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The effect of computer aided navigation techniques on the precision of endodontic access cavities: A systematic review and meta-analysis

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Abstract

AIM. To assess the impact of computer-assisted navigation techniques on the precision of endodontic access cavity preparation.

MATERIALS AND METHODS. A systematic review was conducted following the PRISMA 2020 guidelines. Articles were searched for online using electronic databases, including Scopus, PubMed, Cochrane, and Web of Sciences. The success rate of root canal location using computer-aided navigation techniques in root canal access cavity preparation, along with the time required for cavity preparation and the extent of tooth substance removal were assessed in this review. After eliminating duplicate articles and applying inclusion criteria, 10 studies were chosen for analysis.

RESULTS. Accuracy in location of root canal is significantly higher in the static and dynamic navigation group compared to the conventional group. Also, computer-aided static and dynamic navigation techniques removed significantly less tooth substance compared to conventional groups. Moreover, static navigation technique took significantly less time for access cavity preparation than conventional while there was no significant difference in the time taken for access cavity preparation between dynamic navigation technique and conventional technique.

CONCLUSION. The root canal access cavities prepared using static and dynamic computer-aided navigation techniques are highly precise in detecting the root canal system, require less tooth substance removal, and take less time to complete.

Keywords: computer-aided navigation, dynamic navigation, guided access opening, static navigation

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Влияние технологий компьютерной навигации на точность доступа в полость зуба при эндодонтическом лечении: систематический обзор и мета-анализ

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Резюме

ЦЕЛЬ. Оценить влияние компьютерных навигационных технологий на точность подготовки полости доступа в корневой канал.

МАТЕРИАЛЫ И МЕТОДЫ. Был проведен систематический обзор в соответствии с руководящими принципами PRISMA 2020. Поиск статей был проведен в электронных базах данных, включая Scopus, PubMed, Cochrane и Web of Sciences. В данном обзоре оценивались успешность нахождения корневого канала с использованием компьютерной навигации при подготовке полости доступа в канал, а также время, необходимое для подготовки полости, и объем удаляемого зубного вещества. После устранения дублирующихся статей и применения критериев включения для анализа было отобрано 10 исследований.

РЕЗУЛЬТАТЫ. Точность нахождения корневого канала значительно выше в группе со статической и динамической навигацией по сравнению с традиционной методикой. Также компьютерные статические

и динамические навигационные технологии удаляли значительно меньшее количество зубного вещества по сравнению с традиционными методами. Более того, статическая навигационная техника заняла значительно меньше времени для подготовки полости доступа, чем традиционная методика, тогда как значительной разницы во времени между динамической навигацией и традиционной методикой не было.
ВЫВОД. Полости доступа в корневой канал, подготовленные с использованием статической и динамической компьютерной навигации, обладают высокой точностью в обнаружении системы корневых каналов, требуют меньшего удаления зубного вещества и занимают меньше времени на выполнение.

Ключевые слова: компьютерная навигация, динамическая навигация, направленное открытие доступа, статическая навигация

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INTRODUCTION

The goals of root canal therapy (RCT) include achieving precise access opening, as well as proper biomechanical shaping, cleaning and three-dimensional(3D) filling of the entire root canal system (RCS) in order to ensure a hermetic seal [1]. Failing to meet these objectives can result in poor treatment outcomes. Of all these steps, preparing root canal access cavities is the crucial first step in successful endodontic treatment. However, it is also one of the most challenging aspects, often considered the foundation upon which all other endodontic procedures depend. Traditionally, this is done freehand based on the operator's clinical experience and understanding of the tooth morphology, as dictated by the extent of the lesion and the tooth structure already lost [2]. Anatomical features of the pulp chamber as described by the principles of Krasner and Rankow, are used to locate the canal orifices, often aided by dental loupes or dental operating microscope to reduce iatrogenic errors [3].

Negotiating canals and creating a glide path after this step is easier and less cumbersome, however, in certain conditions, the entry into the canal orifice and its subsequent pre-flaring to achieve a glide path, due to a condition like obliteration of the pulpal chamber or of the canal itself, can extend treatment times and could also lay the groundwork for iatrogenic errors. Technical failures, such as missing canals, weakened tooth structure, tooth perforations or transportation of canal can lead to a compromised outcome, a reduction in the time to failure and may necessitate tooth extraction sooner rather than later. In cases where the tooth is a strategic one or the systemic condition of the patient precludes extraction, the extraction of teeth could be disastrous for the patient, and it demands that heroic efforts be made to locate the obliterated canals and treat them [3; 4].

