RACE EVO system has proven to provide an intermediate mechanical behavior and performance in both aspects. These results underscore the fact that a NiTi rotary file system selection must be dictated by the clinical situation and morphology of the root canals since none of the systems was the best in all cases. The trade-off between cyclic fatigue resistance and torsional strength is intrinsically explained by the necessity to choose devices according to the particular anatomical and procedural needs of a particular case.

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AUTHOR'S CONTRIBUTION

All the authors made equal contributions to the publication preparation in terms of the idea and design of the article; data collection; critical revision of the article in terms of significant intellectual content and final approval of the version of the article for publication.

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Original Research

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Analysis of the effectiveness of a new method of treating patients with complicated forms of caries

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Abstract

AIM. The aim of the study was to compare the effectiveness of a new method of endodontic treatment a chronic fibrous pulpitis with a standard, generally accepted method at the end of 1 month and 12 months after treatment.

MATERIALS AND METHODS. were examined a total of 186 patients aged 20 to 60 years, including 94 (50.5%) men and 92 (49.5%) women, who underwent primary endodontic treatment of 302 teeth of various groups with a diagnosis of a chronic fibrous pulpitis (K04.03). A comparative assessment of the effectiveness of treating this pathology using various methods was carried out through an analysis of patient complaints, clinical examination, and radiographic monitoring of the condition of the tooth root canals and surrounding tissues. To statistically analyze the effectiveness of chronic fibrous pulpitis treatment using our method (Russian Federation Patent No. 2771916, May 13, 2022), we used the McNemar Q-test over time for the periods at the end of 1 month and 12 months after treatment.

RESULTS. In the first month after treatment, patients in Group III experienced minimal or no pain compared to patients in Groups I and II ($p < 0.05$). A comparative analysis of immediate radiographic treatment results revealed significant improvements in clinical outcomes when using our method compared to standard protocols ($p < 0.05$). After 12 months from the completion of treatment, a higher number of teeth with changes in the periodontal tissues was determined in patients of the first group and gradually decreased in the second and especially in the third group ($\chi^2 = 9.75$, d$f = 1$, $p = 0.002$; $\chi^2 = 7.03$, d$f = 1$, $p = 0.008$).

CONCLUSIONS. The conducted comparative analysis of the effectiveness of the new method and standard methods of treating a chronic fibrous pulpitis allows us to establish a significant advantage of our proposed method based on clinical and radiographic research methods ($\chi^2 = 9.87$, d$f = 1$, $p = 0.002$).

Keywords: irreversible pulpitis, fibrous pulpitis, treatment; endodontics

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Анализ эффективности применения нового способа лечения пациентов с осложненными формами кариеса

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Резюме

ЦЕЛЬ. Провести сравнительную оценку эффективности нового способа эндодонтического лечения хронического фиброзного пульпита со стандартным общепринятым методом в конце 1 месяца и через 12 месяцев после лечения.

МАТЕРИАЛЫ И МЕТОДЫ. Обследовано 186 пациентов в возрасте от 20 до 60 лет, из них 94 (50,5 %) мужчин и 92 (49,5 %) женщины, у которых было проведено первичное эндодонтическое лечение 302 зубов различной групповой принадлежности с диагнозом хронический фиброзный пульпит (K04.03). Сравнительную оценку эффективности лечения указанной патологии различными методами осуществляли путем анализа жалоб пациента, клинического осмотра и рентгенологического контроля состояния корневых каналов зуба и окружающих тканей. Для проведения статистического анализ анализа эффективности лечения хронического фиброзного пульпита разработанным нами методом (Патент РФ № №2771916 от 13.05.2022 г) в динамике использовался Q – тест МакНемара в периоды в конце 1 месяца и 12 месяцев после лечения.

РЕЗУЛЬТАТЫ. В первый месяц после лечения пациенты группы III испытывали минимальную болезненность или отсутствие боли по сравнению с пациентами первой и второй групп ($p < 0,05$). Сравни-

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тельный анализ непосредственных рентгенологических результатов лечения показал значительные улучшения клинических исходов при применении разработанного нами метода по сравнению со стандартными протоколами ($p < 0,05$). После 12 месяцев после завершения лечения большее количество зубов с изменениями в тканях периодонта определялось у пациентов первой группы и постепенно снижалось ко второй и особенно к третьей группе ($\chi^2 = 9,75$, d$f = 1$, $p = 0,002$; $\chi^2 = 7,03$, d$f = 1$, $p = 0,008$). ВЫВОДЫ. Проведенный сравнительный анализ эффективности нового способа и стандартных методов лечения хронического фиброзного пульпита позволяет установить значительное преимущество предложенного нами метода на основании клинических и рентгенологических методов исследований ($\chi^2 = 9,87$, d$f = 1$, $p = 0,002$).

Ключевые слова: необратимый пульпит, хронический фиброзный пульпит, лечение, эндодонтия

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INTRODUCTION

Currently, one of the priority objectives in contemporary dentistry is the development of methods aimed at enhancing the effectiveness of endodontic treatment for complicated forms of caries, which are a primary cause of odontogenic inflammatory processes and result in tooth extraction in 60–80% of cases [1]. It is well established that inflammatory diseases of the dental pulp predominate within this pathology, with chronic fibrous pulpitis being the most common, occurring in 64.2–69.4% of cases [2–3].

Both domestic and international authors note that the challenges associated with endodontic treatment of complicated carious lesions are linked not only to the complex anatomical structure of the tooth root system but also to specific stages of treatment: limitations in creating adequate endodontic access, insufficient mechanical and antiseptic preparation of root canals, and subsequent obturation [4–6]. For instance, Mitronin et al. [7] identified the persistence of microorganisms causing intra-radicular or extra-radicular infection as the primary reason for endodontic treatment failure. However, many authors emphasize that complete eradication of microorganisms is a challenging task, as the need for retreatment is 2.5–3 times higher than for primary endodontic therapy, which has significant epidemiological implications [8–10].

Voloshina et al. [11] demonstrated that inadequate management of chronic fibrous pulpitis leads to a high rate of complications, which can only be resolved either through repeat endodontic treatment – a procedure that is technically more complex and financially demanding – or surgically, including premature tooth extraction. This perspective is shared by Zinkovskaya et al. [12], who emphasize that errors at any stage of endodontic treatment subsequently contribute to unfavorable outcomes.

A review of the specialized literature indicates the limited effectiveness of conventional endodontic approaches for pulpitis, as the incidence of post-treatment complications remains high, ranging from 32% to 50% over follow-up periods exceeding two years [13].

Thus, the high prevalence of chronic fibrous pulpitis, the disease's progression characteristics, the impact of odontogenic infection foci on individual organs, systems, and the body as a whole, together with the complexity, labor intensity, and interdependence of the stages of therapeutic intervention, underscore the need for the development of modern, optimized methods for managing this pathology.

AIM

The aim of this study is to perform a comparative evaluation of the effectiveness of a novel endodontic treatment approach for chronic fibrous pulpitis versus the conventional standard method over both short-term and long-term follow-up periods.

MATERIALS AND METHODS

For the purpose of evaluating and analyzing the effectiveness of a novel endodontic treatment method for chronic fibrous pulpitis (RF Patent No. 2771916 dated 13.05.2022), 186 patients aged 20 to 60 years were examined, including 94 (50.5%) men and 92 (49.5%) women, who underwent primary endodontic treatment of 302 teeth of various groups diagnosed with chronic fibrous pulpitis (K04.03). The treatments were performed at the Department of Therapeutic Dentistry with an osteopathy course at the Federal State Budgetary Educational Institution of Higher Education "Samara State Medical University" of the Ministry of Health of the Russian Federation, as well as in the dental clinics Eldent LLC and Mir LLC in Samara, during the period from 2016 to 2025.

All study participants were randomly assigned to three groups: Group I – 42 patients ($n = 82$ teeth) treated using the conventional method; Group II – 60 patients ($n = 102$ teeth) treated with the addition of low-frequency ultrasound; Group III – 84 patients ($n = 118$ teeth) treated using the proposed method. No statistically significant differences were observed between the groups in terms of age, sex, or number of root canals ($p > 0.05$), indicating that the groups were representative.

Inclusion criteria for the study were: informed voluntary consent for medical intervention (Order of the Ministry of Health of the Russian Federation No. 1051n, dated 12.11.2021), age between 20 and 60 years, absence

of concomitant somatic pathology, and confirmed diagnosis of chronic fibrous pulpitis (K04.03). Exclusion criteria included: refusal to participate, mechanical tooth trauma or teeth along a jaw fracture line, other forms of endodontic pathology, depulpation for prosthetic reasons, internal or external root resorption, teeth with incomplete root formation, localized or generalized moderate-to-severe periodontitis, and severe systemic pathology limiting activity or posing a life threat.

The standard treatment method for Group I patients with chronic fibrous pulpitis included: anesthesia, isolation of the operative field, preparation of the carious cavity and formation of endodontic access, initial negotiation of the root canals and creation of a "carpet track", working length measurement using a digital apex locator, mechanical preparation of root canals using rotary ProTaper Universal files (Dentsply Sirona), irrigation of root canals with 3% sodium hypochlorite at each stage of instrumentation using an endodontic syringe, followed by final irrigation with 17% EDTA solution, drying of the canals with paper points, obturation by vertical condensation using thermoplasticized gutta-percha and epoxy resin–based sealer, radiographic control, and post-endodontic restoration.

