Odovtos-International Journal of Dental Sciences (Odovtos-Int. J. Dent. Sc.), Online First, 2026. ISSN: 2215-3411
https://doi.org/10.15517/jth6x974

ODOVTOS
International Journal of Dental Sciences

UNIVERSIDAD DE COSTA RICA FOd Facultad de Odontología

https://revistas.ucr.ac.cr/index.php/Odontos

BASIC RESEARCH:

Push Out Bond Strength and Adaptation of MTA-Based Root Canal Sealers to Dentin with or Without Gutta-Percha: *In vitro*-Study

Resistencia adhesiva y adaptación de cementos selladores de conductos radiculares a base de MTA a la dentina con o sin gutapercha: estudio *in vitro*

Shady Eweda[1]
Nasr EL-Deen Rashed[2] https://orcid.org/0000-0002-1717-8185
Marwa Sharaan[3] https://orcid.org/0000-0002-4373-6099

[1]Post graduate, Department of Endodontics, Faculty of Dentistry, Suez Canal University, Egypt.
[2]Associate Professor of Endodontics, Department of Endodontics, Faculty of Dentistry, Suez Canal University, Egypt.
[3]Professor of Endodontics, Department of Endodontics, Faculty of Dentistry, Suez Canal University, Egypt.

Correspondence to: Marwa Sharaan - marwa_sharaan@dent.suez.edu.eg

Received: 16-VIII-2025 Accepted: 17-XI-2025

ABSTRACT: This *in vitro* study investigated the push-out bond strength and adaptation of three root canal sealers AH Plus Jet (epoxy resin-based), MTA Fillapex, and EndoSeal Mineral Trioxide Aggregate (MTA) both with and without gutta-percha obturation, utilizing 90 straight, single-rooted teeth randomly assigned to groups and subgroups. Push-out bond strength was measured using an Instron universal testing machine, while adaptation was assessed via scanning electron microscopy, with statistical analysis performed using one-way ANOVA and Tukey's post-hoc test ($p<0.05$). EndoSeal MTA demonstrated the highest statistically significant push-out bond strength ($p<0.001$) in both conditions, though no significant difference existed between MTA Fillapex and AH Plus Jet without gutta-percha, where AH Plus Jet still showed higher bond strength at root levels than MTA Fillapex ($p<0.001$). While adaptation showed no significant differences among sealers with gutta-percha, AH Plus Jet achieved the lowest significant gap percentage in its absence. Ultimately, EndoSeal MTA exhibited the highest push-out bond strength overall, making its superior adhesion a promising choice for root canal obturation.

KEYWORDS: Adaptation; Gutta-percha; MTA-based sealers; Push-out bond strength; Resin-based sealers.

RESUMEN: Este estudio *in vitro* investigó la resistencia adhesiva (push-out) y la adaptación de tres selladores endodónticos: AH Plus Jet (a base de resina), MTA Fillapex y EndoSeal Mineral Trioxide Aggregate (MTA), tanto con obturación con gutapercha como sin ella, utilizando 90 dientes unirradiculares rectos asignados aleatoriamente en grupos y subgrupos. La resistencia adhesiva push-out se midió mediante una máquina universal de ensayos Instron, mientras que la adaptación se evaluó mediante microscopía electrónica de barrido. El análisis estadístico se realizó utilizando ANOVA de una vía y la prueba post hoc de Tukey ($p<0.05$). EndoSeal MTA mostró la resistencia adhesiva (push-out) más alta y estadísticamente significativa ($p<0.001$) en ambas condiciones, aunque no se observaron diferencias significativas entre MTA Fillapex y AH Plus Jet en ausencia de gutapercha, donde AH Plus Jet presentó una mayor resistencia adhesiva a nivel del conducto radicular que MTA Fillapex ($p<0.001$). Aunque la adaptación no mostró diferencias significativas entre los selladores en presencia de gutapercha, AH Plus Jet presentó el menor porcentaje de brechas en su ausencia. En conclusión, EndoSeal MTA exhibió la mayor resistencia adhesiva (push-out) en general, lo que convierte a su adhesión superior en una opción prometedora para la obturación de conductos radiculares.

PALABRAS CLAVE: Adaptación; Gutapercha; Selladores a base de MTA; Resistencia adhesiva push-out; Selladores a base de resina.

INTRODUCTION

Root canal obturation is crucial for the long-term success of root canal therapy. Its primary goals are to establish a hermetic seal at the apical foramen and to densely fill the entire canal system, thereby eliminating voids that could compromise the outcome. Successful obturation prevents leakage and confines any remaining microorganisms within the root canal (1).

Many techniques and materials are used for obturation. To achieve a complete seal, most procedures use a core filling substance and a sealer. The sealer is essential for creating a fluid-tight seal of the root canal by filling the space between the core filling material and the prepared dentinal wall. The sealer also has an antibacterial effect and can reach lateral canals and tubules that gutta-percha cones cannot (2).

Resin sealers, such as AH Plus Jet (DENTSPLY, Sirona, Germany), offer excellent adhesion to the canal wall and are non-eugenol sealants. These resin-based sealers provide several advantages, including superior sealing and adhesion, along with good apical tissue tolerance. However, they have also been shown to induce an early inflammatory response, potentially influencing mutagenic and allergic reactions (3).

MTA Fillapex (Angelus, Curitiba, Brazil) and EndoSeal MTA (Maruchi, Wonju, Korea) are two commercially available root canal sealers. Based on MTA's composition, these sealers facilitate firm tissue mineralization by releasing calcium and creating an alkaline environment (4). Additionally, they demonstrated superior penetrability across all root canal thirds (5).

EndoSeal MTA is a pozzolan-cement-derived, paste-type root canal sealer with exceptional biological and physical properties. Unlike many other root canal sealers, it comes pre-loaded and pre-mixed in a syringe, eliminating the need for powder/liquid mixing and enabling direct administration into the root canal. This feature offers a significant clinical advantage in terms of ease and speed of application. Its outstanding maneuverability and flowability ensure it can thoroughly fill the intricate root canal system, including lateral and accessory canals, promoting a hermetic seal. Furthermore, EndoSeal MTA is eugenol-free, thus preventing potential interference with adhesion within the root canal (6).

