Research Square

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Comparison of Push-Out Bond Strength of Root Canals Obturated with Resin- Based and Bioactive Glass Sealers: An Ex Vivo Study

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Abstract

Background

The success of endodontic therapy relies on a three-dimensional seal to prevent microbial recontamination. Epoxy resin-based sealers like AH Plus® are favored for their mechanical properties and dentinal collagen bonding, but potential cytotoxicity is a concern. Bioactive glass-based sealers, such as Nishika Canal Sealer BG®, are osteoinductive alternatives that form hydroxyapatite crystals with dentinal fluids. This study evaluated the push-out bond strength and failure dynamics of Nishika BG® versus AH Plus® across radicular regions.

Methods

Forty extracted single-rooted mandibular premolars were instrumented to a master apical file size of X5 (size 50, .06 taper) using the ProTaper Next system. After irrigation with 2.5% NaOCl and 17% EDTA, specimens were obturated with gutta-percha cones and randomly assigned to AH Plus® or Nishika BG® groups (n = 20). Roots were embedded in resin and sectioned into 2-mm slices at apical (3 mm), middle (6 mm), and coronal (9 mm) levels. Push-out bond strength was measured with a universal testing machine at 0.1 mm/min. Failure modes were classified as adhesive, cohesive, or mixed via stereomicroscopy. Data were analyzed using independent T-tests and one-way ANOVA followed by Tukey's post-hoc test.

Results

Nishika BG® showed higher bond strength in the coronal (2.57 ± 0.25 MPa) and middle thirds (2.82 ± 0.26 MPa) than AH Plus® (1.09 ± 0.11 MPa and 0.89 ± 0.11 MPa, respectively). In the apical third, both sealers achieved their highest values, with no significant difference ($p > 0.05$). Failure mode analysis showed mixed failures in both groups; AH Plus had high interfacial adhesion with zero adhesive failures and 33.3% cohesive failures, while Nishika BG showed fewer adhesive failures (8.3%).

Conclusions

Nishika BG® is a reliable, biologically integrated alternative to resin-based sealers. Its enhanced dislodgement resistance in the coronal and middle segments is due to mineral induction and hydroxyapatite precipitation within tubule-dense dentin. Both sealers provide a robust apical seal, ensuring suitability for cases requiring post space preparation.

Introduction

The primary objective of endodontic intervention is the prevention and interception of pulpal and periradicular pathosis, exemplified by apical periodontitis, to preserve the function of the natural dentition (AAE, 2018). This objective is achieved through the clinical paradigm of eliminating microbial irritants by means of thorough chemomechanical preparation of the root canal system, followed by high-quality, three-dimensional obturation with a hermetic seal to prevent microbial recontamination and support periradicular healing. This sealing prevents bacterial ingress and ensures long-term treatment success (1). The effectiveness of root canal sealers in achieving this seal is paramount, and various materials have been investigated over the years for their sealing properties, adhesion to dentin, and biocompatibility (2).

Gutta-percha has been the most commonly used root canal filling material for over a century because of its favorable handling and biocompatibility. However, gutta-percha does not inherently provide a hermetic seal and requires the use of a root canal sealer to fill voids and enhance its sealing ability (3). Among these, resin-based sealers, such as AH Plus® (Dentsply Maillefer, Ballaigues, Switzerland), are widely used because of their superior bonding properties to dentin. These sealers penetrate the dentinal tubules, provide strong adhesion to the root canal walls, and have low solubility, enhancing the overall sealing effectiveness (4, 5). Despite their advantages, resin-based sealers, such as AH Plus®, can be cytotoxic during setting (6), potentially causing adverse reactions owing to their chemical composition, particularly epoxy resins and amines (7). This has prompted ongoing research into alternative root canal sealers that offer enhanced biocompatibility without compromising sealing properties.