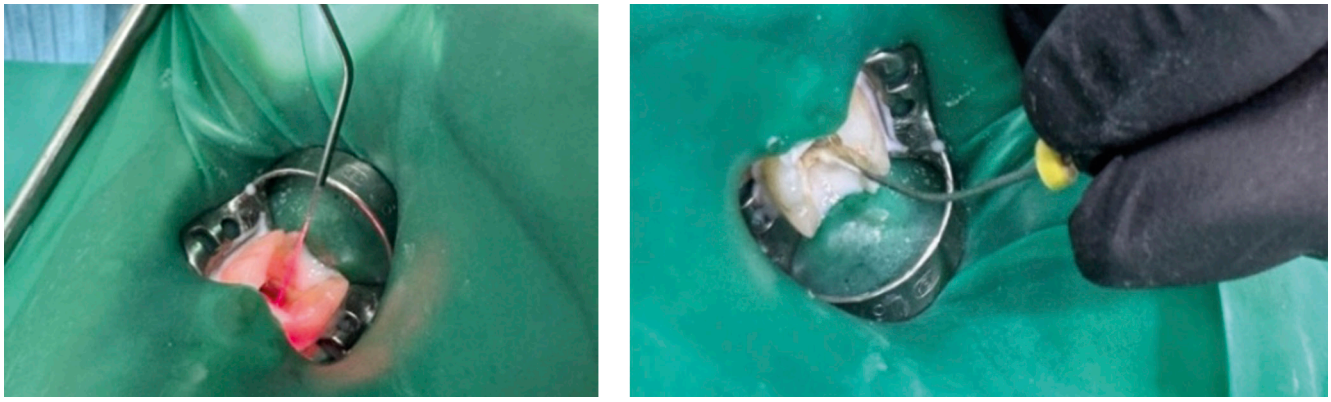
Treatment for Group II patients was performed similarly; however, at each irrigation stage, low-frequency ultrasound (VDW Ultra, VDW Germany) was used to activate the antiseptic solution, with parameters set at 28 kHz frequency and an exposure time of 30–60 seconds.

The treatment protocol for chronic fibrous pulpitis in Group III patients was as follows: anesthesia was administered, the operative field was isolated, the carious cavity was prepared, and straight-line access to the root canal orifices was established using endodontic burs. Final cavity preparation and detection of hidden canal orifices were performed with VDW Ultra ultrasonic tips in the sequence Cavi 1, Cavi 2, and Cavi 3 under a 3% sodium hypochlorite bath with an exposure time of 30–60 seconds.

Initial canal negotiation was performed using a high-strength, highly flexible C-Pilot file (#06, 08, 10) with an EDTA-based endolubricant. Working length was verified with a digital apex locator. A "carpet track" in narrow and curved canals was created using R-Pilot files (size 12.5, taper 0.4) with reciprocal motion. Canal shaping and enlargement were completed using reciprocal nickel-titanium instruments in conjunction with a VDW Gold endomotor equipped with a built-in apex locator, allowing working length control at each stage of mechanical preparation. Straight canals were prepared with standard Reciproc files, while curved canals were treated with Reciproc Blue files. After each instrumentation stage, root canals were irrigated with 3% sodium hypochlorite solution, followed by ultrasonic cavitation using the IRRI-S VDW Ultra tip. Prior to final antiseptic irrigation, 17% EDTA solution was ultrasonically activated.

The final stage of antiseptic canal treatment involved diode laser activation using the Doctor Smile Wiser (Italy) with a wavelength of 980 nm in a nanosecond pulsed mode, at an average output of 1.2 W and pulse duration of 200 ns, with a 200 μm fiber optic tip (Fig. 1, *A*). The procedure was performed as follows: the canal was irrigated with 3% sodium hypochlorite, the fiber was inserted 1 mm short of the working length, with depth fixed using a stopper. Laser activation was applied with reciprocating and rotational movements of the fiber three times for 5 seconds each, with a 100 ns pause between pulses. The canal was then dried with paper points and obturated.

For sealer placement, a specially designed instrument was used (RF Patent for Utility Model "Endodontic Instrument for Sealer Placement in the Tooth Root Canal" No. 208382, dated 16.12.2021), sized according to the canal diameter and taper and customized for each patient. A stopper was set 1 mm short of the working length. Two-thirds of the plastic shaft of the instrument was immersed in the endosealer, and several rolling movements were applied to the handle to distribute the sealer evenly. The instrument was then smoothly inserted into the canal with reciprocating and rotational movements, distributing the sealer evenly along the canal walls over 10 seconds (Fig. 1, *B*).



A **B**

Fig. 1. Root canal handling with Doctor Smile Wiser laser (*A*), sealer insertion into the root canal with a developed instrument (*B*)

Рис. 1. Лазерная обработка корневого канала Doctor Smile Wiser (*A*), внесение силера в корневой канал разработанным нами инструментом (*B*)

Canal obturation was performed using vertical condensation of thermoplasticized gutta-percha, and the treatment was completed with final tooth restoration.

The comparative evaluation of the effectiveness of chronic fibrous pulpitis treatment was carried out through analysis of patient-reported complaints, clinical examination, and radiographic assessment of the root canals and surrounding tissues at different time points: immediately (within the first month) after treatment and 12 months post-treatment.

For statistical data analysis, IBM SPSS Statistics 24 and PS IMAGO 4.0 software were used. The effectiveness of the treatment using the method developed by our team was analyzed over time using the Q-test of McNemar, which is applicable for paired data sets. The periods "end of 1 month" and "12 months after treatment" were sequentially compared. McNemar test values were interpreted by comparison with critical values and significance levels (p) using the StatTech statistical software.

RESULTS

In the comparative evaluation of treatment methods among the study groups, an important indicator of the effectiveness of chronic fibrous pulpitis management was the assessment of pain. Analysis of pain intensity using the Numeric Rating Scale (NRS) [14] allowed us to quantify the patients' subjective perception of pain immediately following treatment of chronic fibrous pulpitis with the different methods (Table 1).

Immediate clinical outcomes and radiographic assessment of root canal obturation quality are presented in Tables 2 and 3. The data in Table 2 show that both subjective patient perceptions and objective indicators of tooth and surrounding tissue condition met the "excellent" evaluation criteria in 22 patients of the first group (49 teeth, 59.8%), 38 patients of the second group (68 teeth, 66.7%), and 71 patients of the third group (101 teeth, 85.6%). Comparison of these results indicates a significant advantage of the proposed treatment method over the standard approach ($\chi^2 = 17.22$, d$f = 1$, $p = 0.001$).

Table 1. Quantitative assessment of pain intensity using the NRS digital rating system

Таблица 1. Сравнительная оценка интенсивности болевого синдрома по цифровой рейтинговой шкале NRS

Points	Standard Method (Group 1)	Standard Method + Ultrasound (Group 2)	Modified Method (Group 3)	Group Comparison – Statistical Significance / Degrees of Freedom / Probability (χ^2, d$f = 1$, p)		
	Abs. (%)	Abs. (%)	Abs. (%)	Groups 1 vs 2	Groups 1 vs 3	Groups 2 vs 3
0–3 points (no pain or mild pain)	54 (65.9%)	81 (79.4%)	109 (92.4%)	$\chi^2 = 4.28$ d$f = 1$ $p = 0.039$	$\chi^2 = 22.57$ d$f = 1$ $p < 0.001$	$\chi^2 = 7.80$ d$f = 1$ $p = 0.005$
4–6 points (moderate pain)	21 (25.6%)	17 (16.7%)	9 (7.6%)	$\chi^2 = 2.22$ d$f = 1$ $p = 0.136$	$\chi^2 = 12.27$ d$f = 1$ $p < 0.001$	$\chi^2 = 4.29$ d$f = 1$ $p = 0.038$
7–9 points (severe pain)	7 (8.5%)	4 (3.9%)	0 (0.0%)	$\chi^2 = 1.72$ d$f = 1$ $p = 0.189$	$\chi^2 = 10.44$ d$f = 1$ $p = 0.001$	$\chi^2 = 4.71$ d$f = 1$ $p = 0.030$
10 points (unbearable pain)	0 (0.0%)	0 (0.0%)	0 (0.0%)	–	–	–
Total (teeth)	82 (100.0%)	102 (100.0%)	118 (100.0%)			

Table 2. Comparative analysis of immediate results of treatment of chronic fibrous pulpitis

Таблица 2. Сравнительный анализ непосредственных результатов лечения хронического фиброзного пульпита

Grade	Standard Method (Group 1, $n = 82$)	Standard Method + Ultrasound (Group 2, $n = 102$)	Modified Method (Group 3, $n = 118$)	Group Comparison – Statistical Significance / Degrees of Freedom / Probability (χ^2, d$f = 1$, p)		
	Abs. (%)	Abs. (%)	Abs. (%)	Groups 1 vs 2	Groups 1 vs 3	Groups 2 vs 3
Excellent	49 (59.8%)	68 (66.7%)	101 (85.6%)	$\chi^2 = 0.94$ d$f = 1$ $p = 0.333$	$\chi^2 = 17.22$ d$f = 1$ $p < 0.001$	$\chi^2 = 11.01$ d$f = 1$ $p = 0.001$
Good	19 (23.2%)	24 (23.5%)	14 (11.9%)	$\chi^2 = 0.00$ d$f = 1$ $p = 0.954$	$\chi^2 = 4.49$ d$f = 1$ $p = 0.034$	$\chi^2 = 5.21$ d$f = 1$ $p = 0.022$
Satisfactory	14 (17.1%)	10 (9.8%)	3 (2.5%)	$\chi^2 = 2.12$ d$f = 1$ $p = 0.146$	$\chi^2 = 13.13$ d$f = 1$ $p < 0.001$	$\chi^2 = 5.19$ d$f = 1$ $p = 0.023$
Unsatisfactory	0 (0.0%)	0 (0.0%)	0 (0.0%)	–	–	–
Total (teeth)	82 (100.0%)	102 (100.0%)	118 (100.0%)			