Cone beam computed tomography (CBCT) is useful in such complex cases where conventional 2D radiographs fail to provide the necessary information to gain access into the calcified chamber and canal. CBCT on the other hand is able to provide a clear 3D representation of the tooth and is a more reliable method for understanding the root canal system and negotiating canals. When comparing treatment done with traditional radiographs vs. that done with CBCT, the latter was found to have greater accuracy and lesser iatrogenic errors. The availability of 3D data enables the operator to better understand the morphology and assists in creating a mental 3D map of the root canal system [5].

Recently, the concept of guided endodontics has been introduced, where 3D data can be integrated with the surface information of teeth, obtained by using an intraoral scanner to design and 3D print a guide for access cavity preparation. Preliminary studies have demonstrated a high accuracy with this method, comparing the actual drilled path to the planned treatment without being affected by the variable of the operator's skill. Furthermore, using a guide for the procedure reduces chair time. This innovative approach could assist clinicians during treatments, minimize unnecessary removal of tooth structure, avoid complications, and consequently enhance the prognosis of the treatment [1].

Guided endodontics can be classified into static and dynamic types. The static approach involves creating 3D printed templates using CBCT images, surface scans, and virtual imaging software. The dynamic navigation system (DNS) employs a computer-assisted guided technology originally developed for precise implant placement. This system provides real-time feedback to the clinician about the drill path being prepared during treatment. It employs multiple cameras and motion tracking devices connected to both the dental handpiece and the patient, constantly comparing the actual drill path with the planned one using specific software on the CBCT images of teeth [6]. Numerous clinical applications of computer-assisted navigation in endodontics are emerging, highlighting the need for a systematic review and quality assessment of the literature to better understand this new treatment concept.

This systematic review aims to assess the impact of computer-assisted navigation techniques on the precision of endodontic access cavity preparation. It tests the null hypothesis (H0) that there is no significant difference in the effectiveness of different computer-assisted navigation techniques regarding the precision of endodontic access cavities.

MATERIALS AND METHODS

1. Study design

This systematic review was conducted following the PRISMA guidelines. It is registered with the number CRD42024579912 in PROSPERO. The review adhered to the PRISMA 2020 Checklist and was carried out in line with current recommendations for endodontic systematic reviews and meta-analyses.

PICO Question: What is the impact of computer-aided navigation techniques on the precision of root canal location, the time required, and the amount of tooth substance removed during endodontic access cavity preparation?

– *Population*: Teeth undergoing endodontic access cavity preparation with the assistance of computer-aided navigation techniques.

– *Intervention*: Use of computer-aided navigation techniques for performing endodontic access cavities.

– *Comparison*: Endodontic access cavities performed using either static navigation (SN) or dynamic navigation (DN) systems.

– *Outcome*: The precision of canal location, the time taken to complete the procedure, and the extent of tooth substance removed during endodontic access cavity preparation.

An electronic search was carried out using the following databases: PubMed, Scopus, Cochrane, and Web of Sciences. The search assessed all the literature published internationally till December 2023. Thirteen medical subject heading (MeSH) terms were included in the search: “endodontic access cavity”; “conservative access cavity”; “guided access cavity”; “navigation access cavity”; “ninja access cavity”; “minimally invasive access cavity”; “static navigation”; “dynamic navigation”; “cone beam navigation”; “guided access opening”; “computer-aided navigation”.

(a) Eligibility criteria

Inclusion criteria:

1) articles published in the English language or those having a summary in English;
2) case series;
3) randomized controlled trials;
4) randomized experimental trials.

[Studies in which endodontic access cavities were performed using computer-aided techniques (either static or dynamic navigation techniques) were included.]

Exclusion criteria:

1) clinical case report < 3 cases;
2) systematic reviews;
3) in vivo studies;
4) abstracts;
5) letters to editors.

(b) Data collection and data items

Two authors conducted an initial comprehensive screening to identify articles meeting the eligibility criteria. Full-text articles were retrieved for further evaluation if they met the inclusion criteria. Articles with insufficient data were excluded. Discrepancies were resolved through discussion until agreement was reached between the two primary authors.

(c) Data extraction

A Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, Washington) was specifically designed to document inclusion and exclusion criteria, along with detailed reasons for data extraction processing. Two authors comprehensively selected the studies, and any discrepancies were resolved through discussion to reach a consensus.

2. Flow diagram

10 articles were selected after the selection process for final qualitative and quantitative analysis which has been described in the following flow diagram (Fig. 1).