A promising alternative is bioactive glass-based sealers, such as Nishika Canal Sealer BG® (Nippon Shika Yakuhin, Yamaguchi, Japan). These materials are designed to form hydroxyapatite (HA) crystals upon contact with bodily fluids, promoting bioactivity and better integration with dentin. It also exhibits prominent biocompatibility and low cytotoxicity to periapical tissue (8). Bioactive glasses are known for their ability to chemically bond with hard and soft tissues (9, 10), which may promote a more durable and biologically favorable seal than traditional materials. The Nishika BG® penetrates the dentinal tubules and forms a strong bond with the root canal walls, potentially providing superior sealing capabilities (11).

Reliable in vitro evaluation methods are crucial for critically assessing the sealing capabilities of root canal sealers. The push-out bond strength test is considered one of the most accurate and reliable laboratory methods for evaluating the adhesion between root canal filling materials and dentin. This method demonstrates low variability and is sufficiently sensitive to detect subtle differences in bond strength under clinically relevant conditions (12, 13). In this test, force is applied parallel to the adhesion interface, allowing for a more realistic assessment of the resistance of the sealer to dislodgement than tests applying perpendicular forces (12, 14). However, the push-out bond strength of bioactive glass sealer in comparison to resin-based sealers is not clearly established. Therefore, this study aims to evaluate and compare the sealing ability of Nishika BG® with AH Plus® sealer in single-rooted teeth using push-out bond strength test.

Materials and Methods

This study was approved by the Human Research Ethics Committee of Naresuan University (approval no. P1-0087/2566). The sample size was calculated using G*Power 3.1 with α = 0.05, power = 0.8, and an effect size of 1, resulting in 17 required specimens; however, 20 teeth were included in each sealer group to account for any possible error. Mandibular first premolars extracted for orthodontic purposes were collected and stored in 0.1% thymol solution. Single-root teeth with straight or slightly curved canals, based on Schneider's classification (15), were selected. Only teeth exhibiting no caries extending to the cementoenamel junction, no cracks or fractures investigated under 10× magnification using an OPMI Pico dental microscope (Carl Zeiss, Jena, Germany), fully closed apices, and a single canal configuration consistent with Vertucci Type I confirmed radiographically (M–D and B–L views) were included. Teeth with caries extending to the CEJ, cracks, open apices, multiple canals, or canal curvature exceeding 5° were excluded. All teeth were cleaned using an ultrasonic scaler, and the root portion was standardized to a length of 14 mm using an SS White Superflex diamond disc (SS White Dental, Lakewood, NJ, USA). The working length was established by inserting a #10 K-file until its tip reached the apical foramen and subtracting 1 mm from this measurement. Chemomechanical preparation was performed using the ProTaper Next system (Dentsply Sirona, Johnson City, TN, USA) in the following sequence: X1 (size 17, .04 taper), X2 (size 25, .06 taper), X3 (size 30, .075 taper), X4 (size 40, .065 taper), and X5 (size 50, .06 taper). Each file was advanced to the full WL with RC-Prep (Premier Dental Products Company, Plymouth Meeting, PA, USA) used as a lubricant. Between each instrument change, the canals were irrigated with 2 mL 2.5% NaOCl. Instrumentation for each size was concluded once the WL was reached, and canal patency was verified throughout the procedure using a #10 K file. Final irrigation was performed with 17% EDTA (5 mL for 1 min), followed by 2 mL of normal saline before the canals were dried with paper points. A ProTaper Next Conform Fit™ Gutta-Percha X5 cone was fitted to the working length, with radiographic confirmation of apical adaptation.

The specimens were randomly assigned to two groups (n = 20 each) according to the sealer type: AH Plus® or Nishika BG®, both mixed according to the manufacturer's instructions. Root canal obturation was performed using the downpack–backfill technique with Conform fit gutta-percha cones, cut using the Super Endo Alpha II system (B&L Biotech) at temperatures not exceeding 180°C. Root canal fillings were confirmed to have a homogeneous density using periapical radiographs in both mesio-distal and bucco-lingual directions. The coronal access was sealed with Cavit, and the roots were wrapped in moist gauze and stored at 37°C with 100% humidity for 24 h to allow complete sealer setting.