Table 3. X-ray quality control of root canal obturation

Таблица 3. Рентгенологический контроль качества обтурации корневых каналов

Stage	Standard Method (Group 1, *n* = 82)	Standard Method + Ultrasound (Group 2, *n* = 102)	Modified Method (Group 3, *n* = 118)	Group Comparison – Statistical Significance / Degrees of Freedom / Probability (χ^2, d*f* = 1, *p*)		
	Abs. (%)	Abs. (%)	Abs. (%)	Groups 1 vs 2	Groups 1 vs 3	Groups 2 vs 3
High-Quality Obturation, Intact Periodontium Underfilled Root Canal	62 (75.6%)	81 (79.4%)	107 (90.7%)	$\chi^2 = 0.38$ d*f* = 1 *p* = 0.538	$\chi^2 = 8.39$ d*f* = 1 *p* = 0.004	$\chi^2 = 5.59$ d*f* = 1 *p* = 0.018
Underfilled Root Canal	8 (9.8%)	7 (6.9%)	6 (5.1%)	$\chi^2 = 0.51$ d*f* = 1 *p* = 0.476	$\chi^2 = 1.62$ d*f* = 1 *p* = 0.203	$\chi^2 = 0.31$ d*f* = 1 *p* = 0.577
Sealer Extrusion Beyond the Apex	12 (14.6%)	14 (13.7%)	5 (4.2%)	$\chi^2 = 0.03$ d*f* = 1 *p* = 0.860	$\chi^2 = 6.72$ d*f* = 1 *p* = 0.010	$\chi^2 = 6.24$ d*f* = 1 *p* = 0.012
Total (teeth)	82 (100.0%)	102 (100.0%)	118 (100.0%)			

Table 4. Comparative analysis of clinical results of treatment a chronic fibrous pulpitis after 12 months

Таблица 4. Сравнительный анализ клинических результатов лечения хронического фиброзного пульпита через 12 месяцев

Grade	Standard Method (Group 1, *n* = 82)	Standard Method + Ultrasound (Group 2, *n* = 102)	Modified Method (Group 3, *n* = 118)	Group Comparison – Statistical Significance / Degrees of Freedom / Probability (χ^2, d*f* = 1, *p*)		
	Abs. (%)	Abs. (%)	Abs. (%)	Groups 1 vs 2	Groups 1 vs 3	Groups 2 vs 3
Excellent	40 (60.6%)	71 (80.7%)	99 (94.3%)	$\chi^2 = 7.55$ d*f* = 1 *p* = 0.006	$\chi^2 = 30.22$ d*f* = 1 *p* < 0.001	$\chi^2 = 8.44$ d*f* = 1 *p* = 0.004
Good	18 (27.3%)	11 (12.5%)	4 (3.8%)	$\chi^2 = 5.38$ d*f* = 1 *p* = 0.020	$\chi^2 = 19.90$ d*f* = 1 *p* < 0.001	$\chi^2 = 5.04$ d*f* = 1 *p* = 0.025
Satisfactory	8 (12.1%)	6 (6.8%)	2 (1.9%)	$\chi^2 = 1.28$ d*f* = 1 *p* = 0.257	$\chi^2 = 7.68$ d*f* = 1 *p* = 0.006	$\chi^2 = 2.91$ d*f* = 1 *p* = 0.088
Unsatisfactory	0 (0.0%)	0 (0.0%)	0 (0.0%)	–	–	–
Total (teeth)	66 (100.0%)	88 (100.0%)	105 (100.0%)			

Table 5. Comparative analysis of radiographic parameters of treatment a chronic fibrous pulpitis after 12 months

Таблица 5. Сравнительный анализ рентгенологических показателей через 12 месяцев после лечения хронического фиброзного пульпита

Parameter	Standard Method (Group 1, *n* = 82)	Standard Method + Ultrasound (Group 2, *n* = 102)	Modified Method (Group 3, *n* = 118)	Group Comparison – Statistical Significance / Degrees of Freedom / Probability (χ^2, d*f* = 1, *p*)		
	Abs. (%)	Abs. (%)	Abs. (%)	Groups 1 vs 2	Groups 1 vs 3	Groups 2 vs 3
Intact Periodontium	44 (66.7%)	68 (77.3%)	91 (86.7%)	$\chi^2 = 2.14$ d*f* = 1 *p* = 0.144	$\chi^2 = 9.75$ d*f* = 1 *p* = 0.002	$\chi^2 = 2.91$ d*f* = 1 *p* = 0.088
Periodontal Changes, including:	22 (33.3%)	20 (22.7%)	14 (13.3%)	$\chi^2 = 2.14$ d*f* = 1 *p* = 0.144	$\chi^2 = 9.75$ d*f* = 1 *p* = 0.002	$\chi^2 = 2.91$ d*f* = 1 *p* = 0.088
of which: Deformation	18 (27.3%)	17 (19.3%)	12 (11.4%)	$\chi^2 = 1.36$ d*f* = 1 *p* = 0.244	$\chi^2 = 7.03$ d*f* = 1 *p* = 0.008	$\chi^2 = 2.33$ d*f* = 1 *p* = 0.127
of which: Destruction	4 (6.1%)	3 (3.4%)	2 (1.9%)	$\chi^2 = 0.61$ d*f* = 1 *p* = 0.434	$\chi^2 = 2.07$ d*f* = 1 *p* = 0.150	$\chi^2 = 0.43$ d*f* = 1 *p* = 0.512
Total (teeth)	66 (100.0%)	88 (100.0%)	105 (100.0%)			

A comparative analysis of the quality of endodontic treatment for chronic fibrous pulpitis at 12 months post-treatment among the study groups is presented in Tables 4 and 5.

DISCUSSION

According to the data in Table 1, in the group treated using the standard protocol (54 teeth), only 65.9% of patients reported no pain or mild pain. In Group II, where ultrasound was applied during treatment (81 teeth), this proportion increased to 79.4%. Statistical analysis confirmed the significance of this improvement ($\chi^2 = 4.28$, d$f = 1$, $p = 0.039$), indicating that the use of ultrasound positively influenced the reduction of postoperative pain. An even more pronounced effect was observed in Group III, where 92.4% of patients reported no pain or only mild pain. The statistical significance of this result was very high ($\chi^2 = 22.57$, d$f = 1$, $p < 0.001$), demonstrating the substantial advantage of the proposed treatment method in controlling postoperative discomfort.

High-quality root canal obturation, based on radiographic assessment (Table 3), was observed in 62 teeth (75.6%) of patients in the first group, 81 teeth (79.4%) in the second group, and 107 teeth (90.7%) in the third group ($\chi^2 = 8.39$, d$f = 1$, $p = 0.004$). Sealer extrusion beyond the apex occurred more frequently in patients of the first two groups, with a statistically significant difference between the first and third groups ($\chi^2 = 6.72$, d$f = 1$, $p = 0.010$). The optimal level of root canal obturation in Group III patients is likely associated with the use of the specially designed instrument for sealer placement, which allows precise control over the amount of endosealer introduced. These findings confirm the effectiveness of the new treatment method for chronic fibrous pulpitis in achieving high-quality canal obturation and minimizing complications related to sealer extrusion beyond the apex.

According to the data presented in Table 4, at this follow-up period, the condition of the teeth, periapical tissues, and post-endodontic restorations was rated as “excellent” in 40 teeth (60.6%) of patients in the first group, 71 teeth (80.7%) in the second group, and 99 teeth (94.3%) in the third group; rated as “good” in 18 teeth (27.3%) of the first group, 11 teeth (12.5%) of the second group, and 4 teeth (3.8%) of the third group; and rated as “satisfactory” in 8 teeth (12.1%) of the first group, 6 teeth (6.8%) of the second group, and 2 teeth (1.9%) of the third group.

Analysis of the radiographic status of the periodontium 12 months after treatment for chronic fibrous pulpitis (Table 5) revealed the following key points: changes in the periodontium were observed in 22 teeth (33.3%) of the first group, 20 teeth (22.7%) of the second group, and 14 teeth (13.3%) of the third group. A statistically significant difference was detected only between the first and third groups ($\chi^2 = 9.75$, d$f = 1$, $p = 0.002$). Deformation of the periodontal ligament space was noted in 18 teeth (27.3%) of the first group, 17 teeth (19.3%) of the second group, and 12 teeth (11.4%) of the third group, with statistical significance observed only between the first and third groups ($\chi^2 = 7.03$, d$f = 1$, $p = 0.008$). Destructive changes in the periodontium and early signs of alveolar bone resorption were identified in 4 teeth (6.0%), 3 teeth (3.4%), and 2 teeth (1.9%) respectively, with no statistically significant differences between groups. Overall, a greater number of teeth with periodontium changes was observed in the first group, gradually decreasing in the second group and particularly in the third group.

Thus, the treatment outcomes among patients in the study groups were distributed as follows: “successful” treatment was observed in 54 teeth (81.8%) in the first group, 79 teeth (89.8%) in the second group, and 101 teeth (96.2%) in the third group; “questionable” outcomes were recorded in 8 teeth (12.1%) of the first group, 6 teeth (6.8%) of the second group, and 2 teeth (1.9%) of the third group; “unsuccessful” outcomes were noted in 4 teeth (6.1%), 3 teeth (3.4%), and 2 teeth (1.9%), respectively.

CONCLUSION

Analysis of the clinical and radiographic data demonstrated that patients in the third group, treated for chronic fibrous pulpitis using the proposed method, experienced minimal postoperative pain, including a significant reduction in “moderate and severe” pain compared with patients in the first and second groups ($p < 0.05$). During root canal obturation, no sealer extrusion beyond the apex was observed in Group III, likely due to the use of the specially designed instrument for sealer placement, which allows precise control over the amount of endosealer introduced ($p < 0.001$). Accordingly, the “success rate” of treatment in the third group was statistically significant when compared with the first and second groups, highlighting the high effectiveness of the proposed method and its low rate of unsuccessful outcomes ($\chi^2 = 9.87$, d$f = 1$, $p = 0.002$).

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Original Research

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Awareness, comprehension, and sentiments of dentists in Najaf City on oral cancer screening: a questioner-based study

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Abstract

INTRODUCTION. Oral cancer screening during dental consultations is a simple and non-invasive method for identifying pre-malignant lesions and early-stage malignancies. This research aimed to examine the knowledge, behaviours, and attitudes related to oral cancer screening among dentists in Najaf City.

