ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
March 2025 • Vol. 37

Effect of Blood Contamination on Marginal Adaptation, Surface Hardness, and Bond Strength of Two Different Retrograde Root End Filling Materials: An In-Vitro Study

Hisham Mahmoud Hamdy Abada[1], Abeer Abd Elwahab Mohammed Mostafa Elhatery[2]

Aim: Evaluate Effect of blood contamination on marginal adaptation, surface hardness, and bond strength of two retrograde materials.

Materials and methods: 144 single-rooted mandibular premolars were collected, disinfected, crowns were removed, roots were endodontically treated, and root-end resection was made by cutting 3 mm from apex. Root-end cavities were prepared, then classified into two groups (n=72) according to root-end filling materials, Group I, restored with ProRoot MTA (PMTA), Group 2 restored by Well-Root PT (WRPT). Each group was classified into two subgroups (n=36) according to the setting environment; subgroup A; the materials allowed to set in deionized water (PMTA/W and WRPT/W), while subgroup B; the materials allowed to set in human blood (PMTA/B and WRPT/B). Twelve samples from each subgroup were used to study the marginal adaptation, surface hardness, and bond strength.

Results: In contact to deionized water and human blood, WRPT showed less significant marginal gap distance and non-significant less hardness value than PMTA, the push-out bond strength for WRPT was highly significant than PMTA in contact to deionized water, and highly non-significant than PMTA in contact to human blood. The blood contamination had negative significant effect on marginal adaptation of PMTA, hardness number of WRPT, and push-out bond strength of both root-end filling materials.

Conclusion: The marginal adaptation and bond strength for WRPT are superior to those for PMTA. Blood contamination negatively effect on the studied properties of both materials.

Keywords: Marginal Adaptation, Surface Hardness, Push-out, bond strength, bioceramic sealer.

1. Lecturer in Department of Endodontics, Faculty of Dentistry, Kafrelsheikh University, Kafrelsheikh, Egypt.
2. Assistant Professor in Department of Biomaterial, Faculty of Dentistry, Kafrelsheikh University, Kafrelsheikh, Egypt.
Corresponding author: Hisham Mahmoud Hamdy Abada, email: hisham.dentist@gmail.com

Introduction

Endodontic surgery is indicated when nonsurgical root canal treatment has failed or when treating periradicular pathosis of endodontic origin is not practical.[1] A biocompatible root-end filling materials that can promote regeneration of periodontium is intended to be placed after the diseased tissues have been removed during periradicular surgery,[2] the optimal root-end filling material should have both a fluid-tight and bacterial-tight seal[3] that should not be compromised by moisture exposure or blood contamination.[4] Dimensional stability and biocompatibility are other crucial prerequisites. Also, it should be easy manipulated, insoluble in tissue fluids, having a degree of radio opacity to facilitate detection on the radiograph examination,[5] and good marginal adaptation which considered to be the key factor in the success of endodontic surgery.[6] Root-end filling materials play an important role in the apical surgery, with properties, such as sealing ability, marginal adaptation, and resistance to deformation and/or dislodgment being important factors.[7,8]

According to many authors, mineral trioxide aggregate (MTA) is considered a gold-standard for comparison between different root-end filling materials, as it often yields promising results. MTA has many favorable properties such as tissue biocompatibility and absence of toxicity, excellent sealing ability and good hard tissue repair.[8,9] In many situations MTA is highly recommended as a root-end filling material due to its osteogenic and regenerative potential.[6,10] Recently a number of innovative calcium silicate-based materials (CSMs) have been developed, such as Well-Root PT, to address the drawbacks of MTA, including its prolonged setting time, possibility for tooth discoloration, and challenging handling. Well-Root PT is a white hydraulic putty that is ready to use and comes in a premixed jar or syringe. It reduces the possibility of uneven consistency which could be occurred on-site mixing.[11]

During clinical application, root-end filling material may expose to blood during setting reaction, such exposure might negatively affect the properties of the material. Therefore, the aim of this study was to evaluate the influence of blood contamination on the marginal adaptation, hardness, and bond strength of PMTA (Dentsply Tulsa Dental, Tulsa, OK, USA), and WRPT (Vericom Co., Chuncheon, Korea) as root-end filling materials. The null hypothesis tested is that blood contamination will not have any effect on the marginal adaptation, hardness, and bond strength of both evaluated materials PMTA and WRPT.

