ORIGINAL RESEARCH

Comparison of Marginal Adaptation, Surface Hardness and Bond Strength of Resected and Retrofilled Calcium Silicate-based Cements Used in Endodontic Surgery: An *In Vitro* Study

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Abstract

Aims: This study compared the effects of orthograde and retrograde methods on marginal adaptation, surface hardness, and push-out bond strength (POBS) of three calcium silicate-based used in endodontic surgery.

Materials and methods: Ninety single-rooted human mandibular premolars were randomly assigned into six groups ($n = 15$/group): groups I and II, ProRoot mineral trioxide aggregate (MTA) with orthograde and retrograde methods; groups III and IV, Biodentine (BD) with orthograde and retrograde methods; groups V and VI, iRoot BP Plus (BP-RPM) with orthograde and retrograde methods. After obturation, the apical 3 mm of each root was sectioned into two 1-mm-thick root slices and evaluated for marginal adaptation using a scanning electron microscope, surface hardness using Vickers hardness tester and POBS using a universal testing machine.

Results: Orthograde placement had a higher maximum gap width than retrograde placement ($p < 0.05$), but there was no significant difference among the tested materials ($p > 0.05$). Biodentine exhibited lower surface hardness than ProRoot MTA and iRoot BP Plus ($p < 0.05$), but there was no significant difference between ProRoot MTA and iRoot BP Plus ($p > 0.05$). Orthograde placement had higher POBS compared with retrograde placement ($p < 0.05$). Biodentine had higher POBS than iRoot BP Plus ($p < 0.05$), but no significant difference from ProRoot MTA ($p > 0.05$). The failure mode was mainly mixed for all the tested materials regardless of material type or placement technique.

Conclusion: The retrograde method had better marginal adaptation; however, the orthograde method provided better dislodgement resistance. Biodentine had lower surface hardness than MTA and iRoot BP Plus with both techniques, whereas iRoot BP Plus demonstrated lower dislodging resistance than BD.

Clinical significance: The current findings suggest that orthograde technique, a simpler periapical surgery, with ProRoot MTA provides potentially better surface hardness and POBS than BD and iRoot BP Plus in single-canal teeth.

Keywords: Apicoectomy, Biodentine, Bond strength, Calcium silicate, iRoot BP Plus, Marginal adaptation, Orthograde, ProRoot MTA, Retrograde, Surface hardness.

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Introduction

In general, endodontic surgery may be indicated when previous nonsurgical root canal treatment fails or unfeasible to treat periradicular pathosis of endodontic origin.[1] The goals of periradicular surgery are to remove the diseased tissues and place a biocompatible root-end filling that can seal the root canal system and stimulate periodontium regeneration.[2] The introduction of microsurgical techniques, the use of dental operating microscope (DOM), and the advent of biocompatible root-end filling materials, such as ProRoot mineral trioxide aggregate (PMTA; Dentsply Tulsa Dental, Tulsa, OK, USA), have resulted in a remarkable improvement in surgical root canal treatment.[3] Recently, a number of novel calcium silicate-based materials (CSMs) have been produced, such as [Biodentine (BD); Septodont, St. Maur-des-Fossés, France] and [iRoot BP Plus root repair material (BP-RPM); Innovative BioCeramix, Inc, Vancouver, Canada)] with the purpose of improving MTA shortcomings, such as the prolonged setting time, potential of tooth discoloration, and difficult handling.

Biodentine is a calcium silicate-based cement that comes in the form of a powder in capsules with a predosed calcium chloride solution which acts as an accelerator. The powder composition consists of tricalcium silicate, dicalcium silicate, calcium carbonate, zirconium oxide, and iron oxide.[4] According to the manufacturer, this bioactive substance has a short initial setting time of approximately 12 minutes. Biodentine has improved physical properties, more compressive strength than MTA.[5] It is biocompatible with tissue and stimulates hard tissue formation.[6]

BP-RRM is a ready-to-use, white hydraulic premixed putty materials available in a jar or a syringe which reduce the possibility

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of uneven consistency during on-site mixing. Its component consists of tricalcium silicate, dicalcium silicate, calcium phosphates monobasic (CPM), zirconium oxide, tantalum pentoxide, calcium sulfate and filler agents.[7] According to the manufacturer, it requires the presence of water to set and harden, and it takes at least 2 hours to set. BP-RRM has been demonstrated to be biocompatible, antibacterial, and able to seal root-end cavities.[8]