MATERIALS AND METHODS. Data were gathered using a structured questionnaire and self-reported interviews with 250 dentists, performed from October 15, 2023, to December 20, 2024, at the Martyr Nasser specialised Centre and the specialised centre in the Maysan area. Each dentist required around 5 to 10 minutes to complete the self-report questionnaire and participate in the interview on their knowledge of screening.

RESULTS. 250 dentists were asked to participate in the research, and all of them filled out the survey, yielding a 100% response rate. The dentists' knowledge of oral cancer in this study was not very good overall. Most dentists in this survey (87.6%) regularly check their patients' oral mucosa, but only a small number (49.2%) say they are sure they can diagnose and find oral cancer. About 49% of dentists lack confidence in diagnosing and detecting oral cancer.

CONCLUSIONS. Dentists have a good understanding of oral cancer, but they need more training on how to prevent it and find it early. They should also keep learning and going to seminars.

Keywords: oral cancer, oral squamous cell carcinoma screening, oral cancer diagnosis.

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Осведомленность, понимание и отношение стоматологов г. Наджаф к скринингу рака полости рта: исследование-анкетирование

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Резюме

ВВЕДЕНИЕ. Скрининг рака полости рта во время стоматологического приема является простым и неинвазивным методом выявления предраковых поражений и злокачественных новообразований на ранних стадиях. Целью данного исследования было изучить уровень знаний, практические навыки и отношение стоматологов города Наджаф к скринингу рака полости рта.

МАТЕРИАЛЫ И МЕТОДЫ. Сбор данных проводился с использованием структурированной анкеты и самоотчетных интервью с участием 250 стоматологов в период с 15 октября 2023 г. по 20 декабря 2024 г. в специализированном центре имени Шахида Насера и специализированном центре района Майсан. Каждому стоматологу требовалось около 5–10 минут для заполнения анкеты и участия в интервью, посвященном их знаниям в области скрининга.

РЕЗУЛЬТАТЫ. В исследовании приняли участие 250 стоматологов, все они заполнили анкету, что обеспечило 100% уровень отклика. В целом уровень знаний стоматологов о раке полости рта оказался недостаточным. Большинство респондентов (87,6 %) регулярно осматривают слизистую оболочку полости рта пациентов, однако лишь небольшая часть (49,2 %) уверены в своей способности диагностировать и выявлять рак полости рта. Около 49 % стоматологов испытывают недостаток уверенности при диагностике и обнаружении рака полости рта.

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ВЫВОДЫ. Стоматологи обладают общим пониманием проблемы рака полости рта, однако нуждаются в дополнительной подготовке по вопросам профилактики и раннего выявления заболевания. Также рекомендуется непрерывное профессиональное обучение и участие в профильных семинарах.

Ключевые слова: рак полости рта, скрининг плоскоклеточного рака полости рта, диагностика рака полости рта

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INTRODUCTION

Oral cancer is one of the most common cancers in the world. It is the sixth most common cancer overall. In 2020, there were 377,713 new cases and 177,757 reported deaths. This is a big jump from 2018, when there were 354,864 new cases and 177,384 deaths [1; 2]. Squamous cell carcinoma (SCC) is the most common type of mouth cancer, making up most cases. In 2020, SCC accounted for a substantial percentage of global cases of oral squamous cell carcinoma [3].

Squamous cell carcinoma arises from squamous epithelial cells in the oral mucosa and is marked by an aggressive clinical progression, significant infiltration of local neck tissues, and a high incidence of regional lymphatic and distant organ metastasis [4]. The aggressive nature of squamous cell carcinoma necessitates a focus on disease prevention and its complications via early detection and intervention [5; 6].

There are some well-known risk factors that are closely related to the rise of SCC. Among these, the consumption of tobacco products and the misuse of alcoholic beverages are the primary factors, and these risk factors exacerbate the SCC's multiplicative effects. Also, the infection with some oncogenic strains of the human papillomavirus (HPV), especially HPV-16 and HPV-18, has been found to be a major risk in this population, particularly in younger and non-smoking individuals [7]. Due to the multifactorial nature of SCC, a holistic risk assessment and preventive approach are required.

In a clinic setting, squamous cell carcinoma (SCC) may be seen as non-healing ulcers, achandratising red or white patches (such as ethroplakia or leukoplakia) or palpable painless lumpy or indurated nodules within the oral cavity. These signs and symptoms may be regarded as harmless conditions and may hinder the initial diagnosis. Therefore, patient's treating physicians should be more vigilant and perform more in depth deviated examinations in order to preserve patient health [8].

Oral cancer counts among the diseases of public health significance and therefore, there is a need to objectively assess the knowledge and the attitudes of dental practitioners regarding oral cancer screening. Understanding the beliefs of dental professionals is critical in enhancing and improving screening techniques and increasing detection at early stage so as to decrease the associated oral cancer morbidity and mortality.

Many studies have addressed the knowledge and attitudes of dentists toward oral cancer screening. Al-Maweri et al. conducted a kw survey that was aimed to determine the awareness, attitude and practices of dentists after an oral cancer awareness campaign [9]. The study assessed the knowledge of the risk factors, the methods of screening and the frequency of the screening both prior to and during the campaign. Reddy & Nalliah [10] carried out a study among general dentists in Midwestern USA to assess their practices in oral cancer screening and lesion detection. Of the respondents assessed the frequency of screens, the confidence of dentists' audiences in lesion assessment and factors that restricted screening practices.

In this research, the study was intended to Examine the Knowledge and Attitudes of Dentists in Al-Najaf City, Iraq regarding Oral Cancer Screening. The study will assess dentists' understanding concerning the screening procedures adopted in oral cancer, its risk factors, and Clinical presentation. The study aims to target the opinions of dentists about oral cancer screening using a well-crafted survey.

MATERIALS AND METHODS

Collection of samples

Subsequent an examination of related literature and previous studies, the investigators established and articulated the questionnaire used in this study, which was modified from an earlier survey with many alterations [1–3]. The questionnaire underwent pre-testing for clarity and consistency, and its reliability was validated in pilot research with a reduced sample of dentists. The questionnaire Consists three primary components: Part (1) Evaluation of Knowledge Concerning Oral Cancer (OC) Screening Among Dentists in Al-Najaf City, Iraq. Section (2) Evaluates Their Disposition, Section (3) Incorporate Targeted Enquiries Regarding Oral Cancer (OC), including 19 items composed as multiple-choice enquiries. The scoring system has two components. One right answer and many erroneous responses. Subsequently, the degree of knowledge is assessed. Based on the average score and threshold (1.5).

To determine the interval length, we used the following equation (Pimentel, 2010).

$$Interval\ length = \frac{Range\ of\ maximum - Minimum\ value}{Number\ of\ intervals} = \frac{3-2}{3} = 0.667.$$

Table 1. Calculation of intervals based on a 3-point Likert scale

Таблица 1. Расчет интервалов на основе 3-балльной шкалы Лайкерта

Scale	Disagree	Neutral	Agree
Degree	1	2	3
Interval length	0.667	0.667	0.667
Range	1–1.67	1.68–2.33	2.34–3
Assessment	low	Moderate	High

Data were gathered using a designed questionnaire and self-reporting via interviews with 250 dentists from October 15, 2023, to December 20, 2024, at the Martyr Nasser Specialized Centre and the specialized center in the Maysan area. The self-report from the questionnaire and interview required roughly 5 to 10 minutes for each dentist.

Statistical examination

The data were inputted and analyzed by Microsoft 365 Excel 2024 and version 26 of the Statistical Package for the Social Sciences (SPSS, IBM) software. The findings are shown in tables and/or graphs. A T-test and ANOVA were used for the statistical analysis of the variables. In all statistical studies, the significance threshold (*p*-value) was established at 0.05.

RESULTS

Table 2 delineates the awareness of dentists in Najaf on oral cancer screening, risk factors, and symptoms. Most of the people who answered correctly identified major risk factors (like smoking and being over 40) and symptoms (like ulcers). Unfortunately, some people believed oral cancer was contagious. Overall awareness was low, indicating that more education is needed, especially on oral cancer early detection and frequent misconceptions.

Table 3 illustrates dentists' perceptions concerning oral cancer screening. Numerous dentists demonstrated a favourable disposition regarding routine oral cancer screenings and highlighted the importance of early detection. Only 50% of dentists expressed confidence in their ability to diagnose oral cancer, indicating a need for additional training. The dentists' elevated overall attitude score indicates their awareness of the significance of their role in oral cancer prevention; however, there may be a need for additional resources and enhanced confidence.