Materials and methods

Teeth Selection

The study proposal of this research was approved from the institutional research board. 144 single-rooted sound human mandibular premolar teeth extracted for periodontal or orthodontal reasons were collected from surgical department after obtaining a written consent from the patients that their teeth will be used for research in the future. The inclusion criteria of the selected teeth were straight root, single root canal anatomy, rounded canal cross section with similar dimension, the exclusion criteria of the tooth were calcified root canals, internal or external resorption, crack or fracture root, and presence of root canal filling materials.[12] Firstly, teeth were carefully cleaned with curettes to remove any soft tissue remnants, then they were mechanically cleaned to remove any calculus or soft tissues using an ultrasonic scaler (Satelec, Cedex, France). For disinfection, teeth were immersed in 5.25% NaOCl solution for 30 min then stored in saline solution (El Nasr Pharmaceutical Chemicals Co., Cairo, Egypt) until instrumentation.

Teeth preparation:

All teeth' crowns were removed by using low speed diamond disk with copious irrigation of water, the root length was standardized to be nearly 16 mm ± 1, working length was measured to be 0.5 mm short to the apical foramen. The biomechanical preparation of teeth were performed using Protaper Universal rotary nickel titanium system (Dentsply Maillefer, Ballaigues, Switzerland) until finishing file F4[6], irrigation throughout instrumentation was done using 5 ml of 2.5% NaOCl, the smear layer was removed with a flush by 5 ml of EDTA 17% using a 27-gauge needle for 1 minutes, finally the root canals were flushed with saline solution (El Nasr Pharmaceutical Chemicals Co., Cairo, Egypt).[13] All root canals were dried using paper points #40. Gutta percha cones (Meta Biomed, Chungcheongbuk- do, Republic of Korea) of #40/0.04 were used with Adseal resin sealer (Meta Biomed, Chungcheongbuk-do, Republic of Korea) in lateral compaction technique. All teeth were stored in 100% humidity at 37 °C for 7 days before root-end preparation.[6,14]

Root-end cavity preparation and restoration

Roots were centered vertically in blocks of cold-cured clear acrylic resin. After that root-end resection was made by cutting 3 mm from the apical part of the root perpendicular to its long axis using a high-speed Zecrya drill (Dentsply Maillefer, Ballaigues, Switzerland) under continuous air/water spray.[15] Root-end cavities were prepared in all teeth under 8x magnification using a dental operating microscope (Semorr, Bondent, China), using AS3D ultrasonic tip (Satelec, Cedex, France) attached to an ultrasonic unit (Satelec, Cedex, France) at a medium power setting unit and under continuous irrigation with saline solution. All cavities were standardized to 3 mm depth. PMTA material was mixed and manipulated according to manufacture instructions, the desirable consistency was achieved when the material preserves its shape and attachment to the plastic instrument and is easily plugged with a microplugger. After that, roots were divided into two groups (n=72 teeth for each group) according to the root-end filling material, Group 1, root end cavities were filled by mixed PMTA, Group 2 in which root end cavities were filled by ready-made WRPT. Then the restored teeth in each group were randomly divided into 2 sub-groups (n = 36) according to the setting environment in which the root-end filling were allowed to set, for the sub-group A; the restored roots were allowed to set in tubes containing 1 ml of deionized water (PMTA/W for group 1 and WRPT/W for group 2), for sub-group B; the restored roots were allowed to set inside tubes (Eppendorf, Hamburg, Germany) containing 1 ml of human blood with sodium citrate added as an anticoagulant (PMTA/B for group 1 and WRPT/ B for group 2),[16] the human blood were collected from three donors at the institutional university hospital after tested negatively for blood diseases and getting a donor's approval.

After that all tubes were stored in an incubator at 37 °C for 45 min to ensure final setting of the material. After that, every tooth was removed from the tubes and cleaned with saline wash (El Nasr Pharmaceutical Chemicals Co., Cairo, Egypt). The specimens were then stored in 100% humidity at 37 °C for 1 week before testing.

Root discs 2 ± 0.1 mm in thickness were cut from the apical third of each root using water-cooled precision slow-speed saw (IsoMet 1000; Buehler), digital caliper (Pachymeter, Electronic Digital Instruments, China) was used to confirm the thickness of obtained disks.[6] The root disks within each sub-group were further subdivided into three groups (n=12) for evaluation of marginal adaptation, hardness number, and bond strength for the tested materials.