Although periradicular surgery with these CSMs gives a considerably high success rates of 84–94%,[7,9] the technique is still complicated and sensitive, such as the use of DOM demands the clinician's skills to work in confined spaces, the difficulty in root-end cavity preparation which can cause the crack initiation with the use of ultrasonics,[10] the exposure to acidic environment caused by periapical inflammation and blood contamination during material setting which may affect the physical and mechanical characteristics of root-end filling materials, such as sealing ability,[11] resistance to deformation[12] and resistance to dislodgement.[13]

Under some clinical circumstances, such as those required periradicular surgery but have limited access to the surgical site such as surgery in the palatal root of maxillary molars and certain root of mandibular molars, or those involving iatrogenic events, such as zip perforation, non-negotiable ledged, canal blockage, or anatomic variations which prevent the adequate debridement and obturation of the apical section of the root canal system, CSMs may be used as a root canal filling material; the surgery is then performed by resecting the root-end and exposing the set material without retropreparation and retrofilling. This method is referred to as the "orthograde technique." This method reduces blood contamination and acid exposure, crack formation during root-end cavity preparation, procedure time, and may improve clinical success.

Root filling materials play a crucial role in the apical seal, with properties, such as sealing ability, marginal adaptation, and resistance to deformation and dislodgment being important factors. Previous research has shown no significant difference in sealing ability and marginal adaptation between resected and retrofilled MTA, when 3-mm thickness of MTA remains after resection.[14,15] The healing of periradicular tissue was unaffected by the resected MTA.[16] However, no study has evaluated the orthograde placement of BD and BP-RRM. Thus, this study aimed to evaluate and compare the marginal adaptation, surface hardness, and push-out bond strength (POBS) of three different CSMs, that is, PMTA, BD, and BP-RRM, used as root filling materials in two different material placement methods.

Materials and Methods

Sample Selection and Preparation

This study was an *in vitro* study which was approved by Human Experimentation Committee of the Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand (Clearance no. 13/2022). The study was conducted during July 2022 to October 2022. Ninety human permanent mandibular premolar teeth, extracted for orthodontic reasons, were collected. Sample size was determined based on previous studies with similar methodology.[4,17,18] The inclusion criteria included straight single root with single root canal with minimum root length of 12 mm, no external and internal root resorption, no canal obliteration, complete root formation, and no history of previous root canal treatment. The teeth that lack these characteristics or had cracks or root fractures were excluded. Preoperative radiographs of the root were taken in angulations of mesial to distal and buccal to lingual for observing root canal anatomy and abnormality by using the CS7600, a digital imaging plate (Carestream, Atlanta, GA, USA). All roots were decoronated with diamond discs (Meisinger, Neuss, Germany), leaving a standardized root length of 12 mm. Root canals were prepared 0.5 mm short of the apical foramen by using a rotary nickel–titanium files (Reciproc blue 40/0.06; VDW, Munich, Germany). A new rotary file was replaced for every four root canal preparations. During instrumentation, root canals were irrigated with 10 mL of 2.5% sodium hypochlorite. A final rinse of 2 mL of 17% ethylenediaminetetraacetic acid solution for 1 min, 2 mL of 2.5% sodium hypochlorite solution, and 5 mL of 0.9% sodium chloride solution was used. The canals were then dried with absorbent paper cones. All irrigating solutions were delivered with 27-G needle attached to a disposable syringe 1 mm short of the working length. Subsequently, each root was vertically embedded in self-cured acrylic resin (Tempron, GC Dental Products Corp., Japan).