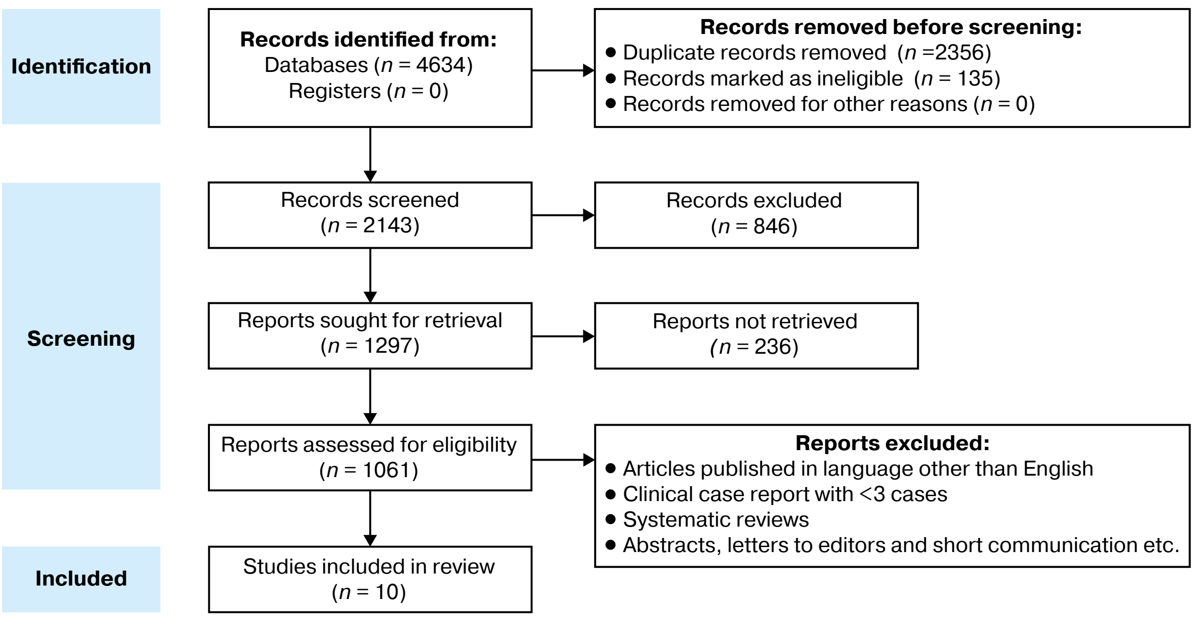

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow diagram

Рис. 1. Диаграмма потока согласно Принципам предпочтительной отчетности для систематических обзоров и мета-анализов (PRISMA)

RESULTS

1. Methodological quality assessment of included studies

Methodological quality assessment of the selected studies was done using Jadad scale and Delphi scale as given below.

(a) Jadad Scale

The Jadad was used to assess the methodological quality of the selected in clinical studies to evaluate risk of bias. This scale comprises five items that assess randomization, researcher and patient blinding, and a description of losses during follow-up, resulting in a final score of 0–5, with scores less than 3 being deemed low quality (Table 1).

(b) Delphi Scale

The Delphi technique, developed by the RAND Corporation, is an iterative, multistage consensus process where individual opinions are combined into a group consensus. In Delphi studies, several rounds of surveys (typically two or three) are conducted, allowing for anonymous feedback and adjustments to ratings with the goal of reaching a consensus. This method is widely used for developing clinical practice guidelines and quality indicators, as well as in creating reporting guidelines and criteria for the appropriateness of interventions or core outcome sets (COS) (Table 2).

Table 1. Methodological quality assessment using the Jadad scale

Таблица 1. Оценка методологического качества с использованием шкалы Джадад

Author (Year)	Is the study randomized?	Is the Study Double-Blinded?	Were withdrawals and dropouts described?	Adequate method of randomization?	Appropriate blinding method?	Score
Buchgreiz et al. (2019)	0	0	0	0	0	0
Emanuele Ambu et al. (2023)	NA	NA	NA	NA	NA	NA
Moreira Maia et al. (2019)	NA	NA	NA	NA	NA	NA
Van der Meer et al. (2016)	NA	NA	NA	NA	NA	NA
Wojciech Dabrowski et al. (2022)	NA	NA	NA	NA	NA	NA
Xioxia Yang et al. (2024)	NA	NA	NA	NA	NA	NA