Evaluation of marginal adaptation by scanning electron microscope (SEM)

For each sub-group twelve root disks (n=12) were selected. Using stereomicroscope (Olympus SZX7; Olympus Optical Co., Ltd.) at 40x magnification any samples having fractures or unclear demarcation between dentin and root filling materials, were excluded. Teeth sections were placed in individual plastic vials containing 2.5% sodium hypochlorite solution for 3h. For dehydration process, the specimens were inserted for 5 h in increasing concentrations of alcohol 70, 90, and 99%. Then, the samples were air-dried, placed on metal stubs from the coronal side, labeled and sputter-coated with 150-Å thick gold using a fine-coat ion sputter JFC-1100 (fine coat ion sputter JFC-1100, JEOL Ltd., Tokyo, Japan), and then the apical surface were evaluated using scanning electron microscope (SEM) (Jeol JSM-6360 LV, JEOL Ltd.). Marginal adaptation was tested by examination of the samples under 1500X magnification to measure the gap distance between root-end filling materials and dentin root surface in micrometers. Readings were taken at eight randomly selected points around the perimeter of the root-end cavities using SEM and then the mean gap distance was calculated.[17]

Evaluation of surface hardness

For each sub-group twelve root disks (n=12) were selected for measuring the surface hardness using Vickers microhardness testing machine. (Microhardness Tester ZWICK/ROELL 2125 Barrett Park Drive, Suite107 30144 Kennesaw, GA USA). Any Samples with cracks or voids that may interfere with the test, as detected by a 40x stereomicroscope (Olympus SZX7; Olympus Optical Co., Ltd.) were excluded from the study. The apical surfaces of root sections were polished sequentially with 600-, 1200-, and 2000-grit silicon carbide papers for 30 s using minimal hand pressure and under constant water irrigation.[17,18] The samples were rinsed for 1 min in distilled water and then 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. Three different indentations, at separate locations, were made on the polished apical surface of cements. The Vickers microhardness value (HV) was calculated by the machine using the following equation: $HV = 1.854 \times (F/d2\ )$, where F is the load (kg) and d is the mean of two diagonals produced by the indenter (mm).[17,18]

Evaluation of bond strength by using push-out test

Twelve root disks for each sub-group (n=12) were used for push-out test, test was performed using a universal testing machine (Instron Model 3365; Tensile Tester 5 KN. USA). Each root disc was mounted in custom-made loading fixture (metallic block with circular cavity at the middle, this cavity for specimen housing having a central whole to facilitate displacement of extruded filling material). Each disc was placed with the apical part facing upwards, and the root-end filling material was subjected to a load at a crosshead speed of 1 mm/min in an apical to coronal direction parallel to the long axis of the disc via a computer-controlled material testing machine.[13,19] The filling material was pushed toward the larger diameter, and thus avoiding any limitation to the filling movement possibly owing to the canal taper and guarantee that the overlaying dentin was sufficiently supported during the loading process. To ensure contact only with the material to be tested without any stresses on surrounding dentin, a cylindrical attachment (plunger) of about 0.7 mm diameter was used which provide for a minimum of 0.2 mm of clearance space from the dentinal wall's edges.[16] The test preceded until failure is manifested by extrusion of filling piece and a sudden drop along the load-deflection curve was recorded by the computer software.[13,20] We recorded the maximum load needed to dislodge the root-end filling material out of the disc in newtons and converted it into MPa. The push-out bond strength for each root slice was calculated using the following formula:

Push-out bond strength (MPa) = Maximum load (N) / Adhesion area (mm^2)

The adhesion area was calculated by using the following formula[13,19]

$\pi\,(r1 + r2)\,\sqrt{[\,(r1 - r2)^2 + h^2\,]}$

where π = 3.14, r1 is the coronal radius, r2 is the apical radius, and h is the thickness of the slice.

Statistical Analysis

Data were collected, tabulated, and presented as mean ± standard deviation, statistical analysis was performed with the Prism 9.4.1 software (GraphPad Software Inc, La Jolla, CA, USA). The descriptive statistical method was used to evaluate the normality of the data. One-way analysis of variance (ANOVA) at 95% level of confidence was performed to detect a statistically significant difference among different groups for each test. Pairwise comparisons between each of the two significant difference groups were conducted using the Tukeye-Karmer post hoc test.

Results

The results are demonstrated in (Table 1 and 2, Figure 1and 2)

Marginal Adaptation

As regard to the type of materials, the WRPT/W showed the lowest gap width (1.51±0.54) with a statistically significant difference compared to PMTA/W (3.24±0.6). Regarding the effect of blood contamination, the gap width was significantly increased for PMTA/B (6.08±1.4), while it non-significantly increase for WRPT/B (2.72±0.71), the gap width results given by WRPT/B was significantly less than PMTA/B.

Table 1: Gap distance, Hardness numbers and Push-out bond strength for all groups

	PMTA/W	PMTA/B	WRPT/W	WRPT/B	p-Value
Gap distance	3.24±0.6 ^{b}	6.08±1.4 ^{a}	1.51±0.54 ^{d}	2.72±0.71 ^{cbd}	<0.0001*
Hardness	84.57±9.15 ^{a}	73.78±11.21 ^{ab}	78.16±12.17 ^{a}	63.05±8.35 ^{b}	<0.0001*
Push-out	54.86±7.48 ^{b}	41.74±6.56 ^{d}	75.38±8.31 ^{a}	49.32±8.04 ^{cbd}	<0.0001*

Different superscript letters in the same row indicate statistically significant values (P < .05).
(*) mean that there was a statistically significant difference between the tested group.