Root Canal Obturation

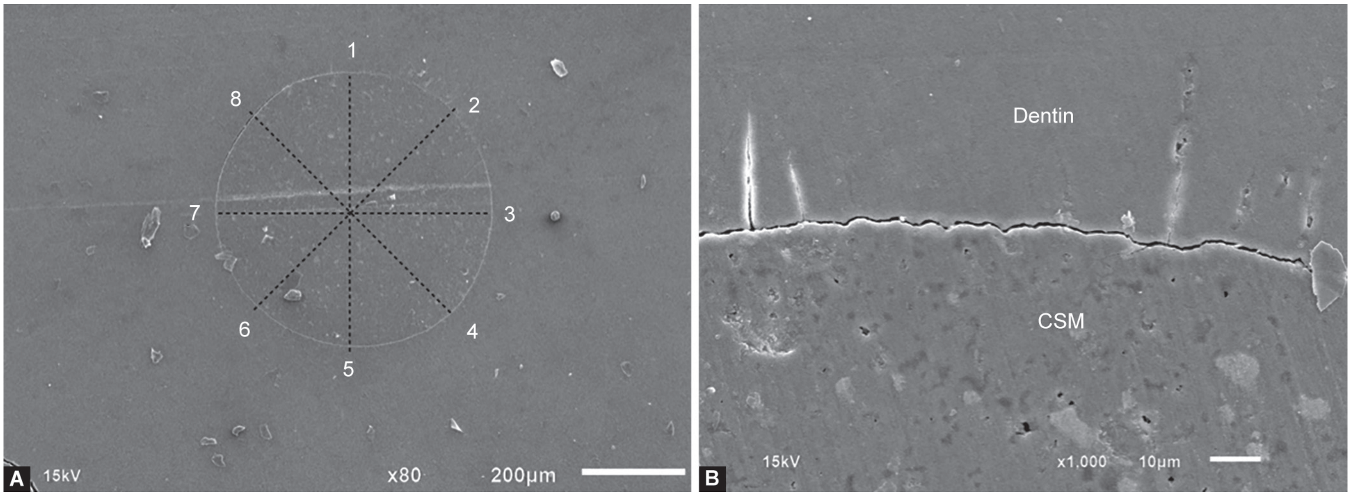
Ninety roots embedded in acrylic resin were randomized into six experimental groups (n = 15/group) based on materials and placement method: groups I and II with PMTA (Lot no. 270375, Dentsply Tulsa Dental, Tulsa, OK, USA) using orthograde and retrograde methods, groups III and IV with BD (Lot no. 28328, Septodont, St. Maur-des-Fossés, France) using orthograde and retrograde methods and groups V and VI with BP-RRM (Lot no. 2105, Innovative BioCeramix Inc., Vancouver, Canada) using orthograde and retrograde methods.

Orthograde Material Placement Method (Groups I, III, and V)

All three tested materials were prepared according to the manufacturer's instructions and obturated in orthograde direction for 6 mm in thickness under DOM (OPMI Pico; ZEISS, Jena, Germany) with 16x magnification. Each material was inserted incrementally using a carrier (MAP System; Dentsply Tulsa Dental) and then vertically compacted with an endodontic plugger (RCP1/3; Hu-Friedy Manufacturing, Chicago, IL, USA). To confirm the well-condensed obturations, radiographs were taken. In PMTA group, a cotton pellet moistened with saline was placed into the root canal-contacting materials to facilitate material setting and access cavities were temporarily closed with temporary restoration (Cavit; 3M ESPE, St. Paul, MN, USA). Each specimen was wrapped in gauze-soaked phosphate-buffered saline solution (PBS), and the solution was replaced every 24 h and stored at 37°C with 100% relative humidity for 7 days.

Retrograde Material Placement Method (Groups II, IV, and VI)

Root canals were obturated with gutta-percha using warm vertical compaction without sealer. Then, the roots were apically resected 3 mm from the root apex at 90° angle to the long axis of the root using slow-speed saw (IsoMet 1000; Buehler, Lake Bluff, IL, USA). The 3 mm-depth root-end cavities were prepared using diamond-coated ultrasonic retrotip (AS3D; Satelec Acteon Group, Merignac, France) connected to an ultrasonic device at a power level of 5 under constant water irrigation. A new retrotip was replaced for every eight root-end cavities. After preparing the root-end cavities, the root-end surfaces were examined for cracks under stereomicroscope (Olympus SZX7; Olympus Optical Co. Ltd., Tokyo, Japan) at 40x magnification. In each group, the 3 mm-deep root-end cavities were dried with paper points and



Figs 1A and B: (A) The perimeter of the root canal was randomly divided into eight sections at 80× magnification; (B) The maximum gap width was measured at each point at 1000× magnification (CSM, calcium silicate-based material)

filled with materials as described for the orthograde group. Each specimen was wrapped in PBS-soaked gauze, the solution was replaced every 24 hours, and the specimens were stored at 37°C and 100% relative humidity for 7 days.