The bond strength of the sealer to the dentin is considered the most critical factor for maintaining the reliability of the root canal seal. The push-out bond strength of root canal obturation material to dentinal walls is substantial in both dynamic and static conditions. In a quiescent state, minimizing fluid filtration between the obturation material and the dentinal wall is crucial. Conversely, under dynamic conditions, preventing filling disruption due to mechanical stresses from tooth flexure or restorative procedures is essential (7).

The comparison of AH Plus Jet (epoxy resin-based), MTA Fillapex (MTA-based), and EndoSeal MTA, with and without core material, lacks substantial information in current literature. Therefore, this study aims to assess the push-out bond strength and adaptation of these three sealers (AH Plus Jet, EndoSeal MTA, and MTA Fillapex) when used in root canals filled both with and without a main cone. The null hypothesis posits no significant variation among the three tested sealers, irrespective of the presence of gutta-percha.

MATERIAL AND METHODS

STUDY DESIGN

This research was conducted according to the Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) guidelines (Nagendrababu *et al.*, 2021) (8), and the design is described in the PRILE flowchart (Figure 1).

The study was done after the approval from the Research Ethics Committee (REC) Faculty of Dentistry, Suez Canal University, Egypt (Ethical Approval No.: 164/2019).The total sample size was determined using G*power analysis based on a sample size estimation from a previous study (n=90), effect size=0.4, α=0.05, and a general statistical power (1-β= 0.82) (9).

This *in vitro* study was carried out on 90 humans with straight single root canals (mandibular premolars). The teeth were freshly extracted for periodontal, prosthodontic, or orthodontic purposes. Roots were mature with no root caries and no internal or external resorption to avoid any loss during transverse sectioning of the roots. The teeth did not receive endodontic treatment before allowing easy instrumentation and obturation; teeth with no signs of cracks to avoid fracture during instrumentation; no anatomic abnormalities, such as fusion or dilacerations; and radiographically, the teeth have one canal in bucco-lingual and mesio-distal dimensions (Type I Vertucci).

Sample preparation: The external tissue fragments and calculus were removed from the external surface of teeth by scaling, and afterwards the teeth were kept in saline solution. The teeth were immersed in 2.5% sodium hypochlorite (NaOCl) (DHARMA, USA) for 2 hours for decontamination. Decoronating of the teeth was done perpendicular to the long axis by using a diamond disk mounted in a shorthand piece with cooling to allow straight-line access and standardize the length at14 mmm (10).

Root canal instrumentation: roots were held using continuously moist gauze, and a K-file size #10 (MANI Inc., Japan) was established into the root to ensure the patency. Then the working length of the roots was verified by introducing k-file size #10 to the apical foramen, and then the length of work for each sample was adjusted at 1 mm before the apical foramen and confirmed by periapical radiograph.

Root canals were flooded using 5 ml of 2.5% NaOCl and instrumented by adjusting the initial file and consuming the next ProTaper files (DENTSPLY, Sirona, Germany) at 300 RPM and a torque from 4-5.2 Ncm (size 0.17,0.25, 0.30, 0.40 taper 6%) as recommended by the manufacturer. A volume of 5 mL of 5.25 % NaOCl was used for canal irrigation among each instrument to flush out dentine debris, followed by 3 mL of 17% EDTA (Meta Biomed Co., Ltd. South Korea) for one minute to remove the smear layer, followed by 3 mL of saline solution. The canals were then dried using absorbent paper points (size 0.40mm taper 6%). The canals were ready for obturation using the single-cone technique.

RANDOMIZATION AND GROUPING

Randomization was done using Microsoft Excel. Later, the blind allocation was conducted by placing papers representing teeth numbers in opaque envelopes. Teeth were equally and randomly categorized into 3 groups based on the sealer used in obturation: Group A1) received obturation using EndoSeal MTA, Group A2) using MTA Fillapex, and Group A3) using AH Plus Jet, then each group was subdivided into two equal subgroups: Subgroup B1: received single cone obturation using sealer with the main cone, and Subgroup B2: received obturation using sealer without main cone (Figure 2).

Roots were kept at 37°C and 100% humidity in an incubator for 7 days to ensure the setting of the sealer. After sealer setting, every root was sectioned perpendicular to the long axis of the root using an accuracy cutting machine into three slices with 2 mm thickness. One slice from the apical part at 2 mm distance from the root apex, then a slice from the middle part, and the other slice from the coronal part at 8 mm distance from the root apex (11).

Figure 1. The study design according to PRILE guidelines ethical approval.

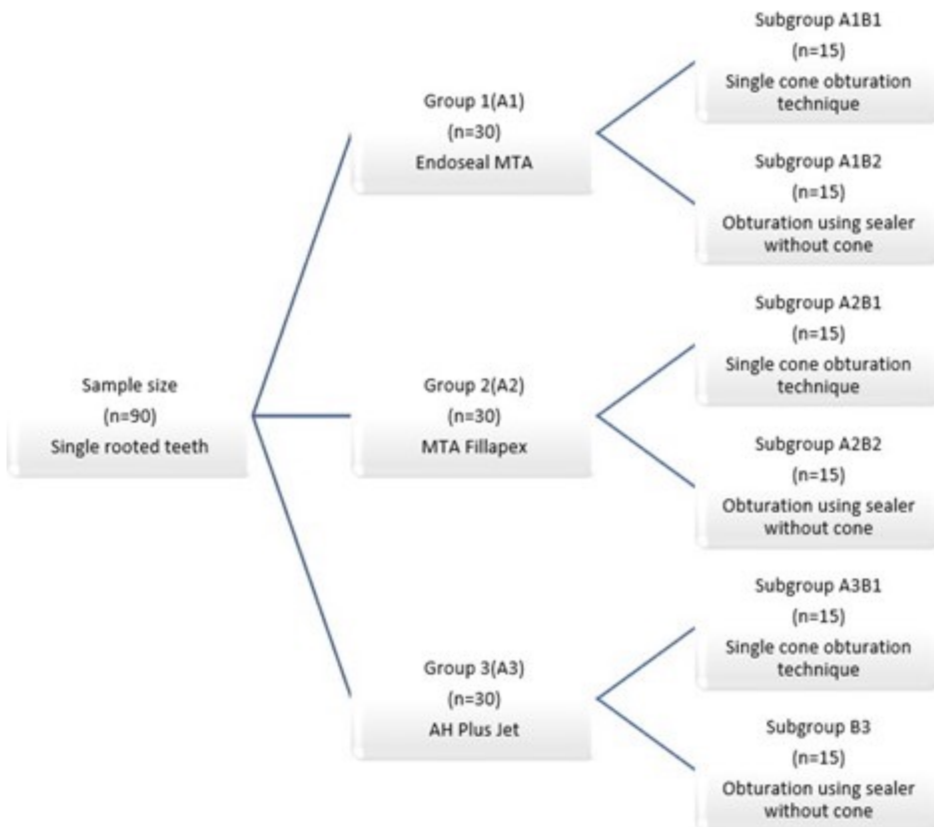

Figure 2. Flow chart of samples grouping and subgrouping.