Table 2: Gap distance, Hardness numbers and Push-out bond strength for the tested materials regardless of the type of materials and regardless of the effect of the setting environment.

	Root-end filling/Water	Root-end/Blood	p-value	PMTA	WRPT	p-value
Gap distance	2.4 ± 1	4.4 ± 2	<0.0001*	4.7 ± 1.8	2.1 ± 0.9	<0.0001*
Hardness	81.4 ± 10.8	68.4 ± 10.9	0.0008*	79.2 ± 11.2	70.6 ± 12.5	0.0496*
Push-out	65.1 ± 12.7	45.5 ± 8	<0.0001*	48.3 ± 9.4	62.4 ± 15.2	0.0004*

(*) mean that there was a statistically significant difference between the tested group.

Surface Hardness

PMTA had non-significantly higher surface hardness than WRPT with and without blood contamination. In contact with blood, the surface hardness was 73.78±11.21 and 63.05±8.35 for PMTA/B and WRPT/B respectively, while in contact with water the surface hardness was 84.57±9.15 and 78.16±12.17 for PMTA/W and WRPT/W respectively. Setting in contact to blood non-significantly decreases the surface hardness for PMTA, while significantly decreases the surface hardness for WRPT.

Figure 1: Bar graphs of Gap distance, Hardness numbers, and Push-out bond strength for all groups

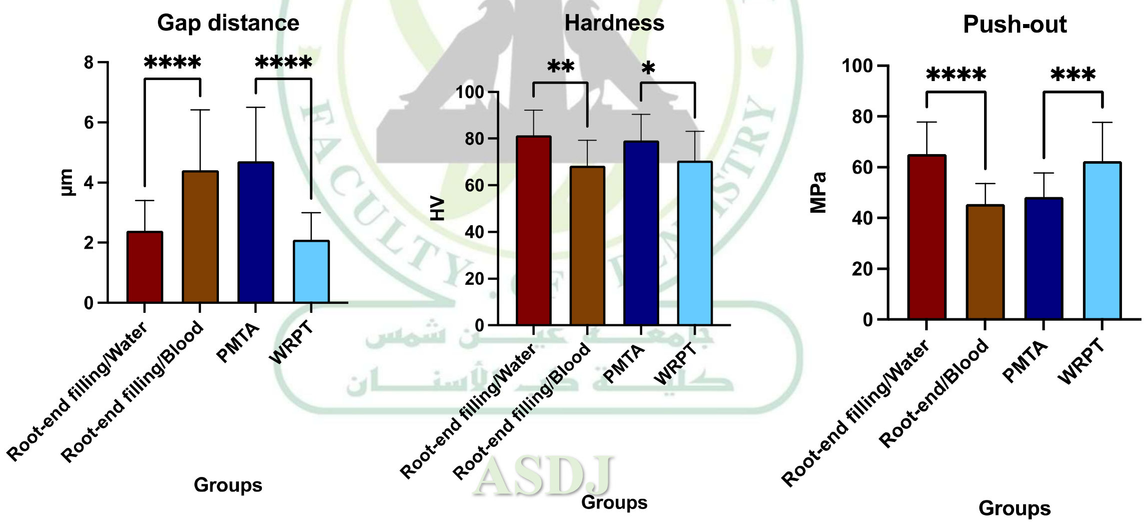

Figure 2: Bar graphs of Gap distance, Hardness numbers, and Push-out bond strength regardless of the type of setting environment and regardless of the type of root-end filling materials

Push-out bond strength

Significant interactions between the groups were observed ($P < 0.0001$), the highest result was recorded for WRPT/W (75.38±8.31) with a statistically significant difference with PMTA/W (54.86±7.48). When both materials allowed to set in contact with blood the bond strength was significantly decreased, the recorded push-out bond strength was 41.74±6.56 and 49.32±8.04 for PMTA/B and WRPT/B respectively, there was no statistically significant difference between the two recorded results.

The effect of setting environment regardless of the type of root-end filling materials

Our results showed that the gap-distance, hardness value and push-out bond strength were statistically significant deteriorated when the materials allowed to set in contact to blood regardless of the type of root-end filling materials. The Gap distance was increased from 2.4 ± 1 when the materials allowed to set in contact to water to be 4.4 ± 2 when allowed to set in contact to blood, the hardness value and push-out bond was decreased from 81.4 ± 10.8 and 65.1 ± 12.7 to 68.4 ± 10.9 and 45.5 ± 8 respectively.