Table 2. Knowledge of oral cancer screening among dentists

Таблица 2. Уровень знаний стоматологов о скрининге рака полости рта

Variable	Agree (%)	Disagree (%)	Not Sure (%)	Mean ± SE	*p*-value	Assessment
Oral cancer is contagious	18.8	66	15.2	1.53±0.05	0.0	Low
Observed a case of oral cancer	19.2	80.8	0	1.38±0.05	0.0	Low
Smoking is the greatest risk factor	48	44	8	2.04±0.06	0.0001	Moderate
Most prevalent age group is over 40	76.4	13.2	10.4	2.63±0.05	0.0	High
Ulcer/erythematous patches as clinical signs	79.2	16	4.8	2.63±0.05	0.0	High
Males have a higher incidence of oral cancer	80	12.4	7.6	2.68±0.04	0.0	High
Total Knowledge Score	–	–	–	2.15±0.03	–	Moderate

Table 3. Attitudes toward oral cancer screening among dentists

Таблица 3. Отношение стоматологов к скринингу рака полости рта

Variable	Agree (%)	Disagree (%)	Not Sure (%)	Mean ± SE	*p*-value	Assessment
Regularly examine patients' oral mucosa	87.6	12.4	0	2.75±0.04	0.0	High
Confident in diagnosing oral cancer	49.2	49.2	1.6	2.00±0.06	0.0	Moderate
Early detection improves outcomes	96.8	2.4	0.8	2.94±0.02	0.0	High
Refer to a specialist if malignancy suspected	96	2	2	2.94±0.02	0.0	High
Total Attitude Score	–	–	–	2.66±0.03	–	High

Table 4. Specific questions about oral cancer

Таблица 4. Специфические вопросы по раку полости рта

Variable	Agree (%)	Disagree (%)	Not Sure (%)	Mean ± SE	*p*-value	Assessment
Squamous cell carcinoma as most common type	80	12.4	7.6	2.68±0.04	0.0	High
Oral cancer most common on floor of mouth	80	12.4	7.6	2.68±0.04	0.0	High
Recognized precancerous lesions like leukoplakia	79.2	16	4.8	2.63±0.05	0.0	High
Non-healing ulcers as common presentation	76.4	13.2	10.4	2.63±0.05	0.0	High
Confident in staging diagnosed oral cancer	49.2	49.2	1.6	2.00±0.06	0.0	Moderate
Total Specific Question Score	–	–	–	2.43±0.03	0.0	High

Table 5. Suggested methods for early detection of oral cancer

Таблица 5. Рекомендуемые методы раннего выявления рака полости рта

Detection Method	Responses (%)
Routine check-up	32.0
Biopsy	26.8
Clinical examination	25.6
Educational initiatives	15.6

Table 4 shows how dentists answered specific questions about the signs of oral cancer and how to diagnose it. Most dentists correctly named the most common types of oral cancer, such as squamous cell carcinoma and persistent ulcers, which are both important signs. Still, people only had a moderate level of trust in the illness stage. Dentists did very well on these questions, but they still have trouble recognising less common signs and stages.

Table 5 demarcates the dentists' views for the most efficacious approaches of early oral cancer detection. The most common procedure was a regular check-up (32%), followed by a biopsy (26.8%) and a clinical exam (25.6%). Dentists rarely chose educational programs, which shows that they prefer practical, hands-on screening methods to teaching people how to avoid problems.

DISCUSSION

Oral cancer is still a major public health problem around the world, especially for dentists. It is one of the ten most common cancers in the world. Despite significant advancements in research and treatment, the overall survival rate for oral cancer has not substantially increased in the past decade, posing a continuous challenge for biomedical sciences [10]. Due to the fact that dentists play a significant role in the early diagnosis of oral cancer via screening and preventative measures, it is very important to evaluate their knowledge and practices in order to enhance the results for patients [11].

The purpose of this study is to investigate the knowledge, attitudes, and behaviours of dentists in Al-Najaf City, Iraq, in relation to oral cancer screening. The results provide important insights into the information that dental practitioners in this area already possess about oral cancer awareness and the procedures that they use to treat patients. An assumption that dentists in Al-Najaf City are not aware of oral cancer screening is referred to as the null hypothesis. However, this assertion is refuted by information that indicates that these dentists have some understanding of the screening technology.

A response rate of one hundred percent was achieved in this research, which is a significant improvement above the previous rates that were observed in Malaysia (41.7%) and Sri Lanka (38%) [12]. Our research has a response rate that is much higher than that of a study that was performed in Yemen that was quite comparable to ours and showed a response rate of 27.6% [13]. The increasing response rate may indicate that dentists in Al-Najaf City are more concerned about or aware of the need of oral cancer screening.

It is important for dentists to know a lot about the risk factors, signs, and symptoms of oral cancer because they play an important role in screening for oral mucosal cancer and preventing it [14]. Our survey indicated that most respondents had a modest understanding of oral cancer and its related risk factors. This assumption encounters other wide-reaching studies that indicated a lack of oral cancer awareness between dental expert [15; 16]. However, approximately risk aspects, particularly smoking, were widely recognized, with 94.6% of contributors (n = 35) identifying smoking as a substantial risk factor for oral cancer, consistent with the results of research directed at the University of Toronto [17].

In existing study, only 29.9% of respondents thought that they regularly screen patients for mucosal lesions as part of clinical measures for oral cancer anticipation. Compared to the findings of previous studies conducted in Saudi Arabia, where only 13% of dentists demonstrated frequent testing [18], this number is much higher. On the other hand, higher rates of frequent screenings were seen in further investigations that were carried out in Kuwait, Sudan, and Aus-

tralia [19; 20]. The observed disparities point to a large amount of variety in the techniques of routine screening that are used in different locations. This variation is most likely linked to differences in healthcare policies, education, and awareness levels.

The evaluation of specific research on oral cancer revealed that the dentists who were polled have various degrees of expertise about the subject. On the other hand, some of the respondents shown a full awareness of the essential characteristics of oral cancer, while others displayed inadequacies in crucial areas such as early diagnosis and the most prevalent locations of incidence. According to the results, there is a pressing need for improved programs of ongoing education and training in order to develop the capabilities of dentists in the areas of oral cancer screening and prevention [21].

CONCLUSION

In a nutshell, dentists in Al-Najaf City have a good understanding of the elements that might lead to oral cancer as well as the causes of the disease. It is very vital to broaden the scope of continuous education programs and improve screening procedures in order to improve the results for patients and the accuracy of early diagnosis.

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AUTHOR'S CONTRIBUTION

All the authors made equal contributions to the publication preparation in terms of the idea and design of the article; data collection; critical revision of the article in terms of significant intellectual content and final approval of the version of the article for publication.

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Original Research

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Application of QLF technology for assessing the oral hygiene status of children living in residential care institutions

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Abstract

INTRODUCTION. Modern approaches to the prevention of dental diseases in children require the use of objective methods for assessing oral hygiene, particularly in socially vulnerable groups.

AIM. The aim of this study was to evaluate the effectiveness of quantitative light-induced fluorescence (QLF) technology in assessing oral hygiene status in children living in residential care institutions.

MATERIALS AND METHODS. The study included 207 students of boarding schools in the Yaroslavl and Moscow regions and 197 children living in families (control group). The observation period lasted 24 months. Examination was carried out before and after the implementation of a comprehensive preventive program, which included instruction in proper oral hygiene techniques, motivational sessions, and supervision of individual oral care. The Qscan (QLF) system, the IGR-U oral hygiene index (modified Green–Vermillion index), and clinical assessment of periodontal tissues (PMA index) were used.

RESULTS. A statistically significant reduction in the area and intensity of fluorescent dental plaque was observed in children from residential care institutions after the program ($p < 0.05$), accompanied by improvement in hygiene indicators. In the control group, positive changes were present but less pronounced.

CONCLUSIONS. QLF technology enabled early detection of hygiene deficiencies and provided more precise monitoring of individual preventive measures compared with visual methods. The findings support the inclusion of QLF in clinical monitoring protocols for oral health in children living in residential care institutions.

Key words: QLF diagnostics, oral hygiene, institutionalized children, caries prevention, Qscan, residential care facilities, hygiene index, pediatric dentistry

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Применение технологии QLF в оценке гигиенического статуса детей, проживающих в учреждениях интернатного типа

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Резюме

ВВЕДЕНИЕ. Современные подходы к профилактике стоматологических заболеваний у детей требуют применения объективных методов контроля гигиенического состояния полости рта, особенно в группах социального риска.

ЦЕЛЬ РАБОТЫ. Изучение эффективности технологии количественной световой люминесценции (QLF) при оценке уровня гигиены полости рта у детей, проживающих в учреждениях интернатного типа.

МАТЕРИАЛЫ И МЕТОДЫ. В исследование включены 207 воспитанников школ-интернатов Ярославской и Московской областей и 197 школьников, проживающих в семьях (контрольная группа). Период наблюдения составил 24 месяца. Оценка проводилась до и после комплексной программы профилактики, включавшей обучение навыкам рациональной гигиены, мотивационные занятия и контроль индивидуального ухода. Использовались аппарат Qscan (QLF), индекс ИГР-У и клиническая оценка состояния тканей пародонта (индекс РМА).

РЕЗУЛЬТАТЫ. Наблюдения продемонстрировали достоверное уменьшение площади и интенсивности флюоресцирующего налета у детей из интернатных учреждений после внедрения программы

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($p < 0,05$), что сопровождалось улучшением гигиенических показателей. В контрольной группе положительная динамика была выражена менее значительно.
ВЫВОДЫ. Применение QLF позволило выявлять ранние нарушения гигиены и оценивать качество индивидуальных профилактических мероприятий более точно, чем визуальные методы. Полученные данные подтверждают целесообразность включения QLF-технологии в программу клинического мониторинга стоматологического здоровья воспитанников интернатных учреждений.

Ключевые слова: QLF-диагностика, гигиена полости рта, дети-сироты, профилактика кариеса, Qscan, интернатные учреждения, индекс ИГР-У, детская стоматология

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INTRODUCTION

The preservation of children's oral health remains a critical objective of both clinical and social dentistry, as the prevalence of dental caries and inflammatory periodontal diseases in the pediatric population continues to be high [1–3]. Particular attention is directed toward children living in residential care institutions, where lifestyle characteristics, limited opportunities for individual supervision, and insufficient motivation for oral hygiene contribute to an increased risk of developing dental pathology [4–6].

Traditional methods for assessing oral hygiene status, primarily based on clinical indices, are widely used in practice and have demonstrated their effectiveness. However, their diagnostic value may be reduced due to subjectivity in interpretation and dependence on the clinician's experience, which becomes especially significant during long-term monitoring of large organized groups [7; 8]. In recent years, objective digital technologies have gained increasing importance, enabling improved diagnostic accuracy and standardization of follow-up assessments [9; 10].

One such method is Quantitative Light-Induced Fluorescence (QLF), which is based on the detection of changes in the optical properties of dental hard tissues and bacterial biofilm. This technology allows the identification of early signs of demineralization, quantification of plaque area and density, and monitoring of preventive interventions over time [11; 12]. An additional advantage lies in its visual nature, which facilitates the development of children's conscious attitude toward oral hygiene – an important consideration when working with socially vulnerable populations [13; 14].