For the push-out bond strength test, each root was embedded in resin with its long axis oriented perpendicular to the block base, as verified using a surveyor. After resecting the apical 1 mm of the tip, the root was sectioned into three levels at the apical (3 mm from the apex), middle (6 mm), and coronal (9 mm) positions using a Buehler Isomet 5000 saw to produce slices with a 2-mm thickness. Specimens exhibiting asymmetry, premature debonding, voids, or cracks under stereomicroscopy (1.6× magnification) were excluded. Push-out testing was performed using an Instron 8872 universal testing machine with plungers of 0.3 mm, 0.5 mm, and 0.8 mm diameters for apical, middle, and coronal slices, respectively. The load was applied vertically at 0.1 mm/min from the apical to coronal direction until debonding occurred. The maximum force (N) prior to dislodgement was recorded and converted to bond

strength (MPa). Failure modes were examined under a light stereomicroscope and classified as adhesive (failure at the sealer-dentin interface), cohesive (failure within the sealer), or mixed.

Statistical analyses were performed using a significance level of $p < 0.05$. Prior to inferential testing, data normality and variance homogeneity were verified using the Kolmogorov–Smirnov and Levene's tests, respectively. Continuous variables are expressed as Mean ± Standard Deviation (SD) Differences in the mean push-out bond strength between the AH Plus® and Nishika BG® groups were compared at the same root sections using T-test. Regional comparisons across the coronal, middle, and apical thirds within each sealer were evaluated using one-way analysis of variance (ANOVA), followed by Tukey's post-hoc test for multiple comparisons.

Result

Table 1 shows the mean push-out bond strength values (MPa ± SD) of the sealers with standard deviations at different root canal levels. Differences in the mean push-out bond strength between the two groups were analyzed using one-way ANOVA and Tukey's post-hoc test. From Fig. 1, the AH Plus® group exhibited the highest push-out bond strength at the apical level (2.69 ± 0.25 MPa), followed by the coronal (1.09 ± 0.11 MPa) and middle levels (0.89 ± 0.11 MPa). In contrast, the Nishika Canal Sealer BG® exhibited the highest bonding at the apical level (3.94 ± 0.24 MPa), followed by the middle (2.82 ± 0.26 MPa) and coronal levels (2.57 ± 0.25 MPa). Cross-root-level comparisons were performed using Tukey's post-hoc test. Figure 2 shows the push-out bond strengths within each sealer group. The Nishika BG exhibited significantly higher push-out bond strength than AH Plus® in the middle and coronal regions, whereas no significant differences were observed in the apical third. Within-group comparisons revealed that Nishika BG varied significantly across all three root levels, whereas AH Plus® showed a significant difference only in the apical third.

Failure mode analysis indicated that AH Plus® predominantly exhibited mixed (66.7%) and cohesive (33.3%) failures, with no adhesive failures. Nishika BG® primarily showed mixed failures (73.3%), with fewer cohesive (18.3%) and adhesive failures (8.3%).

Table 1
Mean push-out bond strength values (MPa ± SD) of sealers at different root canal levels

Sealer	Coronal Third (n = 20)	Middle Third (n = 20)	Apical Third (n = 20)
AH Plus®	1.09 ± 0.11	0.89 ± 0.11	2.69 ± 0.25
Nishika BG®	2.57 ± 0.25	2.82 ± 0.26	3.94 ± 0.24

Discussion

The clinical success of root canal treatment depends on achieving a three-dimensional hermetic seal within the root canal system (1). Various obturation techniques have been developed to optimize the seal. The downpack-backfill technique was employed in this study. This method allows gutta-percha to

adapt to the canal walls approximately 3 mm from the working length, producing a contact comparable to that of the single-cone technique, ensuring high-quality obturation (16). However, thermoplasticized GP injection techniques are used in regions beyond 3 mm from the working length. These techniques enhance the adaptation of gutta-percha to the coronal portion of the canal, resulting in a more homogeneous filling than other conventional methods (17). Successful obturation also requires a root canal sealer to act as an intermediary between gutta-percha points and between gutta-percha and the dentinal walls of the canal (18).