METHODS OF EVALUATION

Push-out test: Thirty specimens were chosen from every group for the push-out test. A stainless-steel plunger with a diameter of 0.9 mm was used to insert the filling material (gutta percha and sealer) for the coronal slice and 0.5 mm for the apical slice (10). The data was documented through the computer software Bluehill 3 version 3.3, and the actuator was fixed on the upper portion of a universal Instron testing machine. Subsequently, the cylindrical stainless-steel plunger was directed toward the canal filling in an apical-coronal direction to prohibit any interference with shrinking, and the segments were positioned in the mechanical testing machine. The load was operated until the infill material was dislodged. The 500N load cell was employed to conduct the experiments at a crosshead speed of 0.5mm/min. The push-out bond strength was determined by the highest recorded load value. The bond strength was determined by dividing the burden by the filling area. The area under load was determined by the formula: Area=2 π r h (12).

Where r= root canal radius in mm, π= 3.14 and h is the thickness of the sample in millimeters. The push-out value in MPa was calculated from force (N) divided by area in mm2. The load was converted to megapascal (MPa) and then the test data was collected.

Push out bond strength (MPa) = maximum load (N)/filling area (mm^2)

Analysis of failure modes: After the pushout test was carried out, the specimens were evaluated under a stereomicroscope to check failure modes according to the dislodgement of the obturation materials from the specimens. Three types of failure mode could occur: Adhesive failure: either at the sealer-dentine or relating to the cohesive failure, sealer-core interfaces: inside the core or sealer material, and mixed failure: which contains both adhesive and cohesive failures (13).

Adaptation analysis with scanning electron microscope (SEM): another 30 slices from each group were evaluated using SEM. Carbon double adhesive tape was employed to secure the samples to aluminum stubs with a standard diameter. The SEM (Model FEI Quanta 3D 200i) was operated at a magnification of 500X, a resolution of 0.1 nm, and an accelerating voltage of 30 kV. Representative images of various samples were chosen. The entire root canal area was photographed at a magnification of 100X to 500X. Image J software was employed to assess the sealer's adaptability to gutta percha and dentine. The scale measurements were adjusted for each image, and the root canal area was marked and distinguished from the adjacent area using polygon selections. The color threshold was accommodated, the gaps were identified, and the gap percentage was determined using the following equation. Data were subsequently collected (14).

$$Gap\,\% = \frac{\text{Total area of gap at dentine} - \text{bond interface } (\mu m^2)}{\text{Total area of root canal } (\mu m^2)} x100$$

STATISTICAL ANALYSIS

Statistical analyses were performed using IBM-SPSS version 26.0 (USA, Armonk, NY, IBM Inc.). The normality of data was checked using the Shapiro-Wilk test at 0.05 level; accordingly, the data was parametric. The mean and standard deviation (SD) of quantitative variables were presented and contrasted among the two groups applying unpaired Student's t-test. The Fisher's exact test or Chi-square test was established to analyze qualitative variables, which were displayed as percentage (%) and frequency when proper. The pushout bond strength of the various sealers was compared using one-way ANOVA. Statistical significance was stated as a two-tailed p-value≤ 0.05. Pearson correlation was employed to distinguish a correlation between two qualitative variables within a single cohort.

RESULTS

ASSESSMENT OF THE PUSH-OUT BOND STRENGTH RESULTS FOR THE 3 TYPES OF SEALERS (MECHANICAL RESULTS)

EndoSeal exhibited significantly bigger bond strength in the coronal region associated with the apical region without gutta-percha ($p<0.001$), while AH Plus Jet also exhibited significantly greater bond strength in the apical region without gutta-percha ($p=0.001$) and in the apical region with gutta-percha ($p=0.009$). When comparing bond strength among non-gutta-percha and gutta-percha groups, EndoSeal had significantly higher coronal bond strength without gutta-percha ($p<0.001$) but lower apical bond strength ($p=0.003$). AH Plus Jet demonstrated significantly greater bond strength without gutta-percha in both the apical and coronal regions ($p<0.001$). MTA Fillapex showed significantly lower apical bond strength without gutta-percha ($p=0.050$). In inter-group comparisons, EndoSeal had the greatest bond strength across all conditions, followed by AH Plus Jet and MTA Fillapex, with highly significant differences ($p<0.001$). However, within-sealer comparisons showed no significant differences for EndoSeal with gutta-percha or MTA Fillapex with or without gutta-percha (Table 1).

ANALYSIS OF FAILURE MODE OF SEALER GUTTA-PERCHA, AND DENTINE

The results of the observational analysis of failure mode after the push-out test showed that the most common mode of failure was the adhesive failure between the sealer and the dentine wall in groups where obturation is without gutta-percha and the adhesive failure between the sealer core material in groups where obturation is with gutta-percha, followed by the mixed failure (Figure 3).

ASSESSMENT OF THE PERCENTAGE OF GAP IN THE SEALER-DENTINE INTERFACE (IMAGE-J ANALYSIS RESULTS)

In the intra-group comparison, AH Plus Jet showed a highly significant reduction in gap percentage without gutta-percha ($p<0.001$), while EndoSeal MTA and MTA Fillapex exhibited non-significant increases ($p= 0.200$ and $p= 0.069$, separately). In the inter-group comparison, no significant contrast was noticed among the three sealers in the existence of gutta-percha ($p>0.05$). However, without gutta-percha, MTA Fillapex had the highest gap percentage, and AH Plus Jet had the lowest, with a significant difference between AH Plus Jet and the other two groups ($p= 0.002$), although the significance between EndoSeal MTA and MTA Fillapex remained non-significant (Table 2; Figure 4).