Table 2. Methodological quality assessment as per Delphi scale

Таблица 2. Оценка методологического качества согласно шкале Дельфи

Issue	Author (Year)					
	Buchgreiz et al. (2019)	Emanuele Ambu et al. (2023)	Moreira Maia et al. (2019)	Van der Meer et al. (2016)	Wojciech Dabrowski et al. (2022)	Xioxia Yang et al. (2024)
1) Treatment allocation						
a) Was a method of randomization performed?	No	NA	NA	NA	NA	NA
b) Was the treatment allocation concealed?	No	NA	NA	NA	NA	NA
2) Were the eligibility criteria specified?	Yes	NA	NA	NA	NA	NA
3) Was the outcome assessor blinded?	No	NA	NA	NA	NA	NA
4) Was the care provider blinded?	No	NA	NA	NA	NA	NA
5) Was the patient blinded?	No	NA	NA	NA	NA	NA
6) Were point estimates and measures of variability presented for the primary outcome measures?	Don't know	NA	NA	NA	NA	NA
7) Did the analysis include an intention-to treat analysis?	Don't know	NA	NA	NA	NA	NA

Table 3. Qualitative analysis of articles forming part of the systematic review for accuracy to locate root canals

Таблица 3. Качественный анализ статей, являющихся частью систематического обзора по точности нахождения корневых каналов

Author (Year)	Control group		Experimental group	
	Event	Total	Event	Total
Sameer Jain et al. (2020)	18	20	19	20
Connert et al. (2021)	35	36	35	36
Aishwarya Vasudevan et al. (2023)	20	21	21	21
Gianluca Gambarini et al. (2020)	10	10	10	10
Omid Dianat et al. (2020)	30	30	30	30
Marco Antonio et al. (2020)	18	20	20	20
Jana Kostunov et al. (2020)	30	30	28	30
Mili Rohra et al. (2023)	11	11	11	11
Dan Wang et al. (2021)	11	11	10	10

2. Qualitative analysis

10 articles were included out of which 9 were experimental trials [7–14] and 1 was an ex-vivo study [15]. Some of the studies compared conventional access with static navigation [7; 10; 12–16] while others compared conventional access with dynamic navigation [8; 9; 11; 12]. Most studies showed sample size greater than 10, even though they ranged as high as 72 in Connert et al. study [9] (Table 3–5).

3. Quantitative analysis

1. Success rate of computer-aided static navigation compared to conventional technique: All the studies included in the meta-analysis reported the success rate of computer-aided static navigation to be 85.47% (95% confidence interval = 0.09–0.66%) with high heterogeneity (*Z* test = 2.80, p = 0.005, and *I* = 53%) suggesting that the accuracy in location of root canal is significantly higher in the static

Table 4. Qualitative analysis of articles forming part of the systematic review for tooth substance removal during access cavity preparation

Таблица 4. Качественный анализ статей, являющихся частью систематического обзора по удалению зубного вещества при подготовке полости доступа

Author (Year)	Study Type	Sample(n)	Measurement procedure	Computer-aided Navigation technique	Tooth-substance loss
Connert et al. (2019)	In vitro	48	Clinical and Radiographical	Control	49.9 mm^3
				SN	9.8 mm^3
Marco Antonio et al. (2020)	Ex vivo	20	Clinical and Radiographical	Control	Incisors: 31.667 mm^3
					Molars: 62.526 mm^3
				SN	Incisors: 26.523 mm^3
					Molars: 45.677 mm^3
Sameer Jain et al. (2020)	In vitro	40	Clinical and Radiographical	Control	40.7 mm^3
				DNS	27.2 mm^3
Connert et al. (2021)	In vitro	72	Clinical and Radiographical	Control	29.7 mm^3
				DN	10.5 mm^3
Aishwarya Vasudevan et al. (2023)	In vitro	42	Clinical and Radiographical	Control	66.87 mm^3
				SN	19.39 mm^3
Jana Kostunov et al. (2020)	In vitro	60	Clinical and Radiographical	Control	Incisor: 16.1 mm^3
					Premolar: 44.2 mm^3
					Molar: 99.3 mm^3
				SN	Incisor: 5.3 mm^3
					Premolar: 14.4 mm^3
					Molar: 25.2 mm^3
Omid Dianat et al. (2020)	In vitro	60	Clinical and Radiographical	Control	CEJ: 1.55 mm
					End drilling point: 1.47 mm
				DN	CEJ: 1.06 mm
					End drilling point: 1.18 mm
Mili Rohra et al. (2023)	In vitro	22	Clinical and Radiographical	Control	27.64 mm^3
				SN	11.73 mm^3
Dan Wang et al. (2021)	In vitro	30	Clinical and Radiographical	TEC	81.78 mm^3
				SN	42.39 mm^3

Table 5. Qualitative analysis of articles forming part of the systematic review for time taken to prepare access cavity