All roots were then apically resected 3 mm from the root apex at 90° angle to the long axis of the root using a slow-speed saw (IsoMet 1000; Buehler) with a 0.3 mm thick diamond blade. Subsequently, the 3-mm apical portion of the embedded root was sectioned into two segments at 1.5 and 3 mm from the proposed apex. After deducting the thickness of the blade, the thickness of each root slice became 1.2 ± 0.1 mm. The apical root slices were subjected to the marginal adaptation and surface hardness test, whereas the remaining root slices were subjected to the POBS test.

Marginal Adaptation Test

Five apical root slices were randomly selected from each group to measure the distance between root-end filling materials and dentin as the apical part represents the location of the cutting end which may affect the marginal adaptation of root filling material differently between the orthograde and retrograde groups. Samples with fractures or unclear demarcation between dentin and root filling, as detected by a stereomicroscope (Olympus SZX7; Olympus Optical Co., Ltd.) at 40x magnification, were excluded from the study. Sample size was calculated based on the data from previous studies with similar methodology,[17,19] using G*Power V3.1.9.6 for Mac OS (Heinrich-Heine-Universität Düsseldorf). The type I error of 0.05, and the type II error of 0.2. A sample size of 5 was obtained for each group. The apical surfaces were polished sequentially with 600-, 1200-, and 2000-grit silicon carbide papers for 30 s under constant water irrigation with minimal hand pressure. To remove the surface debris, the polished specimens were rinsed in distilled water for 1 min and air-dried. Then, the specimens were sputtered with gold. The apical surfaces were analyzed and photographed under scanning electron microscope (SEM) at a magnification of 80x (JSM-6610LV, JEOL Corporation, Tokyo, Japan). Subsequently, eight randomly selected points around the perimeter of the root-end cavities were examined using SEM under 1000x magnification (Fig. 1). The images were analyzed using ImageJ (v1.53; National Institutes of Health, Bethesda, MD, USA). At each point, the maximum gap width (µm) between materials and dentin interface was measured. The void was defined as a narrow, dark groove with a width of <1 µm. The marginal gap of the specimen was calculated using the average maximum width from these eight measurements.

Surface Hardness Test

Ten apical root slices remaining in each group were evaluated for surface hardness using Vickers microhardness testing (STARTECH SMV-1000; Guiyang Sunproc International Trade Co. Ltd., Guiyang, China). Sample size was calculated using G*Power V3.1.9.6 for Mac OS (Heinrich-Heine-Universität Düsseldorf), with α level type I error of 0.05 and β level type II error of 0.2, using the data from previous studies with similar methodology.[4,20,21] A sample size of 10 was obtained for each group. The apical root slice was selected for surface hardness testing because the apical section was the center core of the material in the orthograde group and could reflect the setting process in the innermost of the material, in contrast to retrograde group, where the material was at the root-end exposing the environment. The difference could be attributed to the varying outcomes of different placement techniques. Samples with cracks or voids that interfered with the test, as detected by a 40x stereomicroscope (Olympus SZX7; Olympus Optical Co., Ltd.), were excluded from the study. The apical surfaces were polished sequentially with 600-, 1200-, and 2000-grit silicon carbide papers for 30 s under constant water irrigation and minimal hand pressure. The specimens were then rinsed in distilled water for 1 min and air-dried. The test was performed with a square-based diamond pyramid indenter with a face angle of 136° at a load of 300 gm for 10 s. Our pilot study confirmed that this load created a clear and reliable indentation. At separate locations, three indentations were made on the polished apical surface of cements, with a distance of three times the mean diameter of each indent between indentations and from the periphery. The Vickers microhardness value (HV) was calculated by the machine using the following equation: $HV = 1.854 \times (F/d^2)$, where F is the load (kg) and d is the mean of two diagonals produced by the indenter (mm).[12] The surface hardness of each specimen was determined by averaging the results of three indentations.