The correlation analysis revealed a significant moderate negative correlation between gap percentage and push-out bond strength in AH Plus Jet (A3), both with gutta-percha ($r=-0.579$, $p=0.002$) and without gutta-percha ($r=-0.656$, $p<0.001$), indicating that a higher gap percentage was associated with lower bond strength. Similarly, EndoSeal MTA (A1) showed a significant moderate negative correlation with gutta-percha ($r=-0.491$, $p=0.013$) and without gutta-percha ($r=-0.444$, $p=0.026$). In contrast, MTA Fillapex (A2) demonstrated a moderate negative correlation in both conditions ($r=-0.362$, $p=0.096$ with gutta-percha and $r=-0.381$, $p=0.078$ without gutta-percha), but these correlations were not statistically significant (Table 3).

Table 1. Mean±SD, average, intra-, and inter-group comparison of push-out bond strength between the three sealers in the different thirds with and without gutta-percha.

	Third	B1 (with gutta percha)	B2 (without gutta percha)	Overall	P-value*
A1 (Endoseal MTA)	Coronal	2±0.12	8.38±1.19	3.45±0.36[a]	< 0.001[HS]
	Apical	2.07±0.69	1.34±0.53		0.003[S]
	Overall	2.03±0.39[a]	4.86±0.68[a]		< 0.001[HS]
A2 (MTA Fillapex)	Coronal	0.45±0.32	0.54±0.35	0.48±0.14[c]	0.459[NS]
	Apical	0.66±0.52	0.33±0.22		0.050[S]
	Overall	0.55±0.27[b]	0.44±0.26[c]		0.260[NS]
A3 (AH Plus Jet)	Coronal	0.41±0.22	1.68±1.02	1.46±0.36[b]	< 0.001[HS]
	Apical	0.8±0.48	2.96±0.9		< 0.001[HS]
	Overall	0.60±0.25[b]	2.32±0.54[b]		< 0.001[HS]
P-value**		< 0.001[HS]	< 0.001[HS]	< 0.001[HS]	

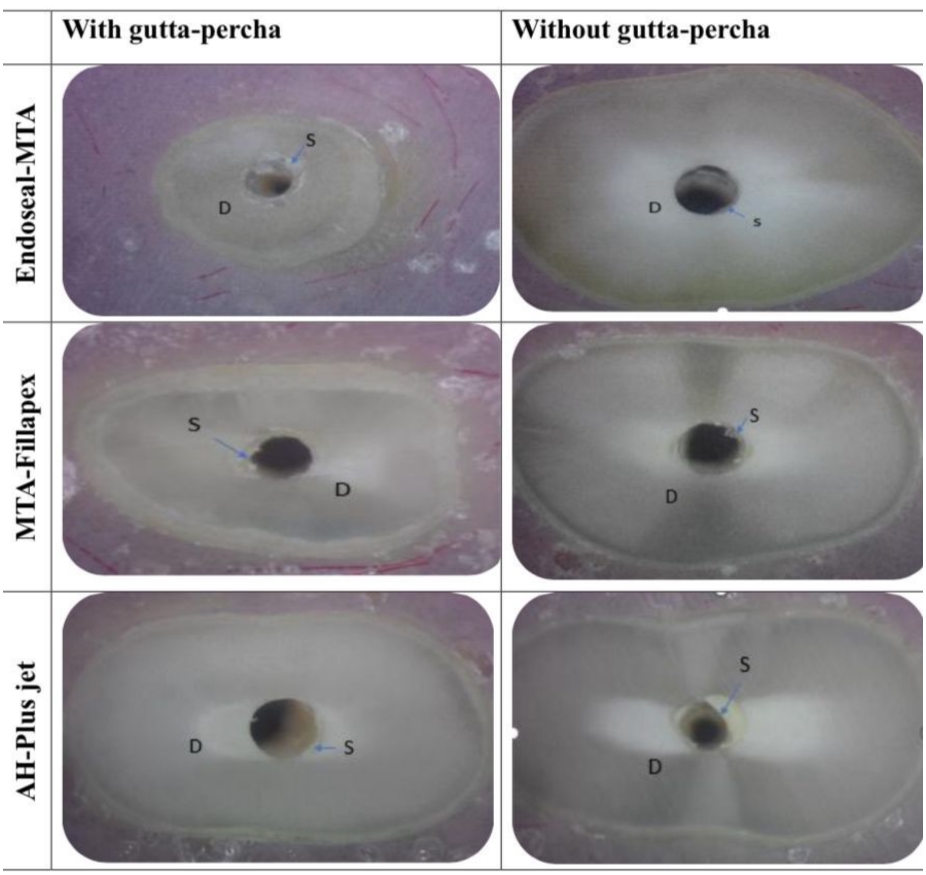

Figure 3. Photographs with a stereomicroscope showing adhesive and mixed failure in all sealer groups between sealer (S), dentine (D).

Table 2. Comparison of gap percentage in the different groups with and without gutta percha.

	With gutta-percha	Without gutta-percha	P-value
Endoseal-MTA	1.68±0.95	2.18±1.17^{a}	0.200
MTA-Fillapex	1.98±1.05	2.63±0.66^{a}	0.069
AH-Plus Jet	2.38±1.23	1.08±0.73^{b}	< 0.001**
P-value*	0.209	0.002*	

Data are presented as mean ± SD. MTA: mineral trioxide aggregate, * Significant P value (<0.05), **Highly significant p -value (<0.001). Superscript letters denoting significance between sealers in vertical direction.