Таблица 5. Качественный анализ статей, являющихся частью систематического обзора по времени, затраченному на подготовку полости доступа

Author (Year)	Study Type	Sample(n)	Measurement procedure	Computer-aided Navigation technique	Time taken
Connert et al. (2019)	In vitro	48	Clinical and Radiographic	Control	21.8 min
				SN	11.3 min
Sameer Jain et al. (2020)	In vitro	40	Clinical and Radiographical	Control	424.8 s
				DN	136.1 s
Connert et al. (2021)	In vitro	72	Clinical and radiographical	Control	193 s
				DN	195 s
Aishwarya Vasudevan et al. (2023)	In vitro	42	Clinical and Radiographical	Control	28.14 min
				SN	16.79 min
Gianluca Gambarini et al. (2020)	In vitro	20	Clinical and Radiographical	Control	12.2 s
				DN	11.5 s
Omid Dianat et al. (2020)	In vitro	60	Clinical and Radiographical	Control	405 s
				DN	227 s

navigation group compared to the conventional group, with an overall Odd's ratio of 0.24 (p = 0.005) (Fig. 2).

2. Success rate of computer-aided dynamic navigation compared to conventional technique: Four studies included reported the success rate of 96.5% (95% confidence interval = 0.09–0.66%) with high heterogeneity (Z test = 2.80, p = 0.005, and I = 53%) which suggests that the accuracy in location of root canal is significantly higher in the dynamic navigation group compared to the conventional group, with an overall Odd's ratio of 0.24 (p = 0.005) (Fig. 3).

3. Amount of tooth-substance removal in computer-aided static navigation compared to conventional technique: All the studies included in the meta-analysis showed the overall mean difference between the computer-aided static navigation and conventional groups to be −50.28 [95% Confidence Interval (CI): −52.43, −48.14] with high variability of heterogeneity. (Z test = 45.98, p = <0.00001, and I^2 = 99%) which indicates that static navigation methods significantly reduce tooth substance removal compared to traditional techniques, with the results being statistically significant and likely robust despite some variability among studies (Fig. 4).

4. Amount of tooth-substance removal in computer-aided static navigation compared to conventional technique: Three studies included in the meta-analysis showed the overall mean difference between the computer-aided dynamic navigation and conventional groups to be −0.71 [95% Confidence Interval (CI): −0.92, −0.51] with high variability of heterogenity.

Study or Subgroup	Control Events	Control Total	Experimental Events	Experimental Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Aishwarya Vasudevan et al. 2023	20	21	21	21	8.5%	0.32 [0.01, 8.26]
Connert et al. 2019	10	24	22	24	74.6%	0.06 [0.01, 0.34]
Dan Wang et al. 2021	11	11	10	10		Not estimable
Jana Kostunov et al. 2020	30	30	28	30	2.7%	5.35 [0.25, 116.31]
Marco Antonio et al. 2020	18	20	20	20	14.2%	0.18 [0.01, 4.01]
Mili Rohra et al. 2023	11	11	11	11		Not estimable
Total (95% CI)		**117**		**116**	**100.0%**	**0.24 [0.09, 0.66]**
Total events	100		112			

Heterogeneity: Chi² = 6.37, df = 3 (p = 0.09); I² = 53%
Test for overall effect: Z = 2.80 (p = 0.05)

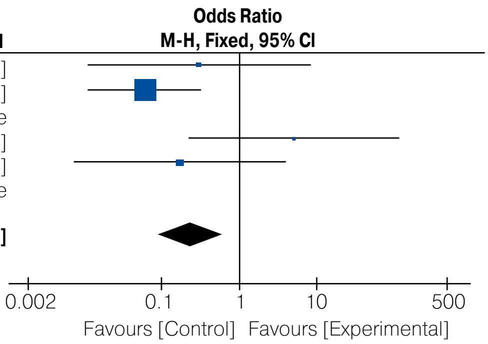

Fig. 2. Forest plot of root canal location success rate between computer-aided static navigation compared to conventional technique

Рис. 2. Лесной график (Forest plot) сравнительного успеха нахождения корневого канала между компьютерной статической навигацией и традиционной техникой

Study or Subgroup	Control Events	Control Total	Experimental Events	Experimental Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Gianluca Gambarini et al. 2020	18	20	20	20	14.2%	0.18 [0.01, 4.01]
Connert et al. 2021	20	21	21	21	8.5%	0.32 [0.01, 8.26]
Omid Dianat et al. 2020	30	30	28	30	2.7%	5.35 [0.25, 116.31]
Omid Dianat et al. 2 2020	10	24	22	24	74.6%	0.06 [0.01, 0.34]
Total (95% CI)		**95**		**95**	**100.0%**	**0.24 [0.09, 0.66]**
Total events	78		91			