The effect of root-end filling materials regardless of the type of setting environment

WRPT showed statistically superior results for the gap-distance (2.1 ± 0.9), hardness value (70.6 ± 12.5) and push-out bond strength (62.4 ± 15.2) over PMTA (4.7 ± 1.8, 79.2 ± 11.2 and 48.3 ± 9.4 for gap-distance, hardness value and push-out bond strength respectively) regardless of the type of the setting environment.

Discussion

When nonsurgical root canal treatment fails or unfeasible to treat periradicular pathosis of endodontic origin, endodontic surgery may be indicated. The aims of such periradicular surgery are to remove the diseased tissues and insert a biocompatible root-end filling material which has the ability to seal the root canal system and stimulate periodontium regeneration. There are plenty of dental materials that could be used as root end filling materials including gutta-percha, amalgam, zinc oxide eugenol cement (IRM, Super- EBA), Cavit, and composite resins.[21–23] The introduction of microsurgical techniques, the use of dental operating microscope (DOM), and the advent of biocompatible root-end filling materials, such as PMTA have resulted in remarkable improvement in surgical root canal treatment.[24] WRPT is one of several new calcium silicate-based materials (CSMs) that have been developed and presented as a premixed putty-type to address the drawbacks of MTA, including its long setting time, possibility for tooth discolorations, and challenging handling.[11,25] The setting reaction of root-end filling material may be affected by blood exposure during surgical procedure, which might negatively impact on physical, mechanical, and biological properties of these materials.[14,26] The aim of this study was to compare the effect of blood contamination on marginal adaptation, hardness, and push-out bond strength for PMTA and WRPT.

In this study, WRPT/W showed significantly better results than PMTA/W regarding the marginal adaptation and push-out bond strength, this could be attributed to that PMTA are available in the powder and liquid form and require mixing step before application, achieving a good consistence form of this marital is difficult to obtained during mixing procedure, this could result in changing in chemical and physical properties of the material.[27,28] At the same time changing in the mixing condition could affect the prosperities of the mixed powder and liquid consistence of the material.[29] However, even in the mixed condition, WRPT maintains a consistent composition, which offers the benefit of predictable treatment outcomes. It also has the benefit of shorter treatment times and less technical sensitivity.[11,28]

Ashi et al[30] studied the physicochemical properties and antibacterial activity of three calcium silicate cements (Mineral trioxide aggregate, Biodentine (BD), and WRPT materials), their results showed that all the three materials had different crystalline features, in which the MTA and BD had a cubic crystals, and they were smaller and more numerous in BD than MTA, WRPT had elongated crystals structures. Many studies evaluated the gap width between the canal wall and PMTA filling materials, Oliveira et al[12] compared the PMTA to those with IRM, amalgam, Super-EBA, and Epiphany/Resilon groups when used as root end filling materials, their study showed that there was no significant difference for marginal adaptation between all groups. Bolbolian et al[31] in their study showed that in the transverse sections, no significant differences for marginal adaptation were identified between the three root end filling materials used in the study (BD, Retro-MTA, and PMTA groups). Thanatipanont et al[17] showed that the maximum gap width among PMTA, BD, and iRoot BP Plus (BP-RPM) were not significantly different when used in endodontic surgery as retrograde filling materials. Jang et al[25] compared the microleakage of five base materials, Fuji II LC, Riva light cure, PMTA, BD, and WRPT, using methylene blue solution and stereoscopic microscope, BD and WRPT showed the lowest microleakage among other groups. Filipe et al[32] compared the marginal adaptation of two calcium silicate-based cements (White PMTA and TotalFill BC RRM Fast Set Putty), when used as apical plugs for teeth with open apices, the results showed that PMTA had significant higher marginal adaptation apically but not cervically for the apical plugs. The better marginal adaptation of WRPT over the PMTA in our study could be explained by better handling of WRPT as it is available as novel premixed putty form, and to its elongated crystals structures that might provide better marginal adaptation than cubic crystal of PMTA.

Regarding the microhardness, there was no significant difference between PMTA and WRPT. In the study made by Kaup et al,[33] BD showed significantly higher microhardness than PMTA. Kosar et al[34] investigated how PMTA qualities were affected by incongruent mixing ratios that various operators frequently experience in clinical settings, their results showed that the microhardness and compressive strength values of the MTA samples in the control pre-weighed, and improvised groups did not show significant difference. Bayraktar et al[35] tested the microhardness values for PMTA, BD, and total fill root repair material putty, at different pH levels and throughout different time periods, they found that microhardness of BD were significantly greater than those of TF-RRM putty and PMTA, all evaluated root repairing materials showed reduced surface microhardness in an acidic environment. Thanatipanont et al[17] in their study showed that BD had lower surface hardness than PMTA and iRoot BP Plus.