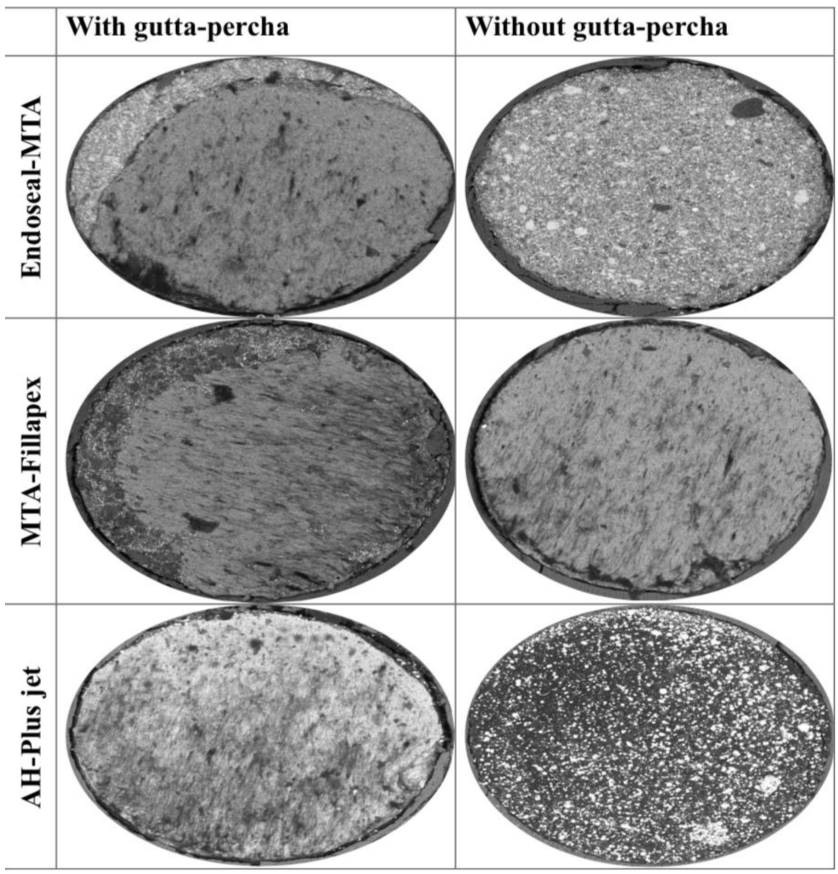

Figure 4. Representative SEM photomicrographs at 500× for different subgroups & groups.

Table 3. Correlation between the percentage of gap in the sealer-dentine interface and push-out bond strength results in the three types of sealers with and without GP core.

	r**	P-value	Correlation type
A1B1	-0.491	0.013*	Moderate Negative
A1B2	-0.444	0.026*	Moderate Negative
A2B1	-0.362	0.096	Moderate Negative
A2B2	-0.381	0.078	Moderate Negative
A3B1	-0.579	0.002*	Moderate Negative
A3B2	-0.656	< 0.001*	Moderate Negative

A1: Endoseal MTA, A2: MTA fillapex, A3: AH Plus Jet, B1: with gutta-percha cones, B2: without gutta-percha.
**r Pearson Correlation. * Significant P value (<0.05).

DISCUSSION

Gutta-percha itself traditionally lacks inherent adhesive properties to dentine; the sealer acts as the critical link, aiming to bond both to the dentinal walls and the gutta-percha. The quality of this bond is paramount for preventing microleakage and maintaining the integrity of the root canal filling. The plasticity of gutta-percha and its bond with the sealer influence the overall bond strength and long-term success of root canal obturation. The thermoplastic nature and plasticity of gutta-percha allow it to be heated and compacted, enabling it to adapt closely to the complex and irregular morphology of the root canal system, including lateral canals and fins, which are often inaccessible to more rigid materials. This close adaptation reduces the potential for voids and provides a better foundation for the sealer to create a tight seal (15).

It has been noted that the obturation procedure influences the endodontic sealer's adherence to root canal dentine. The effects of the obturation technique on bioceramic sealers are still little understood, while the single cone technique has been demonstrated to have an inferior bond strength compared to cold lateral compaction employing epoxy resin sealer (16).

The single cone obturation approach is frequently linked to positive results in root canals that are spherical, narrow, and regular. In cases with irregularly shaped root canals, the result might not be adequate. This method has become popular since it is quick and easy to use, and it does not need compaction. The results of this approach are more dependent on the sealer's qualities (physical, biological, and chemical properties) because it uses a larger volume of sealer than the compaction and condensation processes (16). That is why it is used in the current study.

Bioceramic sealers have many benefits, including biocompatibility that prevents rejection of surrounding tissues. Besides, bioceramic sealers are based on calcium phosphate or calcium silicate, which improves the setting properties of bioceramic and results in a crystalline framework with a chemical structure the same as bone or tooth apatite material, improving sealer-to-root dentine bonding (16, 17).

EndoSeal MTA is a calcium silicate MTA-based sealer. It is composed of premixed paste and pozzolan cement, which exhibits exceptional MTA biological and physical properties.

Regarding the manufacturer, it consists of calcium sulfates, calcium aluminoferrite, and calcium silicates and luminates (18).

AH Plus Jet is a modified root canal sealant associated with epoxy resin. Because of its exceptional qualities, including its little expansion, low solubility, adherence to good sealing capability, and dentine, AH Plus is regarded as the golden standard sealer that serves as a benchmark (19).

In this research, the sealer was only used in obturation to evaluate the bond strength specifically of the sealer itself. A tiny section of a filled root canal with a somewhat conical shape is visible when endodontically treated roots are sliced into slices as thick as 2 mm. The steel plunger that is used to force the tested substrate out of the filler must be positioned in the center. The pushout test has been criticized due to the high degree of setup variability. Results are influenced by variables such as borehole size and taper preparation, testing speed, slice thickness, and plunger size. Furthermore, because root canals are not entirely round, it is rarely possible to calculate the true diameter when testing root canal fillings. The pushout test has been first attempted to be standardized for testing adherence to coronal dentine in bovine teeth. As slices are cut before dentine bonding, specimen manufacturing results in nearly no stress at the bonding contact, which is a good development over the micro-tensile test. Unlike shear tests, they do not also need to be demounted in a particular matrices' holder (20).

The relationship between plunger sizes and root canal diameters may influence the validity and outcomes of the push-out bond strength test (21). In the present study two plunger sizes were used (0.5 and 0.9 mm diameter) for coronal and apical sections separately, according to Tuncer *et al*. and Mohamed *et al*. (22, 23).

