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

Akhila Ajay[1], Krishnan Hari[1], Basil Joy[1], Rechithra R[1], Binila S Babu[1], Dinesh Kamath[2]

[1] Mar Baselios Dental College, Kothamangalam, Kerala-686691, India
[2] Educare Dental College, Malappuram, Kerala-676504, India
akhilamenon9624@gmail.com

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 МТА и биологически активного стекла при использовании различных финишных ирригантов: in-vitro исследование

А. Аджай[1], К. Хари[1], Б. Джой[1], Р. Р[1], Б.С. Бабу[1], Д. Камат[2]

[1] Mar Baselios Dental College, Котамангалам, Керала, 686691, Индия
[2] Educare Dental College, Малаппурам, Керала, 676504, Индия
akhilamenon9624@gmail.com

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 биокерамического герметика на основе МТА и герметика на основе биологически активного стекла (BG) при использовании четырех различных финишных ирригантов.

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].

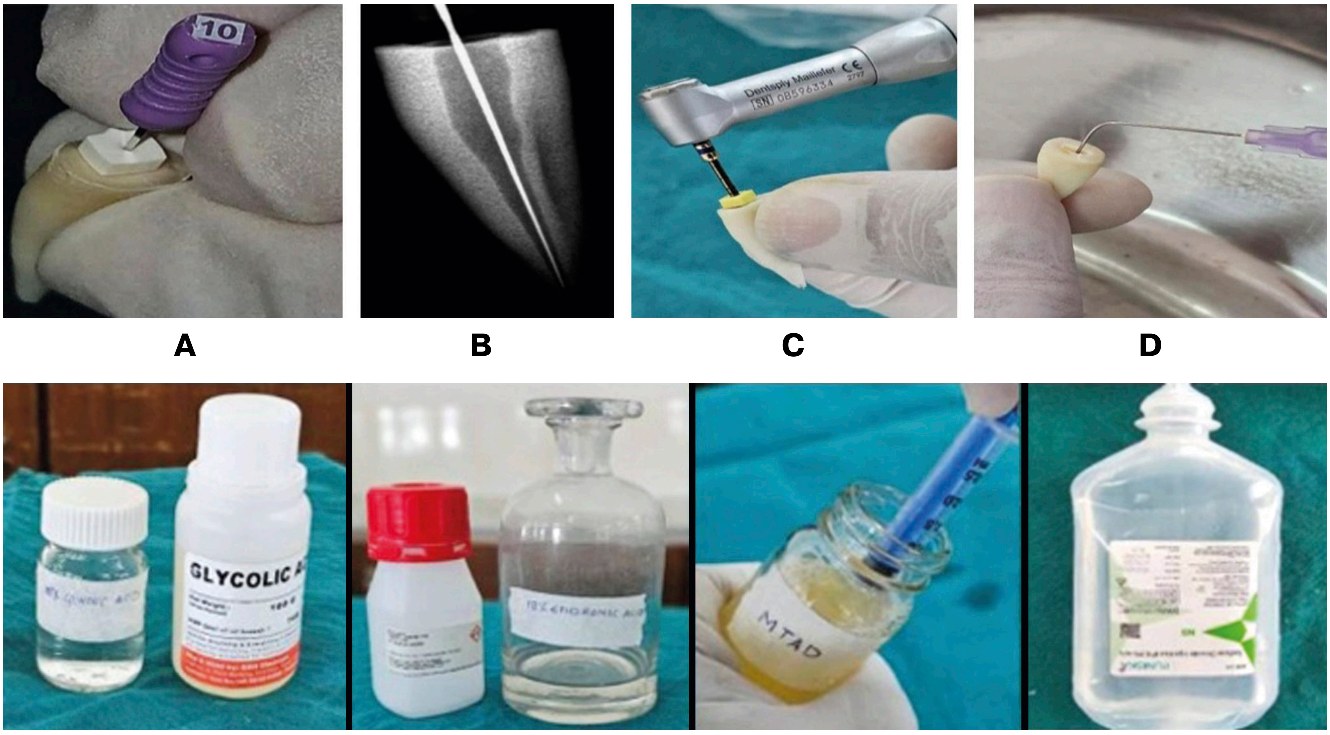
Although Ethylenediaminetetraacetic acid (EDTA) and citric acid are widely in use, HEBP (1-hydroxyethylidene-1,1-bisphosphonate), also referred as etidronate or etidronic acid, has gained attention as a promising alternative. Its appeal lies in its enhanced efficacy, as it does not interact with sodium 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



E

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 K-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).