Heterogeneity: Chi² = 6.37, df = 3 (p = 0.09); I² = 53%
Test for overall effect: Z = 2.80 (p = 0.05)

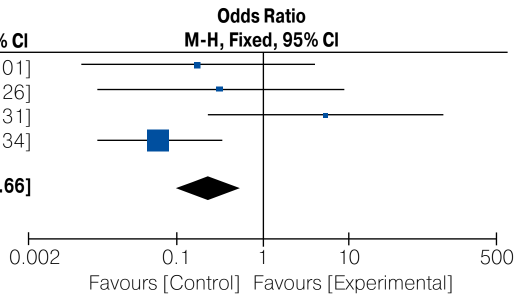

Fig. 3. Forest plot of root canal location success rate between computer-aided dynamic navigation compared to conventional technique

Рис. 3. Лесной график (Forest plot) сравнительного успеха нахождения корневого канала между компьютерной динамической навигацией и традиционной техникой

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Aishwarya Vasudevan et al. 2023	19.39	2.76	21	66.87	12.54	21	15.2%	-47.48 [-52.97, -41.99]
Connert et al. 2019	9.80	1.64	24	49.90	8.97	24	34.5%	-40.10 [-43.75, -36.45]
Dan Wang et al. 2021	42.39	81.78	15	8.17	14.77	15	0.3%	34.22 [-7.84, 76.28]
Jana Kostunov et al. 2020	25.20	4.80	10	99.30	3.10	10	36.6%	-74.10 [-77.64, -70.56]
Marco Antonio et al. 2020	45.677	7.14	5	62.526	11.18	5	3.4%	-16.85 [-28.48, -5.22]
Mili Rohra et al. 2023	11.73	1.85	11	27.64	11.534	11	10.0%	-15.91 [-22.70, -9.12]
Total (95% CI)			**86**			**86**	**100.0%**	**-50.28 [-52.43, -48.14]**

Heterogeneity: Chi² = 350.38, df = 5 (p < 0.00001); I² = 99%
Test for overall effect: Z = 45.98 (p < 0.00001)

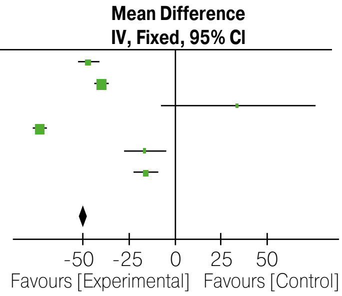

Fig. 4. Forest plot of amount of tooth-substance removal in computer-aided static navigation compared to conventional technique

Рис. 4. Лесной график (Forest plot) объема удаления зубного вещества при компьютерной статической навигации по сравнению с традиционной техникой

(Z test = 6.79, p = <0.00001, and I = 99%) which indicates that dynamic navigation methods significantly reduce tooth substance removal compared to traditional techniques, with the results being statistically significant and likely robust despite some variability among studies (Fig. 5).

5. Total time taken in access cavity preparation in Computer-aided static navigation compared to conventional technique: The meta-analysis employs a continuous random-effects model, focusing on the mean difference in time taken between computer-aided static navigation and conventional groups. The mean difference was −631.69 [95% Confidence Interval (CI): −668.34 to −595.04] with no heterogenity (Z test = 33.78, p = < 0.00001, and I^2 = 0%) which demonstrates a significant mean difference between the static navigation and conventional groups with no significant heterogeneity, indicating consistent findings across the included studies (Fig. 6).

6. Total time taken in access cavity preparation in Computer-aided dynamic navigation compared to conventional technique: The meta-analysis investigates the time taken for procedures using dynamic navigation techniques in experimental and conventional groups between computer-aided dynamic navigation and conventional groups across four studies. The mean difference was −1.80 [95% Confidence Interval (CI): −4.27 to 0.67] with high variability of heterogenity (Z test = 1.43, p = 0.15, and I^2 = 99%) which shows that there is no statistically significant difference in the time taken for dynamic navigation between the experimental and conventional groups (Fig. 7).

DISCUSSION

Traditional root canal therapy relied on tactile sensation for many years, leading to varying degrees of endodontic complications. Since then, the advent of advanced tools such as DG-16 probes, ultrasonic tips, and enhanced visualization techniques utilizing loupes and microscopes has significantly improved the accuracy of locating root canals, particularly in cases of pulp canal obliteration. The introduction of CBCT has enabled 3D visualization of teeth, enhancing diagnostic capabilities [17].