The QLF technique is grounded in the ability of dental hard tissues to emit a fluorescent signal when exposed to light of a specific wavelength. When the tooth surface is illuminated with blue light (approximately 405 nm), sound enamel exhibits a uniform greenish-yellow fluorescence, whereas demineralized areas demonstrate reduced fluorescence intensity due to mineral loss [15; 16].

Dental plaque and biofilm containing endogenous porphyrins emit a characteristic reddish-orange fluorescence, allowing both visual and quantitative differentiation between plaque-accumulated areas and healthy tooth surfaces [5]. This optical contrast enables early detection of enamel changes and objective evaluation of oral hygiene quality.

Modern QLF systems, including the Qscan device, are equipped with software that automatically calculates the area and intensity of fluorescence and generates digital reports for longitudinal monitoring. Owing to its high sensitivity, non-invasive nature, and documentation capabilities, the method has become widely adopted in preventive and pediatric dentistry [9; 10; 17].

Another important advantage of QLF is its demonstrative character: visualization of plaque accumulation and demineralization areas enhances children's motivation to maintain proper oral hygiene, which is particularly relevant in residential care settings where individual supervision is limited [2; 18].

Despite the proven clinical utility of QLF, relatively few studies have investigated its application for systematic oral hygiene monitoring among children living in residential institutions [3; 19]. This underscores the need to further explore the role of QLF technology in evaluating the outcomes of comprehensive preventive programs aimed at improving the oral health status of children residing in institutional care settings.

AIM

Aim of the study – to determine the diagnostic value and practical effectiveness of Quantitative Light-Induced Fluorescence (QLF) technology in assessing the oral hygiene status of children living in residential care institutions during the implementation of a comprehensive preventive dental program.

OBJECTIVES OF THE STUDY

1. To conduct a comparative assessment of the baseline oral hygiene status in children residing in residential care institutions and their peers raised in family environments.

2. To evaluate changes in oral hygiene status among children in residential institutions during the implementation of a comprehensive preventive program.

3. To analyze the potential of QLF technology in detecting early signs of impaired oral hygiene and initial alterations in dental hard tissues.

4. To compare QLF diagnostic findings with traditional clinical indicators of oral hygiene status (OHI-S, PMA index).

5. To assess the role of QLF as a motivational tool for improving children's adherence to individual oral hygiene practices.

6. To determine the practical significance of QLF technology for monitoring the effectiveness of preventive interventions in residential child care institutions.

MATERIALS AND METHODS

The clinical component of the study was conducted between 2022 and 2024 at the Department of Therapeutic Dentistry, Institute of Dentistry, Pirogov Russian National Research Medical University, as well as during outreach preventive examinations in residential child care institutions of the Yaroslavl Region (Pereslavl-Zalessky, Solba settlement) and the Moscow Region (Dmitrov). A total of 404 children aged 6–12 years participated in the study.

Participants were divided into two main groups. The observation group consisted of children residing in social care institutions: the shelter at the Nikolo-Solbinsky Convent (n = 73), the Pereslavl-Zalessky Sanatorium Children's Home (n = 69), and the Dmitrov Residential Care Institution for Children with Physical Disabilities (n = 65). The control group included 197 schoolchildren from School No. 1206 (Moscow).

Children in both groups were further stratified into two age subgroups in accordance with World Health Organization recommendations: Subgroup A – children aged 6–9 years; Subgroup B – children aged 10–12 years. Group allocation was performed using random sampling among children who met the inclusion criteria.

Follow-up dental examinations were performed at baseline and during the implementation of the preventive program at 6, 12, and 24 months. Participation of children from residential institutions was based on official authorization from institutional administrations and voluntary assent of the child. In the family-based control group, written informed consent was obtained from parents or legal guardians.

Inclusion criteria:

– age 6–12 years;

– mixed or permanent dentition (fully primary dentition was excluded);

– consent of the child and legal representatives / institutional administration.

Exclusion criteria:

– refusal of participation by the child or legal guardians;

– age below 6 or above 12 years;

– acute diseases or exacerbation of chronic conditions.

During the observation period, children in residential institutions participated in a comprehensive preventive program that included:

– theoretical instruction on individual oral hygiene practices;

– practical training in toothbrushing techniques with supervised performance;

– regular motivational sessions;

– monitoring of the use of personal oral hygiene products (toothbrush, toothpaste, and additional aids).

Children living in family settings did not receive additional preventive interventions beyond routine school-based dental examinations.

Oral hygiene status was assessed using Quantitative Light-Induced Fluorescence (QLF) with the Qscan device. Examinations were performed under standardized clinical conditions in accordance with the manufacturer's recommendations. The area and intensity of plaque fluorescence were analyzed on the vestibular surfaces of the maxillary anterior teeth and premolars.

The following clinical indices were used for comparative assessment:

– the Simplified Oral Hygiene Index (OHI-S; Green–Vermillion modification);

– the PMA index for evaluation of periodontal tissue status.

Each examination required no more than 15 minutes. All data were recorded using a unified protocol, and photographic materials were archived. Statistical analysis was performed using standard methods of variation statistics. Differences were considered statistically significant at $p < 0.05$.

RESULTS

During the 24-month follow-up period, data were obtained reflecting changes in oral hygiene status among children living in residential care institutions and those residing in family settings.

At baseline, children from residential institutions demonstrated significantly higher values of the Simplified Oral Hygiene Index (OHI-S), averaging 2.06 ± 0.22, compared with 1.22 ± 0.09 in the control group of schoolchildren. The PMA index also indicated more pronounced inflammatory changes of the marginal periodontium in institutionalized children (31.4 ± 2.0%) versus 12.5 ± 1.2% in the control group ($p < 0.05$).

Assessment of oral hygiene using the OHI-S at baseline revealed that children from two residential institutions (the shelter at the Nikolo-Solbinsky Convent and the Pereslavl-Zalessky Sanatorium Children's Home) had a mean OHI-S score of 1.81 ± 0.12, corresponding to a fair level of oral hygiene. In contrast, children from the Dmitrov Residential Care Institution demonstrated significantly higher values (2.55 ± 0.27), indicating poor oral hygiene at the start of the study.

After 24 months, marked positive dynamics were observed in the first two institutions within the observation group: the OHI-S decreased to 0.75 ± 0.10, corresponding to a good level of hygiene. In the Dmitrov institution, the OHI-S decreased to 1.77 ± 0.09; although this reflected improvement, the hygiene level remained unsatisfactory.

Analysis of periodontal tissue status using the PMA index demonstrated a high prevalence of gingival inflammation among children deprived of parental care. At baseline, the mean PMA value was 31.4 ± 2.0%, decreasing to 19.7 ± 5.2% after 24 months, indicating a substantial reduction in inflammatory signs and

improvement in oral hygiene skills among institutionalized children.

In the control group, positive dynamics were also observed, though less pronounced. In Subgroup A, the OHI-S decreased from 1.31±0.52 to 1.25±0.19, and the PMA index decreased from 11.31±0.28% to 9.92±0.78%. In Subgroup B, the OHI-S decreased from 1.12±0.32 to 1.07±0.02, while the PMA index decreased from 13.65±0.02% to 12.28±0.66% (Tables 1, 2).

QLF visualization (Qscan device) initially revealed pronounced fluorescent zones in the cervical regions of anterior teeth in 100% of children from residential institutions, confirming a low level of oral hygiene and the presence of early enamel demineralization areas (Fig. 1).

After 24 months, fluorescence intensity in the same regions was substantially reduced, visually confirming a decrease in bacterial plaque accumulation and enamel stabilization. However, abundant soft dental plaque was still detected in 22% of institutionalized children (Fig. 2).

The longitudinal observation demonstrated that the application of QLF technology allows not only objective monitoring of changes in oral hygiene status but also effective use of visualization for educational purposes. Children who participated in motivational sessions involving demonstration of their individual QLF images showed greater engagement and adherence to oral hygiene practices.

Table 1. Simplified oral hygiene index (OHI-S) values of the study participants

Таблица 1. Показатели индекса гигиены ИГР-У участников исследования

Institution	Subgroup	Baseline	6 months	12 months	24 months
Shelter at the Nikolo-Solbinsky Convent	A	1.72±0.90	0.83±0.10	0.56±0.02	0.52±0.12
	B	1.70±0.10	0.74±0.12	0.48±0.02	0.39±0.14
Pereslavl-Zalessky Sanatorium Children's Home, Yaroslavl Region	A	1.98±0.09	1.38±0.14	1.12±0.09	1.14±0.03
	B	1.84±0.14	0.94±0.03	0.92±0.08	0.94±0.03
Dmitrov Residential Care Institution for Children with Physical Disabilities, Moscow Region	A	2.17±0.02	2.12±0.15	1.85±0.90	1.67±0.03
	B	2.93±0.02	2.57±0.15	2.33±0.09	1.87±0.15
School No. 1206, Moscow	A	1.31±0.52	1.29±0.52	1.23±0.31	1.25±0.19
	B	1.12±0.32	1.14±0.62	0.94±0.57	1.07±0.02

Table 2. Assessment of periodontal tissue status (PMA index) in study participants

Таблица 2. Оценка состояния тканей пародонта (PMA) участников исследования

Institution	Subgroup	Baseline	6 months	12 months	24 months
Shelter at the Nikolo-Solbinsky Convent	A	28.10±0.36	16.92±0.72	13.28±0.78	11.52±0.03
	B	24.70±0.92	11.49±0.63	7.08±0.94	6.81±0.51
Pereslavl-Zalessky Sanatorium Children's Home, Yaroslavl Region	A	31.56±0.67	19.14±0.74	17.7±0.29	16.13±0.11
	B	28.90±0.19	17.61±0.66	13.94±0.61	12.64±0.38
Dmitrov Residential Care Institution for Children with Physical Disabilities, Moscow Region	A	38.20±0.47	33.8±0.28	34.10±0.19	34.8±0.35
	B	36.92±0.82	35.08±0.71	35.16±0.45	36.42±0.38
School No. 1206, Moscow	A	11.31±0.28	10.61±0.08	10.08±0.03	9.92±0.78
	B	13.65±0.02	12.28±0.94	11.61±0.67	12.28±0.66

Fig. 1. Identification of dental plaque at baseline using the Qscan device

Рис. 1. Идентификация зубного налета в начале исследования при помощи аппарата Qscan

Fig. 2. Identification of dental plaque after 24 months of follow-up using the Qscan devicею

Рис. 2. Идентификация зубного налета спустя 24 месяца исследования при помощи аппарата Qscan

The obtained results are consistent with both international and domestic studies confirming the high sensitivity of the QLF method in monitoring the condition of dental hard tissues and the quality of oral hygiene. Unlike subjective indices, QLF technology enables detection of minimal changes in biofilm structure, which supports its integration into preventive programs in organized child populations.