To ensure standardization throughout the procedure, ninety obtained human single-rooted mandibular premolar teeth were chosen in the current study to manage confounding factors as anatomical discrepancies. Decoronation of each tooth was done perpendicular to its long axis to allow straight-line access and standardization of the root length from the apex to the orifice (14mm) (10).

According to the present study results, we rejected the null hypothesis, as there is a significant difference in push-out bond strength results between the three tested sealers: AH Plus, MTA Fillapex, and EndoSeal MTA Plus.

AH Plus Jet shows higher push-out bond strength than MTA Fillapex. The current study is consistent with previous research investigations (5, 24). It has previously been established that AH Plus Jet's root dentine micro retention is enhanced by low polymerization stress, effective molecular cohesion, and long-term dimensional stability (24).

EndoSeal MTA showed a more powerful bond than AH Plus Jet and MTA Fillapex. EndoSeal MTA appears to include a significant amount of MTA, which produces bioactivity and could account for its good binding strength results. Furthermore, the manufacturer claims that EndoSeal MTA exhibits exceptional flowability, which could be attributed to the sealer's capability to penetrate dentinal tubules, anatomical abnormalities, or auxiliary canals, hence increasing sealing capacity and bond strength. Additionally, EndoSeal MTA has superior distribution of dentinal walls that might arise from its self-setting, injection-type, which offers a clinically advantageous application (25).

Compared to MTA Fillapex, EndoSeal MTA demonstrated noticeably better bond strength performance. Adhesion capacity is significantly impacted by a root canal sealer's chemical component. Calcium silicate, the foundation material of EndoSeal MTA, has a chemical component similar to that of MTA cement.

Previous researchers have demonstrated that EndoSeal MTA consistently promotes dentinal tubule mineralization, forming a sealer tag, and exhibits comparable levels of radiopacity, biocompatibility, solubility, and high alkalinity to commercially available MTA (25, 26).

In the current study, the specimens were kept for 7 days to ensure the complete sealer setting. The claim of dentinal tags being "formed within a short 7-day period" is partially supported in the context of initial mineral precipitation and early sealing provided by highly bioactive materials like calcium silicate-based cements. These materials can indeed initiate a rapid biomineralization process that effectively seals dentinal tubules and forms a mineralized interface within this timeframe. The full maturation and development of robust, well-defined dentinal tags, comparable to a hybrid layer formed with resin adhesives, likely requires a longer period than 7 days (27).

In agreement with a previous study, the present finding demonstrates that exclusive MTA-based sealer application in obturation enhances calcium ion release, thereby improving biomineralization potential (28).

In this investigation, MTA Fillapex yielded the worst results. This is consistent with earlier studies that also found low bond strength values for MTA Fillapex. This paste-to-paste sealer creates two significant chemical processes when mixed, the progressive hydration of the reaction and the orthosilicate ions among salicylate resin and MTA, which determines the physical-mechanical properties and material's setting. To provide the appropriate setting, MTA: salicylate resin would need to be mixed 1:1. This makes it possible for an ionic polymer to form a form that reacts with water and contains calcium silicate particles. After the reaction is complete nanoporous, and calcium hydroxide, amorphous calcium silicate hydrate gel is produced. The gel then polymerizes and solidifies into a network (29).

Regarding root sections, in all subgroups where the tested sealers were utilized in combination with gutta-percha, it was noticed that the push-out bond strength at the apical level was almost significantly more advanced than at the coronal level. This might be due to the higher percentage of gutta percha mass at the apical level in relation to the canal cross-section diameter, which increased down packing of the sealer into dentine. In addition to the round cross-section of the apical portion, which might result in more frictional resistance of obturation material against dislodgement force (30).

On the other hand, in subgroups of EndoSeal MTA and MTA Fillapex where the tested sealers were used without gutta-percha, it was observed that the push-out bond strength at the apical level is lower than at the coronal level. This might be due to the absence of gutta-percha that allows hydraulic movement of sealers towards the apical portion, so there is a lack of condensation of sealers towards the dentine wall at the apical portion. But in the subgroup of AH Plus Jet where the tested sealer was used without gutta-percha, it was found that the push-out bond strength at the apical level is higher than the coronal level. This could be due to the little diameter of the root canal at the apical level and the high flowability of the sealer, so it can move toward the apical level and increase down packing of sealer into dentine (31).

When calcium silicate-based sealers come into interaction with physiological fluids covering phosphate, they spontaneously generate an appetite layer, silicon ion incorporation, and dentine intratubular calcium, in addition to an intrafibrillar apatite deposition and the formation of tag-like structures at the sealer-dentine interface. These processes eventually result in dentine remineralization. Bioactivity-induced apatite nucleation reduces gaps at the edge and creates a micromechanical bonding system with dentine, which enhances filling material displacement resistance. The chemical composition of the material, its calcium-releasing characteristics, and the surrounding environment are all strongly related to the capacity to nucleate calcium phosphate (18-20).

While MTA Fillapex is an MTA-based sealer, there are differences in the composition and size of the particles in different MTA types. Less than 20% of MTA particles and larger percentages of resins compose MTA Fillapex, which may not be enough to fully demonstrate this cement's sealing and biological properties. Additionally, the radio pacifier in MTA Fillapex is bismuth oxide, which is linked to a rise in material degradation, porosity, and mechanical strength deterioration. Zirconium oxide mostly replaced bismuth oxide in EndoSeal MTA (32).

Silva EJ *et al*. (33) found that EndoSeal MTA exhibited an injectable bio-tight root canal sealer alternative. EndoSeal MTA showed excellent bond strength for application in endodontic therapy when linked with MTA Fillapex. In addition, Dastorani *et al*. (34) showed a comparable resistance to EndoSeal MTA Sealer in root perforation and bacterial microleakage of Pro-Root MTA.

With qualitative analysis of the failure style of specimens after the push-out test, the commonest mode of failure was the adhesive failure between the dentine wall and sealer in groups where obturation was without gutta-percha and the adhesive failure between the sealer core material in groups where obturation was with gutta-percha. This might be attributed to good bonding of the sealer to irregular dentinal walls that could resist dislodgment and minimum adhesion to gutta percha. This result came aligned with Nagas *et al*. (35).