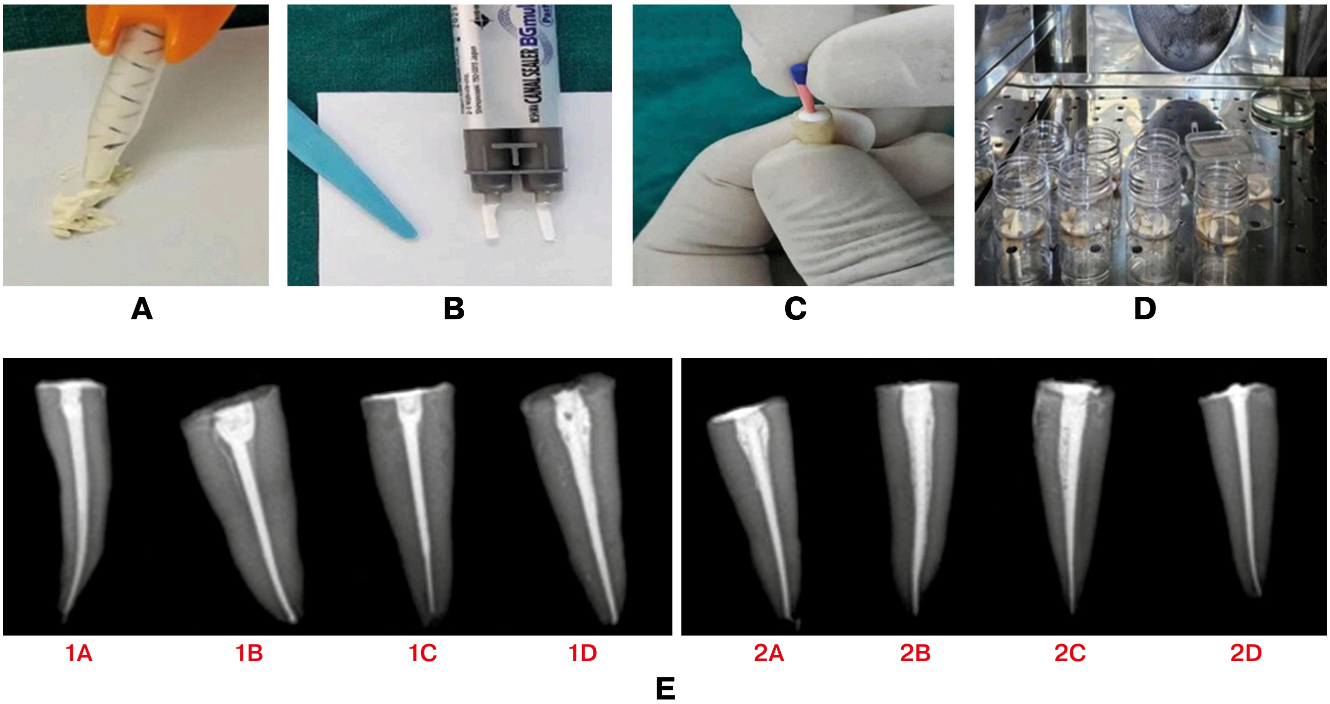


Fig. 2. Restorative procedure followed by incubation of the specimens: *A* – MTA Fillapex extruded through the spiral tip; *B* – manipulation of Nishika canal sealer BG; *C* – obturation with F3 size gutta-percha cone; *D* – specimens kept in incubator at 38°C and 100% relative humidity for 7 days; *E* – 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).