An ideal root canal sealer should possess properties that enable effective penetration into the dentinal tubules along the canal walls and promote reliable adhesion to the radicular dentin (1, 19, 20). Adequate tubular penetration enhances micromechanical interlocking and improves the interfacial adaptation between the obturation material and dentin. Adhesion to the canal walls can be evaluated using various laboratory methods. However, no single test method is considered the gold standard for assessing adhesive performance, as in vitro conditions cannot fully replicate the complex environment of natural teeth in vivo. Despite these limitations, the push-out bond strength test is widely accepted as a practical and reproducible method for assessing the adhesion of root canal filling materials to dentin (21). The push-out test provides a quantitative measure of the interfacial bond strength between the obturation material and canal wall (12, 13) and remains the most frequently employed experimental model in endodontic research laboratories (14). Sealers that demonstrate superior adhesion to radicular dentin exhibit higher push-out bond strength values, reflecting the enhanced sealing ability of the root canal filling (12).

The AH Plus® sealer is one of the most widely used root canal sealers because of its favorable mechanical properties. It can form covalent bonds with collagen within the dentinal tubules(22). This chemical bonding, along with micromechanical interlocking, enhances the adhesion between the root canal filling material and the radicular dentin (23, 24). Our push-out bond strength results for the AH Plus® sealer in mandibular first premolars aligned with those of a previous study that used mandibular molars with single root canals of similar characteristics (22). However, these results contradict the findings of some studies because of the use of different root canal obturation techniques, which resulted in varying values across the studies (18, 20, 25).

Based on our results comparing the push-out bond strengths of resin-based and bioactive glass root canal sealers at the corresponding canal levels, the bioactive glass sealer showed significantly higher push-out bond strength at the coronal and middle thirds than the resin-based sealer. This finding may be attributed to the dentinal tubule anatomy. The coronal and middle thirds contain dentinal tubules with larger diameters and greater tubular densities than those in the apical third (26). These features may facilitate the deeper penetration of the bioactive glass sealer into the dentinal tubules, promoting micromechanical interlocking and interfacial adaptation. A previous study investigated the hydroxyapatite crystal formation and sealing ability of bioactive-glass-based sealers. Their findings showed that Nishika BG® releases ionic components that react with the tissue fluids in the dentinal tubules. This reaction elevates the local pH to approximately 10, creating conditions for hydroxyapatite

crystallization. Once complete, hydroxyapatite crystals precipitate along the root canal wall interface, promoting bonding between the sealer and radicular dentin. The bioactivity of bioactive glass sealers, particularly their ability to induce hydroxyapatite formation along the dentinal wall (8), contributes to improved interfacial adhesion and explains the higher push-out bond strength compared with resin-based sealers. Resin-based sealers primarily rely on covalent bonding mechanisms, such as epoxy ring-opening reactions with amino groups in dentinal collagen (22), without the deposition of bioactive minerals. When root canal obturation uses clinically the single-cone technique without subsequent post placement, a bioactive glass sealer may be the appropriate choice because of its superior adhesion and bioactive bonding potential.

Based on the push-out bond strength evaluation at different canal levels, both resin-based and bioactive glass sealers demonstrated significantly lower bond strengths at the coronal and middle thirds than at the apical third. This finding may be related to the instrumentation and the obturation protocol used. Although sealer penetration into dentinal tubules is generally reduced apically due to smaller tubular diameter and density, the canals were prepared with ProTaper Next instruments from size X1 to X5 to the full working length, followed by obturation with a matched Conform Fit X5 gutta-percha cone. This approach resulted in intimate adaptation of the master cone to the apical canal walls, creating tight apical adaptation. The close conformity between gutta-percha and dentin likely increased frictional resistance and mechanical retention, thereby enhancing resistance to dislodgement during the push-out bond strength testing. Both sealers exhibited significantly higher push-out bond strengths in the apical third than in the coronal and middle thirds