Nasseh and Al-Rawi highlighted the benefits of CBCT in endodontics, which include comprehensive evaluation of endodontic and non-endodontic conditions [18]. Cone beam computed tomography (CBCT)

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Connert et al. 2019	10.50	1.95	36	29.70	5.85	36	1.0%	-19.20 [-21.21, -17.19]
Omid Dianat et al. 2020	1.06	0.18	30	1.55	0.55	30	98.7%	-0.49 [-0.70, -0.28]
Sameer Jain et al. 2020	27.20	5.10	20	40.7	8.78	20	0.2%	-13.50 [-17.95, -9.05]
Total (95% CI)			**86**			**86**	**100.0%**	**-0.71 [-0.92, -0.51]**

Heterogeneity: Chi² = 359.74, df = 2 (p < 0.00001); I² = 99%
Test for overall effect: Z = 6.79 (p < 0.00001)

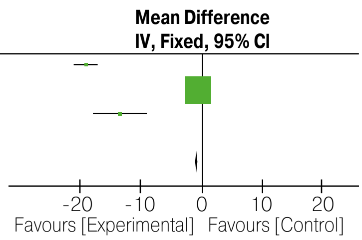

Fig. 5. Forest plot of amount of tooth-substance removal in computer-aided dynamic navigation compared to conventional technique

Рис. 5. Лесной график (Forest plot) объема удаления зубного вещества при компьютерной динамической навигации по сравнению с традиционной техникой

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Aishwarya Vasudevan et al. 2023	1,039	80.4	21	1,688.4	279	21	8.7%	-649.40 [-773.58, -525.22]
Connert et al. 2019	678	40.7	24	1,308	86.8	24	91.3%	-630.00 [-668.35, -591.65]
Total (95% CI)			**45**			**45**	**100.0%**	**-631.69 [-668.34, -595.04]**

Heterogeneity: Chi² = 0.09, df = 1 (p < 0.77); I² = 0%
Test for overall effect: Z = 33.78 (p < 0.00001)

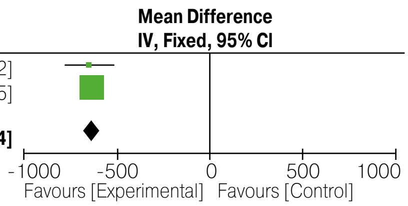

Fig. 6. Forest plot of total time taken in access cavity preparation in Computer-aided static navigation compared to conventional technique

Рис. 6. Лесной график (Forest plot) общего времени, затраченного на подготовку полости доступа при компьютерной статической навигации по сравнению с традиционной техникой

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Connert et al. 2019	195	93	36	193	91	36	0.3%	2.00 [-40.50, 44.50]
Gianluca Gambarini et al. 2020	11.5	2.4	10	12.2	3.2	10	99.2%	-0.70 [-3.18, 1.78]
Omid Dianat et al. 2020	227	97	30	405	246	30	0.1%	-178.00 [-272.62, -83.38]
Sameer Jain et al. 2020	136.1	56	20	424.8	78	20	0.3%	-288.70 [-330.78, -246.62]
Total (95% CI)			**96**			**96**	**100.0%**	**-1.80 [-4.27, 0.67]**

Heterogeneity: Chi² = 192.66, df = 3 (p < 0.00001); I² = 98%
Test for overall effect: Z = 1.43 (p < 0.15)

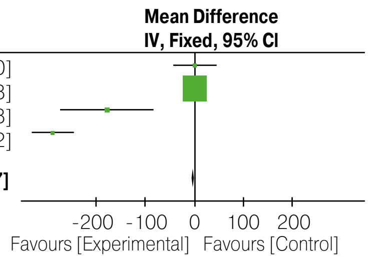

Fig. 7. Forest plot of total time taken in access cavity preparation in Computer-aided dynamic navigation compared to conventional technique

Рис. 7. Лесной график (Forest plot) общего времени, затраченного на подготовку полости доступа при компьютерной динамической навигации по сравнению с традиционной техникой is particularly useful in complex cases where traditional radiographs fail to offer adequate information about the tooth morphology and its surrounding structures [19]. This 3D data can be integrated with surface details obtained from an intraoral scanner, enabling the design and 3D printing of a treatment guide [20].