Our results are in agreement with the study of Mohammed et al[36] who evaluated the effect of different irrigation solutions on push-out bond strength of different bioceramic root repair materials, their results showed that NaOCL significantly increased the WRPT bond strength (72.28±17.54), on other hand EDTA significantly decreased the WRPT bond strength (47.11±13.70), while for MTA group using NaOCL and EDTA significantly decreased the bond strength compared to the control (no irrigation) group, (53.02 ±11.83 and 17.02 ±6.27 for control and NaOCL respectively. Rebolloso de Barrio et al[37] showed that BD had higher bond strength than PMTA, they explained that by higher penetration ability of BD into dentinal tubule due to its small particle size and formation of tag-like structure in the root canal dentin.

When the root end filling materials allowed to set in contact with blood, reduction in the marginal adaptation, surface hardness number and bond strength was observed. Song et al[38] assessed how human blood affected the microhardness and setting of three type of calcium silicate cements (PMTA, OrthoMTA, and RetroMTA), their results showed that the microhardness of the blood groups were lower than those of the saline groups for the 4 mm specimens length, for the 2-mm specimen the microhardness of the RetroMTA and OrthoMTA groups did not showed significant differences between storage conditions, Only one specimen in the PMTA blood group showed decreased microhardness. Mokhtari et al[39] studied the effect of blood contamination on marginal adaptation of MTA and cold ceramic (CC) using SEM, in this study the powder of both materials were mixed with the blood and applied into the cavity, the results showed that CC had significantly higher marginal adaptation than MTA Angelus. Nekoofar et al[40] showed that blood contamination had a negative impact on the surface microhardness of MTA. Shalabi et al[14] showed that bond strength for BD were significantly reduced when allowed to set in contact to human blood in comparison to when allowed to set in deionized water. Paulo et al[41] investigated the effect of blood contamination on push-out bond strength of three calcium silicate-based materials (PMTA, BD, and TotalFill BC Putty), their results showed that push-out bond strength did not affected by blood contamination for the three tested materials. The adverse consequence of the blood on the microhardness showed in this study may be attributed to the significant alterations in the crystalline forms of the MTA,[38] as the crystals became more rounded and less angular in shape, the needle-like crystals were generally lacking.[40,42] Temperamental setting characteristics of MTA is one of its disadvantages, these could have been brought from the low pH of the environment[43] and/or inadequate hydration.[44] Healthy blood has a slightly alkaline pH (pH 7.4)[45] so, other causes of insufficient setting have been considered. Different cells and proteins, including albumin, are the major component of the blood. The hydration process may be slowed down by the blood proteins that are adsorbed into the MTA and block the pores.[46] It is also anticipated that red blood cells affinity to type I collagen which is a main component of dentin's organic phase, may cause dentinal tubule occlusion, gap formation, and decreasing of tag-like structure formation, all of which will negatively affect the bond strength.[47,48] Furthermore, the absence of acicular crystals in the specimens may have been produced due to inhibition of the hydration process by the blood as a result of the decreased water concentration.[42] Blood contamination seems to have had a negative impact on MTA hydration, especially when the material's depth was inadequate, even though the exact mechanisms are unknown.[38]

Conclusion

Within the limitations of this study, it concluded that:

1- WRPT has superior marginal adaptation, and push-out bond strength than PMTA, while PMTA has higher hardness values regardless of the setting environment of the materials.

2- Blood contamination has negative effect on push-out bond strength, marginal adaptation, and hardness for WRPT and PMTA.

Declarations

Funding

None

Data availability

Upon request from the corresponding author.

Ethics approval and consent to participate

Approval of the ethics committee of Kafrelsheikh University, Kafrelsheikh, Egypt (KFSIRB200-177). Eligible participants signed a written informed consent.

Competing interests

None

References

1. Von Arx T. Failed root canals: the case for apicoectomy (periradicular surgery). J Oral Maxillofac Surg. 2005;63(6):832-837.
2. Hargreaves K, Cohen S, Berman L. Cohen's Pathways of the Pulp. (th 11 ed, ed.)., 2016.