Failure mode analysis provides critical insights into the interfacial integrity between the sealer and radicular dentin (12, 13). In this study, mixed failure was the predominant mode for both groups, suggesting that dislodgement resistance arises from a combination of chemical adhesion and micromechanical interlocking (1, 22). The AH Plus® exhibited high interfacial adhesion with 0.0% adhesive failures and 33.3% cohesive failures. This indicates that covalent bonding formed via epoxy ring-opening reactions with dentinal collagen often exceeds the internal cohesive strength of the sealer (22).

Conversely, the Nishika BG® exhibited 73.3% mixed, 18.3% cohesive, and 8.3% adhesive failure. Its cohesive failures are attributed to bioactivity, where ionic species react with dentinal fluid to create an alkaline environment (pH ≈ 10) and induce hydroxyapatite formation. This ionic bond provides a high interfacial strength that effectively integrates the sealer with the radicular dentin (8).

Conclusion

Within the limitations of this *ex vivo* study, Nishika Canal Sealer BG demonstrated superior push-out bond strength compared to AH Plus in the coronal and middle segments of the root canal. This outcome is primarily attributed to the bioactivity of the sealer and the induction of hydroxyapatite formation within the tubule-dense dentin of these regions. Both materials exhibited their highest and most comparable

bonding performance in the apical region, ensuring the robust seal necessary for long-term clinical success. Failure mode analysis indicated the predominance of mixed failures in both groups. Notably, the bioactive glass sealer exhibited a higher frequency of cohesive failure than the resin-based sealer, suggesting that its interfacial adhesion to dentin may exceed its internal material strength. From a clinical perspective, both sealers are suitable for obturation using techniques that ensure tight apical adaptation, such as the single-cone technique and provide sufficient bonding for cases requiring subsequent post placement. The Nishika BG® represents a biologically integrated alternative to traditional resin-based sealers when enhanced adhesion and mineral induction are desired.

Abbreviations

• AAE
American Association of Endodontists
• ANOVA
Analysis of variance
• CEJ
Cementoenamel junction
• EDTA
Ethylenediaminetetraacetic acid
• GP
Gutta-percha
• HA
Hydroxyapatite
• MPa
Megapascal
• NaOCl
Sodium hypochlorite
• SD
Standard deviation
• WL
Working length

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Naresuan University Institutional Review Board (Approval No. P1-0087/2566). All experimental protocols and procedures involving the use of human samples were performed in accordance with Declaration of Helsinki. Since this ex vivo study utilized anonymized, extracted human teeth that were collected as discarded biological waste, the requirement for informed consent was waived by the Naresuan University Institutional Review Board.

Consent for publication

Not applicable. This study does not contain any individual person's data in any form.

Competing interests

The authors declare that they have no competing interests regarding the publication of this research.

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Author Contribution

Conceptualisation, K. Ketpan; Methodology, K. Ketpan, K. Wisithphrom, K. Jarassri and P. Phucharoen; Software, P. Phucharoen; Validation, K. Ketpan, and K. Ruksakiet; Formal analysis, P. Phucharoen; Investigation, P. Phucharoen; Visualisation, P. Phucharoen; Writing—Original Draft, K. Ruksakiet and P. Phucharoen; Writing—Review & Editing, K. Ketpan, K. Ruksakiet, P. Rattanaruangwirot, Z.M. Lohinai and P. Puapichartdumrong; Funding acquisition, K. Ketpan, P. Puapichartdumrong and K. Ruksakiet.