In the absence of gutta-percha, there was a significant difference between the AH Plus Jet sealer and the other two groups. The AH Plus Jet sealer showed the lowest gap width values with the root dentine. A variety of variables could be responsible for AH Plus Jet's improved interfacial bonding and adaptability.

One possible explanation for the exceptional adaptation could be its ability to make covalent interactions among any revealed amino groups in collagen and the epoxy resin by chemical bonding to the root dentine. In addition, AH Plus Jet displays minimal polymerization stresses and compensates for polymerization shrinkage due to its chemical curing process (36).

Sönmez *et al*. (37) found that 7 days after obturation, MTA Fillapex had a worse sticking capability than AH Plus Jet. In contrast to this study, Asawaworarit *et al*. (38) found that after 7 days, AH Plus had lesser leakage than MTA Fillapex, but at 4 weeks, MTA Fillapex outperformed AH Plus Jet in terms of sealing ability. The prolonged chemical reaction time of MTA Fillapex is caused by the high ratio of salicylate resin it contains. Extended time for setting could be one possible cause for microleakage in the short term.

In the presence of gutta-percha there was no significant variance among the 3 types of sealers. Using bioceramic sealer solely without gutta-percha could be clinically conducted in some cases, as it was recommended by Nagas *et al*. (35) as it shows bigger push-out bond strength when utilized as a bulk fill without resilient gutta-percha.

The results of this examination demonstrated a weak-moderate Pearson connection between numerous metrics for all the groups, including push-out bond strength and adaptation. The adhesive's capability to wet the surfaces, the surface energy of the adherend (gutta-percha or dentine), the surface tension of the adhesive (sealer), and the purity of the adherend surface are all factors that contribute to adhesion. Dentine pretreatment chemical compounds, physical properties, and the methods of the sealer are all significant factors in the complex process of sealer adhesion to gutta-percha and dentine (22).

One of the limitations of our study is that the effect of the tested sealers with single cone obturation was not examined in curved canals. That is why more investigations are needed to examine the push-out bond strength using a single cone with MTA sealer in curved canals. Likewise, the influence of push-out bond strength and time on sealer setting is an important point to be investigated. Biological interaction of EndoSeal MTA sealer with the dentine matrix. Examining the push-out bond strength after utilizing different irrigation protocols might be an interesting point of examination.

CONCLUSIONS

EndoSeal MTA sealer has more favorable bond strength than MTA Fillapex and AH-Plus Jet in obturation without gutta-percha and the single cone obturation technique. Additionally, the obturation without gutta-percha has a positive influence on the adaptation of AH Plus Jet sealer and EndoSeal MTA sealers, but it adversely affects MTA Fillapex sealer.

CONFLICT OF INTEREST: There were no reported potential struggles of interest that were pertinent to this article.

FUNDING/SUPPORT: The authors have no financial relationships that are pertinent to this article that they will disclose.

AUTHOR CONTRIBUTION STATEMENT: Conceptualization and design: M.S. and N.E.D.R.; Literature review: M.S., N.E.D.R. and S.E.; Methodology and validation: S.E.; Formal analysis: M.S. and N.E.D.R.; Investigation and data collection: S.E.; Resources: S.E.; Data analysis and interpretation: M.S and N.E.D.R; Writing-review and editing: M.S., N.E.D.R. and S.E.C.; Supervision: M.S. and N.E.D.R. Project administration: S.E. and N.E.D.R. The manuscript has been read and approved by all the authors. The requirements for authorship have been met, and that each author believes that the manuscript represents honest work.

REFERENCES

1. Darcey J., Roudsari R.V., Jawad S., Taylor C., Hunter M. Modern endodontic principle’s part 5: obturation. Dent Update. 2016; 43: 114-29.
2. Rathi C.H., Chandak M., Nikhade P., Mankar N., Chandak M., Khatod S., et al. Functions of root canal sealers-a review. J Evolution Med Dent Sci. 2020; 9: 1454-58.
3. Komabayashi T., Colmenar D., Cvach N., Bhat A., Primus C., Imai Y. Comprehensive review of current endodontic sealers. Dent Mater J .2020; 39: 703-20.
4. Raghavendra S.S., Jadhav G.R., Gathani K.M., Kotadia P. Bioceramics in endodontics-a review. Journal Ist Uni. 2017; 51: 128-37.
5. Ragab M., Sharaan M. Influence of the Remnants of Silicone Oil on Penetration of Three Different Sealers into the Dentinal Tubules: A Confocal Laser Scanning Microscopy Study. Euro Endo J .2022; 7: 234-40.
6. ElAsfouri H.A., Saba A.A.A. Comparative evaluation of the adaptation of two calcium silicate-based endodontic sealers with a conventional resin-based sealer to dentinal walls: An In vitro scanning electron microscopic study. Egy Dent J .2019; 65: 2481-9.
7. Cabral M.A., da Silva Limoeiro A.G., De Martin A.S., Fontana C.E., Pelegrine R.A.,

da Silveira Bueno C.E., et al. Influence of root canal moisture conditions on the bond strength of endodontic sealers to dentine. Res Soc. 2022; 11: e285111133714-e.