3. Gartner AH, Dorn SO. Advances in endodontic surgery. Dent Clin North Am. 1992;36(2):357-378.
4. Ribeiro DA, Yujra VQ, De Moura CFG, Handan BA, Viana MDB, Yamauchi LY, Castelo PM, Aguiar O. Genotoxicity Induced by Dental Materials: A Comprehensive Review. Anticancer Res. 2017;37(8):4017-4024.
5. Galhotra V, Sofat A, Pandit IK, Gambhir RS, Srivastava N, Gugnani N. Comparative evaluation of microleakage of various retrograde filling materials: An in vitro study. J Nat Sci Biol Med. 2013;4(2):403-408.
6. Aly Y, El Shershaby S, El-Sherif S. Bond strength and marginal adaptation of a novel root-end filling material. Bull Natl Res Cent. 2020;44(1).
7. Torabinejad M, Pitt Ford TR. Root end filling materials: a review. Endod Dent Traumatol. 1996;12(4):161-178.
8. Vasudev SK, Goel BR, Tyagi S. Root end filling materials — A review. Endodontology. 2003;15(2):12-18.
9. Torabinejad M, Watson TF, Pitt Ford TR. Sealing ability of a mineral trioxide aggregate when used as a root end filling material. J Endod. 1993;19(12):591-595.
10. Saunders WP. A prospective clinical study of periradicular surgery using mineral trioxide aggregate as a root-end filling. J Endod. 2008;34(6):660-665.
11. Chae YK, Ye JR, Nam OH. Evaluation of biocompatibility and bioactive potential of Well-Root PT by comparison with ProRoot MTA and Biodentine. J Dent Sci. 2024;19(4):2218-2225.
12. Oliveira HF, Gonçalves Alencar AH, Poli Figueiredo JA, Guedes OA, de Almeida Decurcio D, Estrela C. Evaluation of marginal adaptation of root-end filling materials using scanning electron microscopy. Iran Endod J. 2013;8(4):182-186.
13. Abada HM, Farag AM, Alhadainy HA, Darrag AM. Push-out bond strength of different root canal obturation systems to root canal dentin. Tanta Dent J. 2015;12(3):185-191.
14. Shalabi M, Saber S, Elsewify T. Influence of blood contamination on the bond strength and biointeractivity of Biodentine used as root-end filling. Saudi Dent J. 2020;32(8):373-381.
15. Sameh, Rasha, El-Tayeb MM., Nabeel M. The seal quality of two bioceramic materials used as retro-grade filling utilizing different compaction techniques (an in-vitro study). Ain Shams Dent J. 2022;28:36-43.
16. Saeed MA, Saber SE-DM, Elsewify TMA. Effect of blood contamination on some properties of a tricacium silicste based root end filling material (in vitro study). Ain Shams Dent J. 2019;(1):255-259.
17. Thanatipanont N, Louwakul P. 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. J Contemp Dent Pract. 2023;24(9):638-644.
18. Tabrizizadeh M, Dabbagh MM, Badrian H, Davoudi A. Microhardness properties of mineral trioxide aggregate and calcium-enriched mixture cement plugs at different setting conditions. J Int oral Heal JIOH. 2015;7(9):36-39.
19. Prado M, Simao RA, Gomes BPFA. Effect of different irrigation protocols on resin sealer bond strength to dentin. J Endod. 2013;39(5):689-692.
20. Barakat DAF, Hassanien, Ehab El Sayed, El Batouty KM. Evaluation of the effect of diode laser on root canal disinfection canal cleanliness fracture resistance of tooth structure and bond strength to root canal dentin an in vitro study. Ain Shams Dent J. 2021;(3):20-28.
21. Bernabé PFE, Holland R, Morandi R, De Souza V, Nery MJ, Otoboni Filho JA, Dezan E, Gomes-Filho JE. Comparative study of MTA and other materials in retrofilling of pulpless dogs' teeth. Braz Dent J. 2005;16(2):149-155.
22. Lee SJ, Monsef M, Torabinejad M. Sealing ability of a mineral trioxide aggregate for repair of lateral root perforations. J Endod. 1993;19(11):541-544.
23. Torabinejad M, Smith PW, Kettering JD, Pitt Ford TR. Comparative investigation of marginal adaptation of mineral trioxide aggregate and other commonly used root-end filling materials. J Endod. 1995;21(6):295-299.
24. Kim S, Kratchman S. Modern endodontic surgery concepts and practice: a review. J Endod. 2006;32(7):601-623.
25. Jang E, Lee J, Nam S, Kwon T, Kim H. Comparison of microleakage and compressive strength of different base materials. J Korean Acad Pedtatric Dent. 2021;48(2):168-175.
26. Akcay H, Arslan H, Akcay M, Mese M, Sahin NN. Evaluation of the bond strength of root-end placed mineral trioxide aggregate and Biodentine in the absence/presence of blood contamination. Eur J Dent. 2016;10(3):370-375.
27. Cavenago BC, Pereira TC, Duarte MAH, Ordinola-Zapata R, Marciano MA, Bramante CM, Bernardineli N. Influence of powder-to-water ratio on radiopacity, setting time, pH, calcium ion release and a micro-CT volumetric solubility of white mineral trioxide aggregate. Int Endod J. 2014;47(2):120-126.
28. Song M, Lee SM, Bang JY, Kim RH, Kwak SW, Kim HC. Chemomechanical properties and biocompatibility of various premixed putty-type bioactive ceramic cements. J Endod. 2023;49(12):1713-1721.
29. Domingos Pires M, Cordeiro J, Vasconcelos