POBS Test

Fifteen of the remaining root slices in each group were randomly subjected to POBS test using universal testing machine (Instron

Table 1: Pairwise comparison of the mean (standard deviation) of the gap width at the interface between the materials and the dentin (μm), surface hardness value (HV/N/mm^2) and push-out bond strength value (MPa) regarding the placement method and the material type

	Placement methods					
	Gap width (μm)		*Surface hardness (HV/N/mm^2)*		*Push-out bond strength (MPa)*	
Materials	Orthograde	Retrograde	Orthograde	Retrograde	Orthograde	Retrograde
MTA	2.03 (0.52)^{A,a}	1.31 (0.89)^{A,a}	57.93 (3.19)^{A,a}	62.90 (5.3)^{A,a}	17.8 (5.12)^{A,a}	14.79 (6.83)^{A,a}
BD	1.28 (0.7)^{A,a}	1.38 (1.21)^{A,a}	43.97 (7.82)^{A,b}	44.99 (2.55)^{A,b}	21.56 (9.69)^{A,a}	16.54 (7.53)^{A,a}
BP-RRM	2.04 (0.64)^{A,a}	0.67 (0.91)^{A,a}	50.57 (3.77)^{A,a}	54.44 (6.75)^{A,a}	16.59 (7.64)^{A,a}	12.08 (4.45)^{A,a}

BD, biodentine; BP-RRM, iRoot BP Plus; MTA, proRoot mineral trioxide aggregate; Mean values followed by different superscript uppercase letter (row) or lowercase letter (column) are significantly different ($p < 0.05$) The same uppercase letter (A) indicates that there are no significant differences between the data in the same row ($p < 0.05$). The same lowercase letter (a or b) indicates that there are no significant differences between the data in the same column ($p < 0.05$)

5566 Universal Testing Machine; Instron Engineering Corporation, Norwood, MN, USA). The sample size (n = 15) was calculated using G*Power V3.1.9.6 for Mac OS (Heinrich-Heine-Universität Düsseldorf), using the data from previous studies with similar methodology.[18,22] The type I error was kept at 0.05, and the type II error was 0.2. The root slice was selected for POBS testing to evaluate material setting and dislodging force resistance. Samples with cracks detected by stereomicroscope (Olympus SZX7; Olympus Optical Co. Ltd.) at 40x magnification were excluded from the study. Cylindrical stainless steel plungers with 0.5 and 0.6 mm diameters were used based on the root canal diameter. A continuous load was applied to the center of the tested cements, with a constant crosshead speed of 0.5 mm/min from apical to coronal direction until the cement was dislodged. The maximum load applied to the cements before failure was measured in Newtons (N) and converted to megapascals (MPa) using the following formula: MPa = F/A, where F is the force required to dislodge the cement from the root slice (N) and A is the bonded interface area (mm^2). Then, all specimens were examined under microscope (Olympus SZX7, Olympus Optical Co. Ltd) at 40x magnification to determine the failure pattern by classifying them into three categories: (1) adhesive (failure between the root canal filling and the dentin), (2) cohesive (failure within the materials), and (3) mixed.

Statistical Analysis

Data were presented as mean ± standard deviation, and analyzed using IBM SPSS Statistics version 28.0 (IBM Corp., Armonk, NY, USA). Data normality was assessed using descriptive statistical method. The two-way analysis of variance (ANOVA) was used to determine the statistical significance of material type and placement technique on maximum gap width, surface hardness, and POBS values. Post hoc analysis was implemented for multiple comparison test. Statistical significance was set at $p < 0.05$. The intra- and intercalibrations were analyzed using the intraclass correlation coefficient (ICC).

Results

Intraclass correlation coefficient indicated excellent intra-examiner (0.998) and inter-examiner (0.992) reliability. The results showed that the interaction between material type and placement technique was statistically significant only for surface hardness ($p < 0.05$) (Table 1).

Marginal Adaptation

As regards the material type, orthograde method (1.79 ± 0.69 μm) resulted in a higher maximum gap width compared with retrograde method 1.12 ± 0.99 μm) ($p < 0.05$). However, the maximum gap width among PMTA (1.67 ± 0.79 μm), BD (1.33 ± 0.94 μm), and BP-RRM (1.36 ± 1.03 μm) were not significantly different ($p > 0.05$). There was no significant difference in the inter-group comparison ($p > 0.05$) (Table 1).