The accuracy of computer-assisted navigation techniques for dental implant placement has been evaluated by numerous authors, revealing a range of deviations. The horizontal deviation at the dental implant platform has been found to range from 0.00 mm to 6.15 mm, while the vertical deviation at the dental implant apex varies from 0.00 mm to 6.99 mm. Additionally, the average angular deviation relative to the longitudinal axis of the dental implants is approximately 3.81°. These findings highlight the variability in accuracy across different studies and methods [21; 22]. Gambarini et al. reported that the use of a dynamic navigation system yielded a mean horizontal deviation of 0.34 mm and a mean angular deviation of 4.8°. The deviations at the dental implant platform and apex were lower, with values of 0.71 ± 0.40 mm and 1.00 ± 0.49 mm, respectively, and an average angular deviation of 2.26° ± 1.62° relative to the longitudinal axis of the dental implants [23–25]. These findings indicate that dynamic navigation techniques can enhance the accuracy of dental implant placement compared to the freehand method, reducing clinical complications. The increased precision of these systems supports their potential use in performing ultraconservative root canal access openings and reinforces their credibility for clinical applications [26; 27].

Root canal access preparation in calcified teeth presents significant clinical challenges. Errors in this critical step can have severe consequences, especially in teeth with minimal dentin, such as mandibular incisors. Unsuccessful attempts to locate calcified canals can lead to gouging, perforation, and substantial dentin loss. Despite the advancements in treatment efficacy for teeth with pulp canal obliteration (PCO) through the use of dental operating microscopes (DOM) and cone-beam computed tomography (CBCT), the process remains difficult, time-consuming, and prone to technical errors [12]. According to Sameer Jain et al., access cavities prepared using dynamic navigation resulted in significantly less mean tooth substance loss compared to the conventional freehand root canal access opening (27.2 mm^3 vs. 40.7 mm^3) [8]. Similarly, Connert et al. observed that the mean substance loss using the conventional freehand root canal access opening method was 49.9 mm^3 (95% CI, 42.2–57.6 mm^3), while the static-guided approach resulted in a loss of just 9.8 mm^3 (95% CI, 6.8–12.9 mm^3) [7].

Locating canals in calcified teeth requires more time than preparing conventional access cavities, regardless of the operator's experience. Connert et al. reported that the average time for access cavity preparation was 30 seconds, with the total time – including surface scanning, virtual planning, and access cavity preparation – amounting to 613 seconds [9].

In terms of treatment duration, Connert et al. found that conventional techniques took an average of 21.8 minutes, whereas guided endodontics took 11.3 minutes [7]. Likewise, Sato et al. reported that guided access preparation required 25.03 minutes, compared to 16.98 minutes for conventional access preparation. Therefore, guided access is not only faster but also a more reliable option for endodontic treatment. Although designing and preparing an endodontic guide requires considerable time and expertise in CBCT, software handling, and 3D printing, the overall benefits in complex cases justify its use.

Using computer-assisted navigation techniques for locating root canals has generally shown a high success rate (96.2%) compared to conventional methods (83.9%). Notably, computer-assisted static navigation techniques had a slightly higher success rate in root canal location (96.5%) compared to dynamic techniques (95.7%). These studies all conclude that computer-aided navigation techniques offer a more predictable and reliable approach for endodontic access cavities [20].

To be clear, endodontic treatment remains challenging despite advancements in technology. Small root canals and complex anatomy pose significant difficulties. Thus, it is essential to underscore the importance of employing appropriate techniques for a successful outcome. Limited access and visibility in endodontics, particularly in cases involving molars, often contribute to higher failure rates. Consequently, adopting advanced imaging and navigation techniques is vital to achieve precise and effective results. While traditional methods like radiography are useful, they have limitations that can impact the accuracy of the procedure [28]. The integration of computed tomography (CT) and dynamic navigation systems has shown promise in enhancing the precision of endodontic treatments. Utilizing these advanced technologies can help overcome the inherent challenges and improve patient outcomes, ensuring a higher success rate for endodontic procedures [29].

The findings of this study disproved the null hypothesis, which stated that there is no significant difference in the accuracy of endodontic access cavities when using various computer-aided navigation techniques.

This study presents a limitation that all the included articles were limited to those published in English, potentially excluding studies in other languages. Despite this, computer-aided navigation is an emerging technique that is continually developing. As more scientific literature emerges in the future, this method is likely to become a safer and more accurate alternative to traditional access techniques in cases involving calcification.

CONCLUSION

This study leads to the conclusion that:

1. Computer-aided static navigation has proved to be highly accurate in location of root canal orifices with accuracy of 96.2%.
2. Computer-aided navigation techniques removes less tooth substance compared to conventional techniques.
3. Computer-aided navigation techniques take less time in preparation of endodontic access cavity than conventional techniques.

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