I, Alves M, Quaresma SA, Ginjeira A, Camilleri J. Effect of different manipulations on the physical, chemical and microstructural characteristics of Biodentine. Dent Mater. 2021;37(7):e399-e406.
30. Ashi T, Mancino D, Hardan L, Bourgi R, Zghal J, Macaluso V, Al-Ashkar S, Alkhouri S, Haikel Y, Kharouf N. Physicochemical and antibacterial properties of bioactive retrograde filling materials. Bioengineering. 2022;9(11).
31. Bolbolian M, Mostafaei F, Faegh S. Evaluation of the marginal adaptation of proroot mta, biodentine, and retromta as root-end filling materials. Dent Hypotheses. 2020;11(4):97-102.
32. Filipe S, Martinho JP, Paulo S, Carvalho C, Coelho A, Amaro I, Carrilho E, Paula A, Marto CM, Girão H, Zuzarte M, Pires AS, Ferreira MM. Evaluation of the marginal adaptation of two hydraulic calcium silicate cements used in apical plugs: an in vitro study. Appl Sci. 2024;14(2):480.
33. Kaup M, Schäfer E, Dammaschke T. An in vitro study of different material properties of Biodentine compared to ProRoot MTA. Head Face Med. 2015;11(1):1-8.
34. Kosar MA, Basturk F, Turkaydin D, Nekoofar M. The Effect of Operator-induced Variability on the Physical Properties of ProRoot MTA. Niger J Clin Pract. 2019;22:1070-1077.
35. Bayraktar K, Basturk F, Turkaydin Di, Gunday M. Long-term effect of acidic pH on the surface microhardness of ProRoot mineral trioxide aggregate, Biodentine, and total fill root repair material putty. Dent Res J (Isfahan). 2021;18(1):1-5.
36. Mohammed HM, Elfaramawy MT, Fahmy SH. Effect of sodium hypochlorite and ethylene diamine tetra-acetic acid on the push-out bond strength and sealing ability of different bioceramic root repair materials. (in vitro study). Egypt Dent J. 2023;69:801-806.
37. Rebolloso de Barrio E, Gancedo-Caravia L, García-Barbero E, Pérez-Higueras JJ. Effect of exposure to root canal irrigants on the push-out bond strength of calcium silicate–based cements. Clin Oral Investig. 2021;25(5):3267-3274.
38. Song M, Yue W, Kim S, Kim W, Kim Y, Kim JW, Kim E. The effect of human blood on the setting and surface micro-hardness of calcium silicate cements. Clin Oral Investig. 2016;20(8):1997-2005.
39. Mokhtari F, Modaresi J, Bagheri A. Effect of blood contamination on marginal adaptation of cold ceramic and MTA angelus: a scanning electron microscopic study. BMC Oral Health. 2023;23(1):1-6.
40. Nekoofar MH, Oloomi K, Sheykhrezae MS, Tabor R, Stone DF, Dummer PMH. An evaluation of the effect of blood and human serum on the surface microhardness and surface microstructure of mineral trioxide aggregate. 2010;43(10):849-858.
41. Paulo CR, Marques JA, Sequeira DB, Diogo P, Paiva R, Palma PJ, Santos JM. Influence of blood contamination on push-out bond strength of three calcium silicate-based materials to root dentin. Appl Sci. 2021;11(15):1-11.
42. Nekoofar MH, Davies TE, Stone D, Basturk FB, Dummer PMH. Microstructure and chemical analysis of blood-contaminated mineral trioxide aggregate. Int Endod J. 2011;44(11):1011-1018.
43. Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. J Endod. 1999;25(3):197-205.
44. Camilleri J. Hydration mechanisms of mineral trioxide aggregate. Int Endod J. 2007;40(6):462-470.
45. Kellum JA. Determinants of blood pH in health and disease. Crit Care. 2000;4(1):6.
46. Gandolfi MG, Iacono F, Agee K, Siboni F, Tay F, Pashley DH, Prati C. Setting time and expansion in different soaking media of experimental accelerated calcium-silicate cements and ProRoot MTA. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108(6).
47. Ashofteh Yazdi K, Bolhari B, Sabetmoghaddam T, Meraji N, Kharazifard MJ. Effect of blood exposure on push-out bond strength of four calcium silicate based cements. Iran Endod J. 2017;12(2):196-200.
48. Rahimi S, Ghasemi N, Shahi S, Lotfi M, Froughreyhani M, Milani AS, Bahari M. Effect of blood contamination on the retention characteristics of two endodontic biomaterials in simulated furcation perforations. J Endod. 2013;39(5):697-700.