Table 2: Failure mode analysis (%)

	Adhesive	*Cohesive*	*Mixed*
Placement methods			
Orthograde	0	40	60
Retrograde	0	47	53
Materials			
MTA	0	40	60
BD	0	43	57
BP-RRM	0	47	53

BD, biodentine; BP-RRM, iRoot BP Plus; MTA, ProRoot mineral trioxide aggregate

Surface Hardness

Biodentine had significantly lower surface hardness than PMTA ($p < 0.05$) and BP-RRM ($p < 0.05$) either in the orthograde or retrograde method. However, the surface hardness difference between PMTA and BP-RRM for both placement methods were not statistically significant ($p > 0.05$). In the same material type, no significant difference was found between orthograde and retrograde methods ($p > 0.05$) (Table 1).

Push-out Bond Strength

Regardless of the material type, orthograde placement (18.65 ± 7.83 MPa) resulted in higher POBS compared with retrograde placement (14.47 ± 6.53 MPa) ($p < 0.05$). BD (19.05 ± 8.9 MPa) had higher POBS than BP-RRM (14.33 ± 6.56 MPa) ($p < 0.05$), but no significant difference from PMTA (16.29 ± 6.12 MPa) ($p > 0.05$). In the inter-group comparison, there was no significant difference ($p > 0.05$) (Table 1).

Mode of Failure

The examination of all specimens revealed that none of them had adhesive failure. The failure mode was mainly mixed for all the tested materials regardless of material type or placement technique (Table 2).

Discussion

An orthograde technique is helpful for periapical surgery in cases of limited anatomical access, or potentially required periapical surgery, such as canal blockage, non-negotiable ledged, separated instruments, or severe root canal curvature. This technique is simpler than conventional apicoectomy and has been supported by studies showing that apical resection of MTA-containing root does not compromise the sealing ability of set MTA[14,23] or the healing of periradicular tissues.[16] However, the orthograde technique may impact other material properties, such as marginal adaptation, and resistance to deformation and dislodgment which may affect the apical seal of root filling materials. Regardless of the fact that no clinically relevant minimum values have been universally established, less interfacial gap between material and root canal wall, higher surface hardness and higher POBS are more desirable. This study evaluated and compared the marginal adaptation, surface hardness, and POBS of MTA, BD, and BP-RRM, when used as root filling materials in orthograde and retrograde methods.

SEM was used to assess the marginal adaptation of root filling materials to dentine. While it has limitations, such as providing a two-dimensional view and potential artifacts or gaps, it offers high magnification and cost-effectiveness. Inconsistent results among SEM studies may be due to protocol variations such as cutting plane of the root, methods used to determine gap sizes, incubation period, and different storage conditions.[24,25] In this study, we found a few cracks; however, they did not affect the measurement of gap width. This study revealed that orthograde placement had inferior marginal adaptation than retrograde placement, but there was no difference between the materials. Our findings contradicted to similar studies using micro-CT,[15,26] which found that MTA adaptation to dentin tooth structure did not differ significantly between orthograde and retrograde approaches. We hypothesize that the direct contact of retrofilling with PBS allows the precipitation of calcium silicate hydrate and hydroxyapatite[27] and expansion of the materials,[28] resulting in a better marginal adaption of the retrograde technique in our study. However, polishing the surface of the specimen may cause surface debris to obscure the gap defects. The similar marginal adaptation among the three materials was consistent with previous SEM studies.[24,29] A micro-CT study also found no difference between MTA and BD in marginal gaps and internal voids after retrofilling.[30] The fact that all tested materials contained calcium silicate as the main component could explain these similar results. However, some studies have shown that when used as retrograde filling materials, BD has superior marginal adaptation to PMTA.[17,19] This could be due to methodological differences, such as longitudinal specimen sectioning, incubation period, and analysis technique.

Surface microhardness reflects material setting and deformation resistance. Our study found no difference in surface hardness between orthograde and retrograde placements, suggesting adequate material setting in both placement techniques. However, it is important to note that our study did not expose materials to blood or acidic environments, which could impact surface hardness in clinical settings.[31] We found that BD had significantly lowered surface hardness than PMTA and BP-RRM in both placement methods, consistent with previous studies.[4,32] However, the reason for lower hardness remains unknown. In contrast, one study[21] showed that BD had higher hardness than MTA and TF-RRM, while another found that BD had higher hardness than MTA when exposing the acidic environment,[33] potentially due to differences in composition such as thickening agents and the setting time accelerator, which might interfere with the hydration reaction of the cement. Inconsistent hardness results across studies may stem from variations in protocols, including indenter type, applied force and duration during testing, incubation period, and storage conditions.