DISCUSSION

The comprehensive study conducted among children residing in residential care institutions and schoolchildren living in family settings demonstrated statistically significant differences in baseline dental status between the groups. Institutionalized children exhibited higher values of the Simplified Oral Hygiene Index (OHI-S) and the PMA index, as well as a greater area of fluorescent plaque according to QLF assessment, reflecting insufficient individual oral hygiene and more pronounced inflammatory changes in periodontal tissues.

Implementation of a comprehensive preventive program, including oral hygiene education, regular motivational supervision, and monitoring using QLF technology, resulted in a significant improvement in the oral hygiene status of children from residential institutions. After 24 months of follow-up, a statistically significant reduction in OHI-S and PMA values was recorded ($p < 0.05$), along with a 78% decrease in plaque fluorescence intensity, indicating the high effectiveness of the proposed intervention.

Application of Quantitative Light-Induced Fluorescence (QLF) provided an objective assessment of oral hygiene status and enabled detection of even minimal changes in the structure of the bacterial biofilm. Visualization of plaque accumulation and demineralization areas enhanced the educational impact of preventive measures and strengthened children's motivation to adhere to individual oral hygiene practices.

The findings confirm the high sensitivity and reproducibility of the QLF method for longitudinal monitoring of oral health status. Integration of this technology with conventional index-based assessments expands the diagnostic capabilities of the clinician and improves the accuracy of clinical interpretation at early stages of pathological development.

CONCLUSION

QLF technology may be regarded as a promising tool for integration into routine preventive dental examinations of children residing in residential care institutions, as it combines high diagnostic value, safety, visual clarity, and educational potential.

Incorporation of this method into pediatric preventive dentistry practice can enhance the quality of clinical monitoring and improve the effectiveness of oral hygiene education programs, particularly within socially vulnerable populations.

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Aleksey A. Ogloblin – a significant contribution to the idea and design of the study.

Irina A. Nikolskaya – final approval of the version of the article for publication.

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Original Research

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Application of an implant-supported provisional crown in the esthetically critical zone in prosthodontic clinical practice

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Abstract

AIM. To evaluate the attitude of practicing prosthodontists toward the use of implant-supported provisional crowns in the esthetic zone and to identify the main clinical challenges and complications associated with temporary restorations.

MATERIALS AND METHODS. A pilot survey study was conducted using a structured electronic questionnaire consisting of nine questions. A total of 120 prosthodontists with more than 10 years of clinical experience in implant-supported restorations participated. Forty percent worked in public dental institutions and 60% in private clinics. The survey analyzed the frequency of provisional crown use, treatment protocols, application of digital technologies, and soft tissue complications.

RESULTS. Sixty percent of respondents routinely use provisional crowns in the esthetic zone. Immediate implantation is performed by 86% of clinicians. However, 66.7% reported soft tissue complications, including gingival recession, loss of interdental papillae, and changes in gingival contour and color. Digital workflows are implemented by 66.7% of clinicians, while only 20% possess 3D crown modeling skills. Notably, 73% of respondents do not follow a standardized prosthetic protocol in the esthetic zone.

CONCLUSIONS. Implant-supported provisional crowns represent a critical component of esthetic rehabilitation. The absence of a unified treatment protocol highlights the need for evidence-based clinical guidelines. The integration of digital technologies and 3D modeling enhances treatment personalization and improves predictability of esthetic outcomes.

Keywords: esthetics, implant-supported provisional crown, restoration in the esthetically critical zone

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Применение провизорной коронки с опорой на имплантат в эстетически значимой зоне в практике стоматолога-ортопеда

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Резюме

ЦЕЛЬ. Оценить отношение практикующих стоматологов-ортопедов к применению провизорной коронки с опорой на имплантат в эстетически значимой зоне, а также выявить основные клинические проблемы и осложнения, возникающие при использовании временных конструкций.

МАТЕРИАЛЫ И МЕТОДЫ. Проведено пилотное социологическое исследование с использованием электронной анкеты, включающей 9 вопросов. В опросе приняли участие 120 стоматологов-ортопедов со стажем работы более 10 лет, специализирующихся на протезировании с опорой на имплантаты. Из них 40% работали в муниципальных учреждениях, 60 % – в частных клиниках. Анализировали частоту применения временных конструкций, предпочтения протоколов лечения, использование цифровых технологий и характер осложнений в области мягких тканей.

РЕЗУЛЬТАТЫ. Большинство респондентов (60 %) применяют временные коронки в эстетически значимой зоне. Одномоментную имплантацию используют 86 % клиницистов. При этом 66,7 % врачей

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отмечают осложнения в области мягких тканей (рецессия десны, утрата межзубных сосочков, изменение цвета и формы десны). Цифровой протокол применяют 66,7 % опрошенных, однако только 20 % владеют навыками 3D-моделирования коронок. У 73 % респондентов отсутствует единый протокол протезирования в зоне улыбки.
ВЫВОДЫ. Провизорная коронка является важным элементом реабилитации пациентов в эстетически значимой зоне. Отсутствие стандартизированного протокола лечения требует разработки клинических рекомендаций. Внедрение цифровых технологий и 3D-моделирования расширяет возможности индивидуализации лечения и повышения предсказуемости эстетических результатов.

Ключевые слова: эстетика, временная коронка с опорой на имплант, реставрация в эстетически значимой зоне

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INTRODUCTION

The scientific literature reports favorable outcomes in the management of anterior edentulous defects through dental implant therapy [1]. Contemporary treatment protocols require comprehensive aesthetic, functional, and social rehabilitation of the patient from the moment of tooth extraction, throughout osseointegration, and until placement of the definitive crown [2]. Implant-supported provisional prostheses are recommended for defects located in the anterior region or in cases of complete edentulism of the jaws, irrespective of the patient's age or professional activity [3; 4]. The fabrication techniques, component characteristics, and selection criteria for provisional prosthetic restorations – determined by specific clinical scenarios, as well as the potential complications and risks associated with provisional crowns – remain highly relevant issues and warrant further investigation [5; 6].

This article presents the results of a pilot study aimed at assessing practicing prosthodontists' attitudes toward the use of implant-supported provisional restorations in patients requiring reconstruction in the esthetically critical zone of the jaw, as well as the complications and challenges arising from the application of such prosthetic designs [7].

MATERIALS AND METHODS

The study was conducted using a specifically designed electronic questionnaire developed for prosthodontists with expertise in implant dentistry. The survey consisted of nine questions aimed at evaluating clinicians' perspectives regarding the rationale for fabricating provisional restorations, their clinical application in the esthetically critical zone, as well as their perceived advantages and limitations.

The survey targeted practicing prosthodontists specializing in implant-supported restorations with more than 10 years of professional experience. A total of 120 respondents participated in the study. Dentists employed in public dental clinics accounted for 40% (50/120) of the sample, whereas 60% (70/120) were affiliated with privately owned dental practices.

RESULTS

Although current treatment protocols for patients presenting with anterior bounded edentulous defects recommend the use of provisional crowns, this approach has not been formally established as a standardized treatment modality. The availability of a dedicated specialist position and appropriate technological infrastructure within a clinical setting enables the fabrication of implant-supported provisional prosthetic crowns during the patient's rehabilitation period.

Alterations of the peri-implant soft tissues may occur as a consequence of inflammatory processes or may be iatrogenic in nature, resulting from surgical and prosthetic interventions [4].

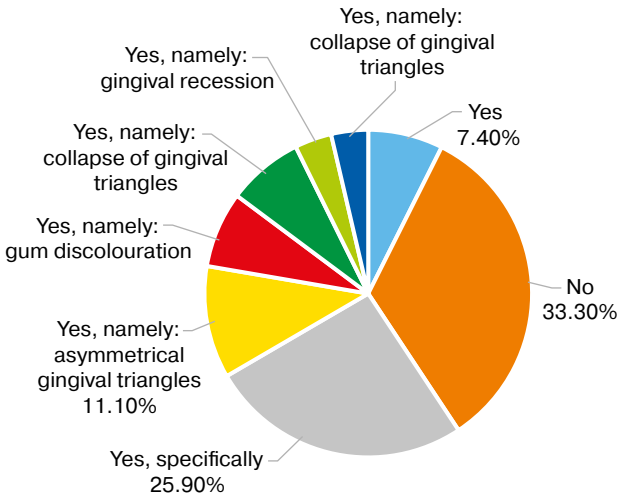

Fig. 1. Distribution of respondents' answersto the question: Do your patients have problems related to the condition of the soft gum tissue in the implant area, and if so, what are they? (27 responses)

Рис. 1. Распределение ответов респондентов на вопрос: бывают ли у ваших пациентов проблемы, связанные с состоянием мягких тканей десны в области имплантатов, и если да, то какие? (27 ответов)

According to the survey findings, 33.3% of respondents reported no experience with soft tissue complications in the area of implant-supported crowns. However, 66.7% of clinicians indicated the occurrence of the following complications:

– asymmetry of the interdental papillae (gingival triangles);

– changes in gingival color and contour;

– loss of the interdental papilla;

– marginal gingival recession.