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Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

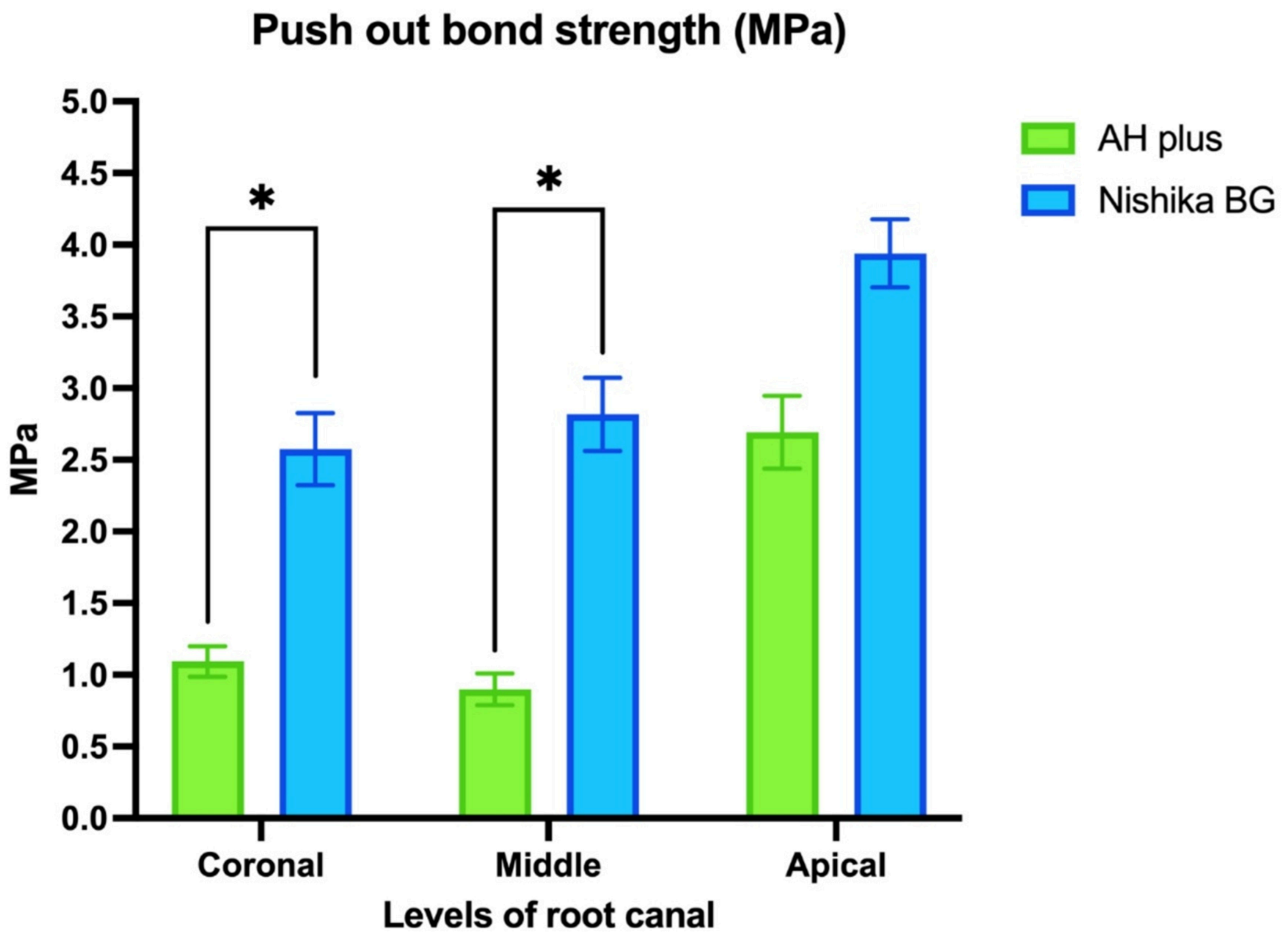


Figure 1

Mean push-out bond strength (MPa±SD) observed in the coronal, middle, and apical thirds were compared between AH plus® and Nishika BG®. T-test when comparing two sealers at the same levels; * statistically significant ($p < 0.05$).