The POBS test was used to assess material setting, dislodging force resistance, and adhesion properties. To minimize POBS variability, a plunger with a diameter of 70–90% of the root canal diameter was used.[34] In this study, we did not standardize the diameter of the canals between the two groups to determine the effect of the placement method on material properties. Following an attempt at gutta-percha removal, the mean diameter of the root canals after root-end cavity preparation was significantly larger in retrograde group (0.95 ± 0.23 mm) than in orthograde group (0.84 ± 0.19 mm). Nevertheless, our results showed that orthograde technique had higher POBS than retrograde technique, and this could be due to the difference in diameter and number of dentinal tubules, which vary with tooth location and increase near the pulp.[35] According to Ulusoy et al.,[36] the dislodgement resistance of BD from root dentin was influenced by remaining dentin thickness, when the remaining dentin thickness was decreased, the resistance to dislodgement of material was also decreased. However, several factors can be related to the dislodgement of the root filling materials from dentin, including the presence of blood contamination,[13] acidic environment,[37] presence of smear layer,[38] and number and size of dentinal tubules.[36] In this study, no significant difference was found between BD and PMTA; however, BD had higher POBS than BP-RRM and PMTA, which was similar to previous studies.[32,39] A higher tricalcium silicate content in BD may promote the formation of calcium phosphate and apatite-like precipitates, increasing mechanical bonding and resistance to dislodgement forces.[40] However, some studies reported higher POBS for TF-RRM[18,41] which may be due to the calcium phosphate monobasic (CPM) component and its nanostructure, which allows for increased contact surface area with tissue fluids.[42] As a result, increased carbonated apatite precipitation and improved tag-like structures are anticipated.

Mixed failures were predominantly observed for all three tested materials in both placement techniques, indicating weaknesses in both the materials themselves (cohesive failure) and their bond to radicular dentine (adhesive failure). The incomplete setting caused by the short incubation period may contribute to these weaknesses. Our findings align with a previous study showing a predominance of mixed failures.[41] However, other studies have reported primarily cohesive[36] or adhesive[32] failures, which can be attributed to differences in study designs.

To the best of our knowledge, this is the first study to compare the effects of orthograde and retrograde method on the marginal adaptation, surface hardness, and POBS of MTA, BD, and BP-RRM. However, our study was conducted in *in vitro* conditions, the results cannot be directly extrapolated clinically, but they do allow for comparison of similar materials. Considering the limitations of the *in vitro* conditions, and the fact that this study focused on single-canal roots, the results may differ for multi-canal roots with complex anatomy. Further studies and clinical trials are required.

Our results suggest that in terms of placement methods, marginal adaptation and POBS tests favor one placement method over another in different manners. In terms of surface hardness, BD showed a lower surface hardness than PMTA and BP-RRM, whereas in terms of POBS, BD showed a higher POBS than BP-RRM, but no significant difference was found between BD and PMTA. The results may not lead to a conclusion regarding the optimal placement technique and material, but the findings of this study encourage clinicians to select PMTA when orthograde endodontic surgery is performed. Orthograde placement simplifies the procedure, reduces the risk of root fracture, minimizes blood and acid contamination, and shortens the duration of the operation. Slow setting and consistency of PMTA may be advantageous in orthograde obturation compared with the other two materials.

Conclusion

Within the limitations of the study, the following conclusions were drawn: (1) The orthograde method with root-end resection provides greater resistance to material dislodging from dentine than the retrograde method. In contrast, the marginal adaptation of materials to dentine is better with the retrograde method. (2) Biodentine has lower surface hardness than ProRoot MTA and BP-RPM but has more resistance to dislodgement than BP-RPM.

Clinical Significance

The current findings suggest that orthograde technique, a simpler periradicular surgery, with PMTA provides potentially better surface hardness and POBS than BD and BP-RRM in single-canal teeth.

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