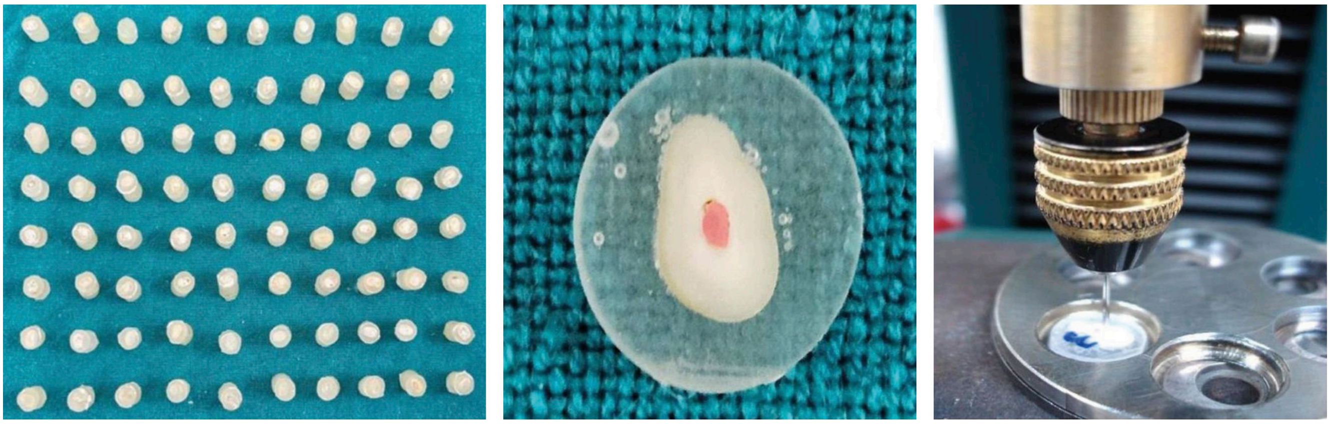
The mean pushout bond strength was least for Nishika Canal Sealer BG with MTAD (0.9818±0.89125 MPa). The mean pushout bond strength was the highest for Nishika Canal Sealer BG with Etidronic acid (2.70001±1.72824 MPa) followed by Nishika Canal Sealer BG with glycolic acid (1.973±0.95195 MPa) (Table 2).

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

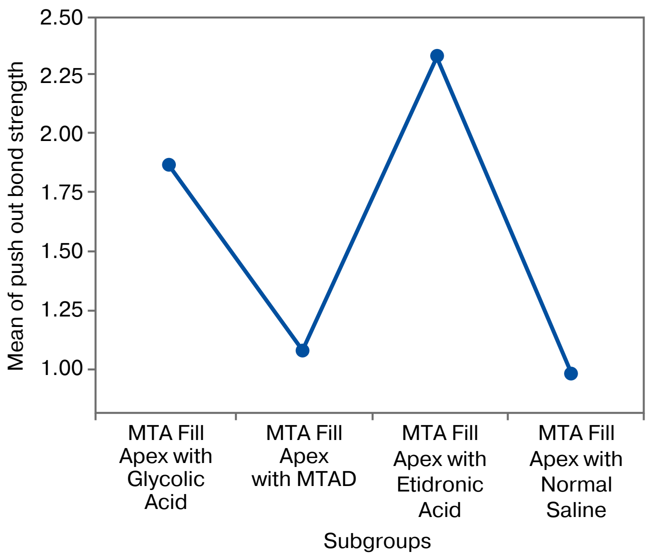


Fig. 4. Graphical illustration of pushout bond strength in 4 groups of MTA Fillapex

Рис. 4. Графическое изображение прочности сцепления на выдавливание в четырех группах MTA Fillapex