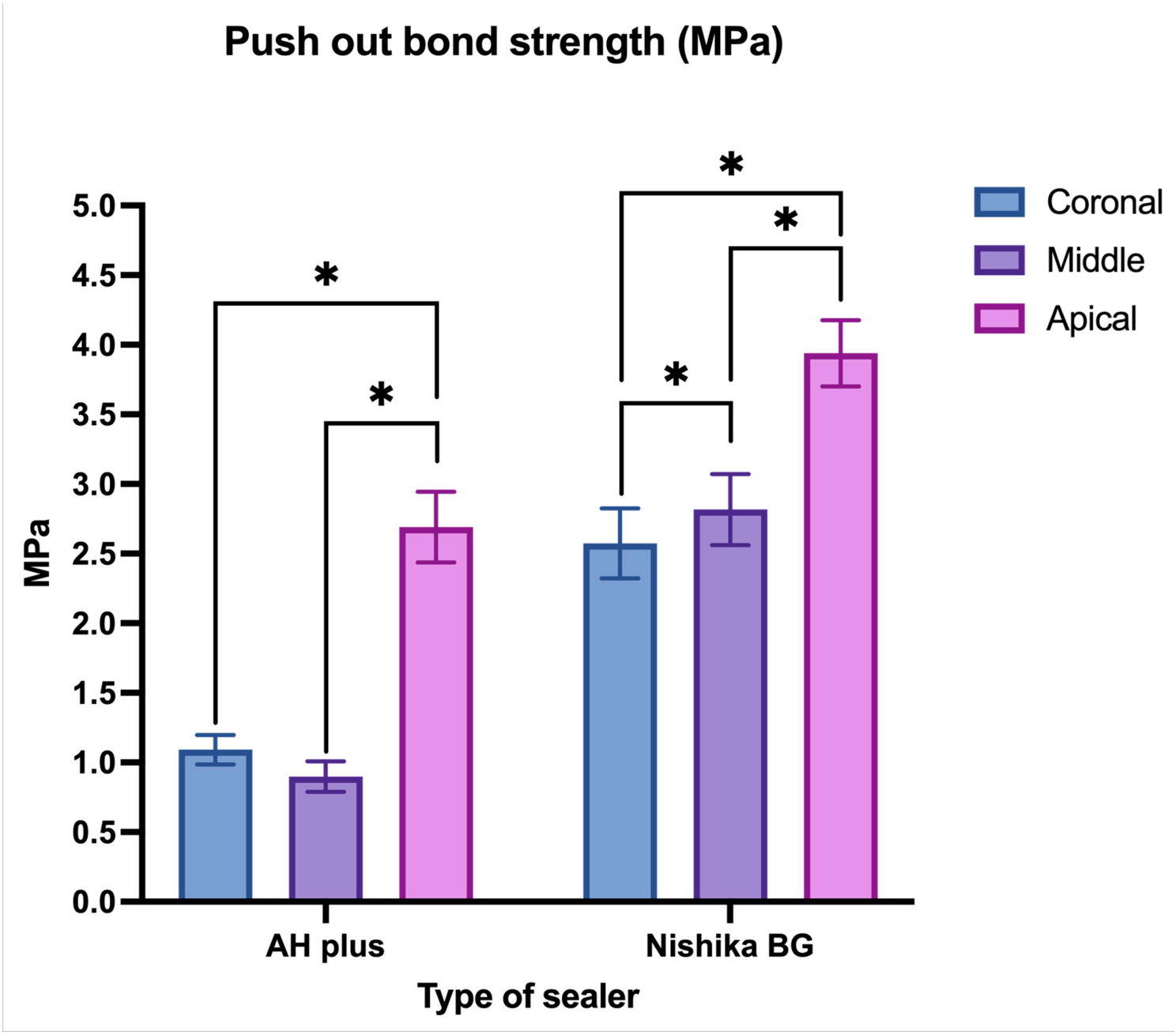


Figure 2

Mean push-out bond strength (MPa±SD) observed in the coronal, middle, and apical thirds within each sealer. One-way ANOVA and Tukey's test were used for comparisons within each sealer; * statistically significant ($p < 0.05$).