8. Nagendrababu, V., Murray, P, Agendrababu, V., Murray, P. E., Ordinola-Zapata, R., Peters, OO.A., Rôças I.N., Siqueira, J.F. Jr, et al. PRILE 2021guidelines for reporting laboratory studies in Endodontology: explanation and elaboration. Int. Endo. J. 2021; 54: 1491-1515.
9. Pécora J.D., Cussioli A.L., Guerişoli D., Marchesan M.A., Sousa-Neto M.D. Evaluation of Er: YAG laser and EDTAC on dentine adhesion of six endodontic sealers. Braz Dent J. 2001; 12: 27- 30.
10. Zhou H.-m., Shen Y., Zheng W., Li L., Zheng Y.-f., Haapasalo M. Physical properties of 5 root canal sealers. J Endod. 2013; 39: 1281-6.
11. Arora S., Hegde V. Comparative evaluation of a novel smart-seal obturating system and its homogeneity of using cone beam computed tomography: In vitro: simulated lateral canal study. J Conserv Dent. 2014; 17: 364-8.
12. Nagas E., Uyanik M.O., Eymirli A., Cehreli Z.C., Vallittu P.K., Lassila L.V., et al. Dentine moisture conditions affect the adhesion of root canal sealers. J Endod. 2012; 38: 240-4.
13. Naser S.H., Al-Zaka I.M. Push-out bond strength of different root canal obturation materials. J Bagh Coll Dent. 2013; 325: 1-7.
14. Eltair M., Pitchika V., Hickel R., Kühnisch J., Diegritz C. Evaluation of the interface between gutta-percha and two types of sealers using scanning electron microscopy (SEM). Clin Oral Investig. 2018; 22: 1631-9.
15. Andriukaitiene L., Song X., Yang N., Lassila L.V., Vallittu P.K., Kerosuo E. The effect of smear layer removal on E. faecalis leakage and bond strength of four resin-based root canal sealers. BMC Oral Health. 2018; 18: 1-9.
16. Al-Hiyasat A.S., Alfirjani S.A. The effect of obturation techniques on the push-out bond strength of a premixed bioceramic root canal sealer. J Dent. 2019; 89: 103169.
17. Loushine B.A., Bryan T.E., Looney S.W., Gillen B.M., Loushine R.J., Weller R.N., et al. Setting properties and cytotoxicity evaluation of a premixed bioceramic root canal sealer. J Endod. 2011; 37 (5): 673-7.
18. Dem K., Wu Y., Kaminga A.C., Dai Z., Cao X., Zhu B. The push out bond strength of polydimethylsiloxane endodontic sealers to dentine. BMC oral health .2019; 19 (1): 1-6.
19. Tyagi S., Mishra P., Tyagi P. Evolution of root canal sealers: An insight story. Eur J Dent.2013; 2: 199-218.
20. Brichko J., Burrow M.F., Parashos P. Design variability of the push-out bond test in endodontic research: a systematic review. J Endod. 2018; 44: 1237-45.
21. Pane E.S., Palamara J.E., Messer H.H. Critical evaluation of the push-out test for root canal filling materials. J Endod. 2013; 39: 669-73.
22. Kara Tuncer A., Tuncer S., Gökyay S.S. Correlation between sealer penetration into dentinal tubules and bond strength of two

new calcium silicate-based and an epoxy resin-based, endodontic sealer. J of Adh Sci Tech. 2014; 28: 702-10.

23. Mohamed D., Ali R., Badawy R.E-s. Comparative evaluation of the interfacial adhesion ability of single versus lateral compaction obturation techniques using different sealer types. an in-vitro study. Egy Dent J. 2022; 68: 2967-83.
24. Silva E., Perez R., Valentim R., Belladonna F., De-Deus G., Lima I., et al. Dissolution, dislocation and dimensional changes of endodontic sealers after a solubility challenge: a micro- CT approach. Int Endod J. 2017; 50: 407-14.
25. Kim R.J.Y., Shin J.H. Cytotoxicity of a novel mineral trioxide aggregated-based root canal sealer. Dent Mater J. 2014; 33: 313-8.
26. Yoo Y.J., Baek S.H., Kum K.Y., Shon W.J., Woo K.M., Lee W. Dynamic intratubular biomineralization following root canal obturation with pozzolan-based mineral trioxide aggregate sealer cement. Scanning. 2016; 38: 50-6.
27. Kunert, M., Piwonski, I., Hardan, L., Bourgi, R.,Sauro, S., Inchingolo, F., Lukomska-Szymanska, M. Dentine Remineralisation Induced by “Bioactive” Materials through Mineral Deposition: An In Vitro Study. Nanomaterials. 2024; 14: 274.
28. Retana-Lobo C., Tanomaru-Filho M., Guerreiro-Tanomaru J.M., Benavides-García M., Hernández-Meza E., Reyes-Carmona J. Push-Out Bond Strength, Characterization, and Ion Release of Premixed and Powder-Liquid Bioceramic Sealers with or without Gutta-Percha. Scanning. 2021.
29. Vitti R.P., Prati C., Sinhoreti M.A.C., Zanchi C.H., e Silva M.G.S., Ogliari F.A., et al. Chemical-physical properties of experimental root canal sealers based on butyl ethylene glycol Di salicylate and MTA. Dent Mat. 2013; 29: 1287-94.
30. Arikatla S.K., Chalasani U., Mandava J., Yelisela R.K. Interfacial adaptation and penetration depth of bioceramic endodontic sealers. J Conserv Dent. 2018; 21: 373-7.
31. Almas Begum A. Characterization of a New Bioactive Calcium Silicate Cement: An Invitro study: Madha Dental College and Hospital, Chennai; master’s thesis 2020.
32. Gandolfi M.G., Taddei P., Modena E., Siboni F., Prati C. Bio interactivity-related versus Chemi/physisorption-related apatite precursor-forming ability of current root end filling materials. J Biomed Mater Res B Appl Biomater. 2013; 101:1107-23.
33. Silva E.J.N.L., Carvalho N.K., Prado M.C., Zanon M., Senna P.M., Souza E.M., et al. Push-out bond strength of injectable pozzolan-based root canal sealer. J Endod. 2016; 42: 1656-9.
34. Dastorani M., Shourvarzi B., Nojoumi F., Ajami M. Comparison of bacterial microleakage of endoseal MTA sealer and pro-root MTA in root perforation. J Dent. 2021; 22 (2): 96.
35. Nagas E., Cehreli Z., Uyanik M.O., Durmaz V. Bond strength of a calcium silicate-based sealer tested in bulk or with different main core materials. Braz Oral Res. 2014; 28: 1-7.
36. De-Deus G., Brandão M., Leal F., Reis C., Souza E., Luna A., et al. Lack of correlation between sealer penetration into dentinal tubules and sealability in nonbonded root fillings. Int Endod J. 2012; 45: 642-51.
37. Sönmez I., Oba A., Sönmez D., Almaz M. In vitro evaluation of apical microleakage of a new MTA-based sealer. Euro Arch Paed Dent. 2012; 13: 252-5.
38. Asawaworarit W., Yachor P., Kijsamanmith K., Vongsavan N. Comparison of the apical sealing ability of calcium silicate-based sealer and resin-based sealer using the fluid-filtration technique. Med Princ Pract. 2016; 25: 561-5.