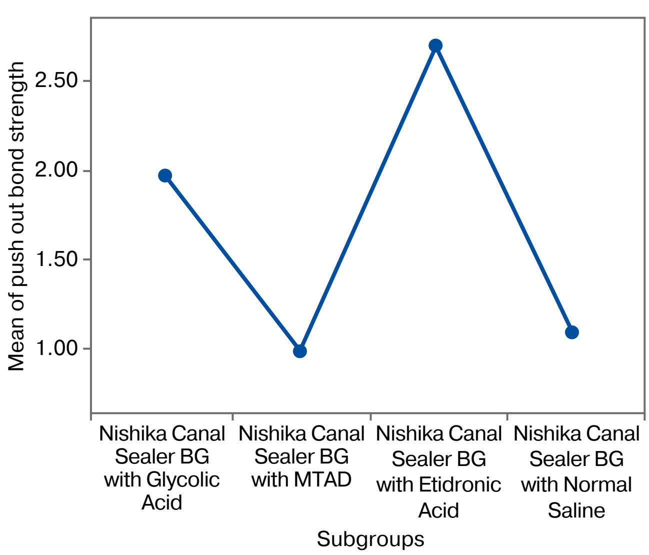


Fig. 5. Graphical illustration of pushout bond strength in 4 groups of Nishika CS BG

Рис. 5. Графическое изображение прочности сцепления на выдавливание в четырех группах Nishika CS BG

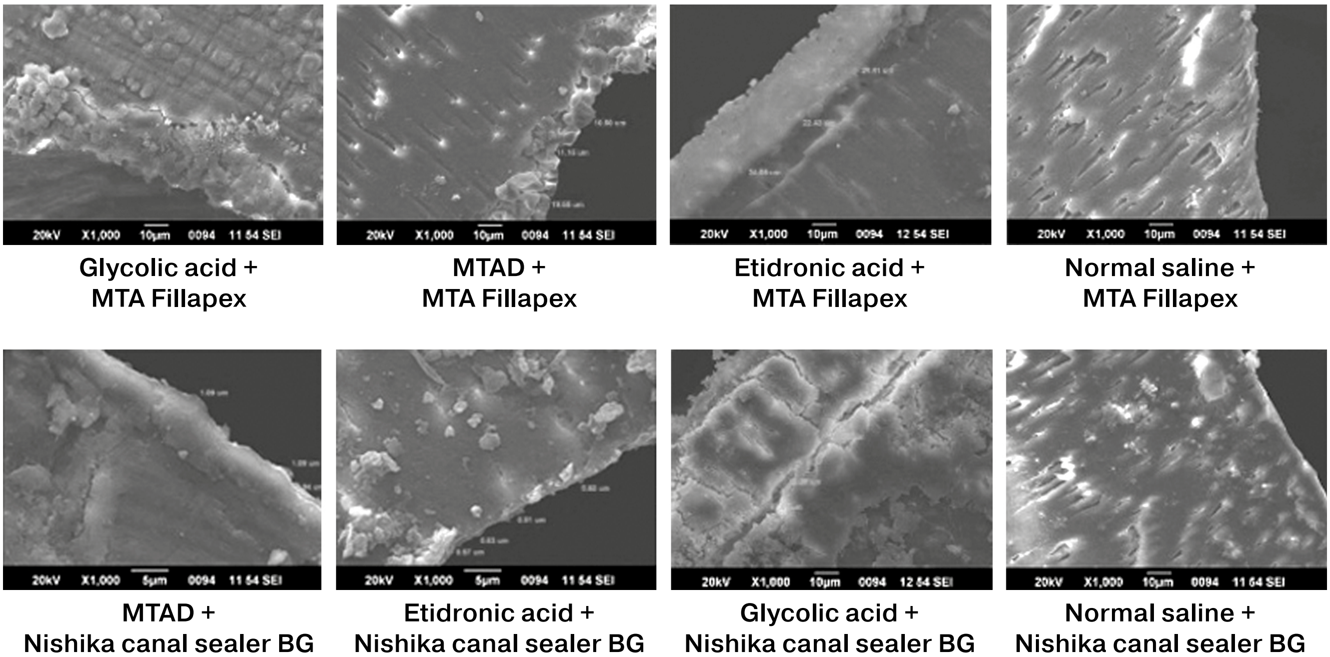


Fig. 6. SEM evaluation of the failure mode of the specimens

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 gutta-percha. 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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INFORMATION ABOUT THE AUTHORS