These complications ultimately contribute to an esthetically unsatisfactory treatment outcome.

Rehabilitation protocols for the esthetically critical zone require the use of a provisional restoration during the treatment period. The survey data indicate that this protocol is implemented in routine clinical practice by a majority of clinicians, with 60% of the surveyed dentists reporting its application.

The data obtained from the survey provide insight into the challenges encountered when managing cases in the esthetically critical zone without the fabrication of a provisional crown. Although structural changes within the dentoalveolar system in the area of the defect are individualized and patient-specific, the absence of a provisional restoration consistently contributes to the development of unfavorable clinical outcomes.

According to the survey results, removable provisional restorations are used in the esthetically critical zone to a comparable extent. However, 50% of the respondents consider the use of removable provisional prostheses to be unjustified, noting that their presence may contribute to complications affecting both soft and hard tissues.

The immediate (one-stage) implant placement protocol in the esthetically critical zone is employed by the majority of clinicians (86% of respondents), which is justified by the following advantages:

– reduction in the number of surgical interventions;

– shortening of treatment duration and faster restoration of the dental arch defect;

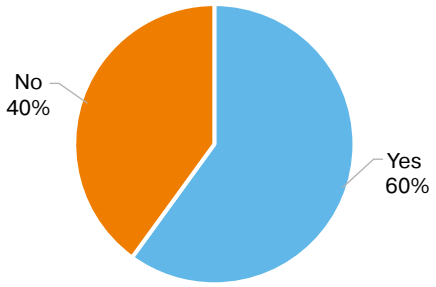

Fig. 2. Distribution of respondents' answers to the question: Do you use provisional prosthetic crowns for implant-supported restorations in the esthetically critical zone? (30 responses)

Рис. 2. Распределение ответов респондентов на вопрос: применяете ли вы временные ортопедические коронки при протезировании на имплантатах в эстетически важной зоне? (30 ответов)

Fig. 4. Distribution of respondents' answers to the question: Do you use removable provisional crowns during implant treatment in the esthetically critical zone? (30 responses)

Рис. 4. Распределение ответов респондентов на вопрос: применяете ли вы съемные временные коронки во время имплантологическом лечении пациента в эстетически важной зоне? (30 ответов)

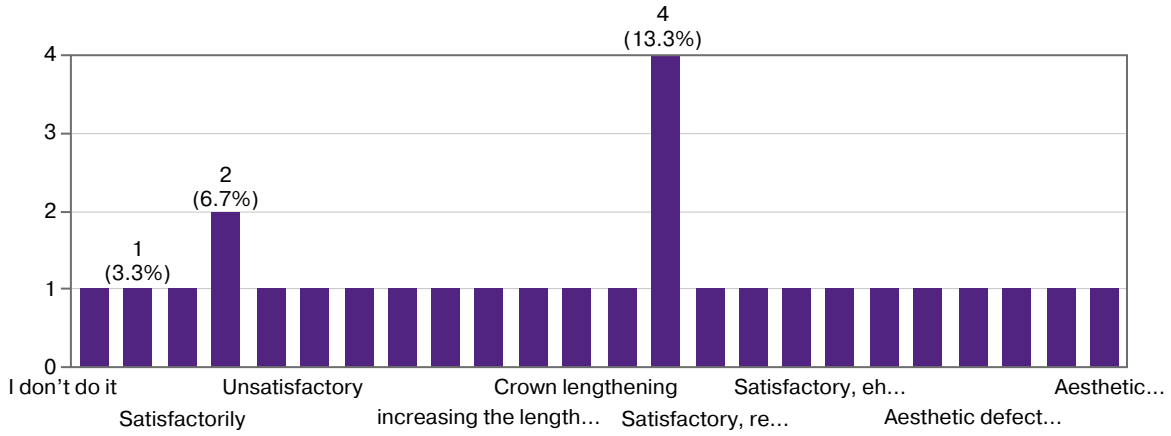

Fig. 3. Distribution of respondents' answers to the question: How do you evaluate the results of prosthetics on implants without the temporary crown stage? What problems arise? (30 responses)

Рис. 3. Распределение ответов респондентов на вопрос: как вы оцениваете результат протезирования на имплантатах без этапа временных коронок? Какие проблемы возникают? (30 ответов)

– ability to position the dental implant in an axially optimal, prosthetically guided orientation;

– minimization of patient stress during treatment.

Conversely, 14% of clinicians do not adhere to the immediate implant placement protocol for anterior edentulous cases due to insufficient bone and soft tissue volume, difficulty achieving primary stability, and factors that may compromise implant survival and long-term esthetic outcomes.

The survey revealed that 73% of clinicians do not follow a defined protocol for implant-supported prosthetic rehabilitation in the esthetically critical zone. This underscores the need for formalized guidelines for the fabrication of implant-supported restorations in the smile zone, developed with consideration of both patient-specific clinical factors and crown fabrication techniques.

The majority of clinicians (66.7% of respondents) adhere to a digital protocol for treatment and fabrication of prosthetic restorations. This approach enables precise treatment planning, increases procedural accuracy and minimally invasive intervention in the oral cavity, enhances the frequency of favorable clinical outcomes, and allows longitudinal monitoring of treatment stability through the maintenance of a digital database of patients' intraoral scan projects.

In contrast, 33.3% of respondents rely on conventional analog methods. In these cases, clinical experience and available technological resources permit the fabrication of hybrid prosthetic constructions.

Only 20% of clinicians possess skills in 3D crown modeling. The development and refinement of CAD/CAM technology enable the dentist to design both provisional and definitive implant-supported restorations while accounting for all parameters of the defect within the dentoalveolar system. Digital modeling allows clinicians to monitor changes in soft tissue architecture throughout treatment via intraoral scanning. The acquired data are cumulative, permitting repeated milling of the crown at each treatment stage without additional intraoral interventions.

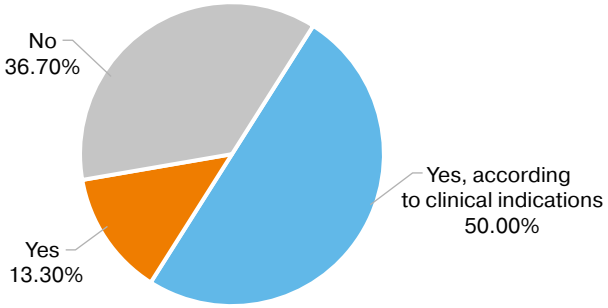

Fig. 5. Distribution of respondents' answers to the question: Do you use an immediate (one-stage) implant placement protocol in the anterior region of the jaw? (30 responses)

Рис. 5. Распределение ответов респондентов на вопрос: применяете ли вы одномоментный протокол установки имплантата в переднем отделе челюсти? (30 ответов)

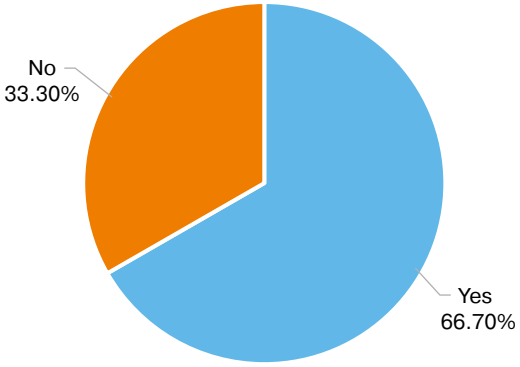

Fig. 7. Distribution of respondents' answers to the question: Do you use a digital protocol for implantological treatment? (30 responses)

Рис. 7. Распределение ответов респондентов на вопрос: используете ли вы цифровой протокол имплантологического лечения? (30 ответов)

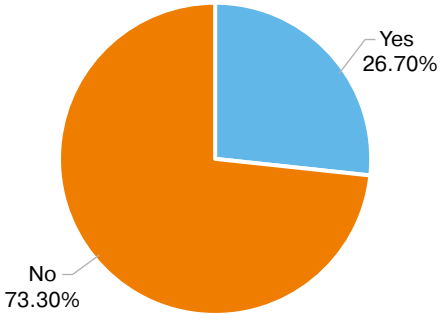

Fig. 6. Distribution of respondents' answers to the question: Do you follow a specific prosthetic protocol for implant-supported restorations in the esthetic zone of the jaw? (30 responses)

Рис. 6. Распределение ответов респондентов на вопрос: применяете ли вы определенный шаблон протезирования на имплантатах в эстетической зоне челюсти? (30 ответов)

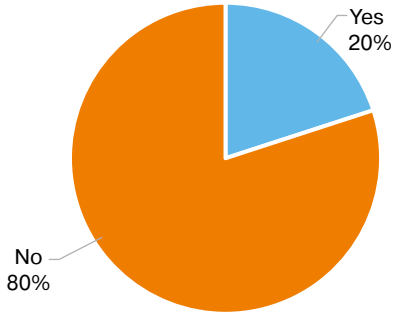

Fig. 8. Distribution of respondents' answers to the question: Do you have modeling skills in the exocad software product or other similar programs? (30 responses)

Рис. 8. Распределение ответов респондентов на вопрос: владеете ли вы навыками моделирования в программном продукте ExoCAD или других аналогичных программах? (30 ответов)

CONCLUSION

Based on the results of the survey, the following conclusions can be drawn:

1. Provisional prosthetic restorations constitute an essential component in the fabrication of implant-supported constructions.

2. To date, there is no universally accepted treatment protocol for the esthetically critical zone, nor are there standardized guidelines regarding the anatomical characteristics of artificial crowns recommended for preserving the morphology of hard and soft gingival tissues.

3. The advancement of 3D technologies provides the opportunity to implement an individualized approach in each clinical case.

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