Akhila Ajay – Postgraduate Student, Department of Conservative Dentistry and Endodontics, Mar Baselios Dental College, Kothamangalam, Kerala-686691, India; https://orcid.org/0009-0008-5596-9624

Krishnan Hari – Professor and HOD, Department of Conservative Dentistry and Endodontics, Mar Baselios Dental College, Kothamangalam, Kerala-686691, India; https://orcid.org/0000-0002-2556-6065

Basil Joy – Reader, Department of Conservative Dentistry and Endodontics, Mar Baselios Dental College, Kothamangalam, Kerala-686691, India; https://orcid.org/0000-0001-9752-4764

Rechithra R – Associate professor, Department of Conservative Dentistry and Endodontics, Mar Baselios Dental College, Kothamangalam, Kerala-686691, India; https://orcid.org/0000-0002-7284-606X

Binila S Babu – Professor, Department of Conservative Dentistry and Endodontics, Mar Baselios Dental College, Kothamangalam, Kerala-686691, India; https://orcid.org/0000-0002-5253-4122

Dinesh Kamath – Professor and HOD, Department of Conservative Dentistry and Endodontics, Educare Dental College, Malappuram, Kerala-676504, India; https://orcid.org/0000-0001-5641-0699

ИНФОРМАЦИЯ ОБ АВТОРАХ

Акилиа Аджай – аспирант кафедры терапевтической стоматологии и эндодонтии, Стоматологический колледж Мар Базелиос (Mar Baselios Dental College), Котамангалам, Керала, 686691, Индия; https://orcid.org/0009-0008-5596-9624

Кришнан Хари – профессор и заведующий кафедрой терапевтической стоматологии и эндодонтии, Стоматологический колледж Мар Базелиос (Mar Baselios Dental College), Котамангалам, Керала, 686691, Индия; https://orcid.org/0000-0002-2556-6065

Бэзил Джой – старший преподаватель кафедры терапевтической стоматологии и эндодонтии, Стоматологический колледж Мар Базелиос (Mar Baselios Dental College), Котамангалам, Керала, 686691, Индия; https://orcid.org/0000-0001-9752-4764

Речитра Р – доцент кафедры терапевтической стоматологии и эндодонтии, Mar Baselios Dental College, Котамангалам, Керала, 686691, Индия; https://orcid.org/0000-0002-7284-606X

Бинила С. Бабу – профессор кафедры терапевтической стоматологии и эндодонтии, Стоматологический колледж Мар Базелиос (Mar Baselios Dental College), Котамангалам, Керала, 686691, Индия; https://orcid.org/0000-0002-5253-4122

Динеш Камат – профессор и заведующий кафедрой терапевтической стоматологии и эндодонтии, Колледж стоматологии «Эдюкэр» (Educare Dental College), Малаппурам, Керала, 676504, Индия; https://orcid.org/0000-0001-5641-0699

AUTHOR'S CONTRIBUTION

Akhila Ajay – a substantial contribution to the concept or design of the article; drafted the article or revised it critically for important intellectual content.

Krishnan Hari – a substantial contribution to the concept or design of the article; drafted the article or revised it critically for important intellectual content.

Basil Joy – a substantial contribution to the concept or design of the article; the acquisition, analysis, or interpretation of data for the article.

Rechithra R – drafted the article or revised it critically for important intellectual content; approved the version to be published.

Binila S Babu – the acquisition, analysis, or interpretation of data for the article; approved the version to be published.

Dinesh Kamath – drafted the article or revised it critically for important intellectual content; approved the version to be published.

ВКЛАД АВТОРОВ

А. Аджай – существенный вклад в концепцию или дизайн статьи; подготовка текста статьи или критическая редакция с учетом значимого интеллектуального содержания.

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