Saudi Dental Journal (2019) 31, 16–22

King Saud University

Saudi Dental Journal

www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLE

Sealing ability of Biodentine versus ProRoot mineral trioxide aggregate as root-end filling materials

Mohamed Nabeel [a], Hossam M. Tawfik [b], Ashraf M.A. Abu-Seida [c,*], Abeer A. Elgendy [b]

[a] *Dept. of Endodontics, Faculty of Dental and Oral Medicine, Misr International University, Giza, Egypt*
[b] *Dept. of Endodontics, Faculty of Dentistry, Ain Shams University, Cairo, Egypt*
[c] *Dept of Surgery, Anesthesiology & Radiology, Faculty of Veterinary Medicine, Cairo University, Giza, Egypt*

Received 31 March 2018; revised 29 August 2018; accepted 30 August 2018
Available online 12 September 2018

KEYWORDS

Endodontic failure;
Endodontic treatment;
Fluid filtration method;
Periapical pathosis;
Root-end cavity preparations;
Surgical endodontic

Abstract *Aim:* This study evaluated the sealing ability of ProRoot MTA and Biodentine as root-end filling materials.

Method: In total, twenty (N = 20) extracted human maxillary central incisor teeth were decontaminated, cleaned and decoronated. Instrumentation was performed according to the step back technique using #50 Flex-o-file. Then the canals were flared to #70 Flex-o-file. Obturation was performed with conventional gutta percha and a resinous sealer (AH26) using the lateral condensation technique. Resection of 3 mm of apical end of each root was achieved perpendicular to the long axis of the root. Root-end cavity was prepared in each sample ultrasonically then filled with tested materials (N = 10). Fluid filtration method was used to assess the sealing ability of each tested material at three different experimental periods; one day, one week and one month after setting. All data were tabulated and statistically analyzed with a level of significance set at $P \leq .05$.

Results: At each specific time interval, the leakage mean values were not consistent among the tested materials. At one day interval, ProRoot MTA samples had a higher leakage mean value than Biodentine samples. However, this difference in leakage was not statistically significant ($P > .05$). At one week interval, both materials showed an increased degree of leakage mean value with no significant difference ($P > .05$). At one month interval, ProRoot MTA samples showed a decrease in leakage mean value, while the Biodentine samples showed a further increase in leakage mean value. This difference was statistically significant ($P < .05$).

* Corresponding author at: Cairo University, Faculty of Veterinary Medicine, Giza, Giza Square, PO: 12211, Egypt.
E-mail address: ashrafseida@cu.edu.eg (A.M.A. Abu-Seida).

Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

https://doi.org/10.1016/j.sdentj.2018.08.001

Conclusion: Although the sealing ability of ProRoot MTA is superior to Biodentine, Biodentine could be considered as an acceptable alternative to ProRoot MTA in peri-radicular surgeries.

1. Introduction

Complete sealing of the root canal system to obtain a fluid tight seal is essential for the success of endodontic therapy (Estrela et al., 2014). Sometimes treatment of the periapical lesions through conventional endodontic therapy is not enough and a surgical endodontic interference is a mandatory therapeutic choice. The main surgical intervention is the root tip resection and periapical curettage (von Arx, 2011).

During the peri-radicular surgery, an exposure of apical dentin surface bounded by cementum usually results from the root-end resection. For good bone regeneration and apical seal, the orthograde gutta-percha filling only is not sufficient. Application of a root-end-filling material after the root-end resection and ultrasonic root-end preparation is recommended for enhancing a good apical seal (von Arx, 2011).

Sealing ability means the ability of a material to resist the microleakage through its entire thickness. The leakage of irritant materials from the infected root canals into the peri-radicular tissues is the main cause for most endodontic failures; therefore, an efficient apical seal is essential for enhancing endodontic success (Muliyar et al., 2014).

Different materials have been used as root-end filling materials such as amalgam, intermediate restorative material (IRM), glass-ionomer cement, Super ethoxy benzoic acid (Super- EBA), and composite resin (Jou and Pertl, 1997; Soundappan et al., 2014; Asawaworarit et al., 2016). However, an ideal root-end filling material has yet to be found.

Nowadays, Mineral Trioxide Aggregate (MTA) has a more clinical success compared with other root-end filling materials due to its lower cytotoxicity, better biocompatibility and microleakage protection (von Arx, 2011; Hassanien et al., 2015). On the other hand, MTA has several disadvantages such as; long setting time, difficult handling, expensiveness, potential discoloration, and lower compressive and flexural strengths (Unal et al., 2010; Negm et al., 2017).

Biodentine is considered as an alternative to MTA because it has several similar properties when compared with MTA with better consistency and faster setting time. Biodentine powder mainly has tricalcium silicate, dicalcium silicate and calcium carbonate which are the main components of MTA. The liquid has an aqueous solution of calcium chloride and an admixture of polycarboxylate. Calcium hydroxide is produced during the setting of the cement (Butt et al., 2014).

According to several previous studies, MTA has a high clinical success as a root-end filling material (Shabahang et al., 1999; Apaydin et al., 2003; Bernabé et al., 2005; Camileri and Pittford, 2006; Felippe et al., 2006; Holland et al., 2007; Chhaparwal et al., 2017).

The manufacturer of Biodentine claims that Biodentine, as an endodontic repair material, has superior features to MTA. Therefore this study evaluated the sealing ability of Gray ProRoot Mineral Trioxide Aggregate versus Biodentine as root-end filling materials.

2. Materials and methods

2.1. Materials

Gray ProRoot MTA (Dentsply/Tulsa Dental, Tulsa, OK-USA)

Biodentine (Septodont, Saint Maur des Fausses, France).

2.2. Sample selection

The research proposal was approved by the Ethical Committee at Faculty of Dentistry Ain Shams University, Egypt. The present study was carried out on twenty extracted human maxillary central anterior teeth collected from the outpatient clinic of Oral Surgery Department at Ain Shams University. All examined teeth had the following criteria; mature apices, absence of multiple canals, severe apical curvatures, obvious fractures/cracks and root resorption and/or root canal calcifications.

2.3. Sample preparation

All teeth were immersed for 30 min in 5.25% Sodium hypochlorite solution for decontamination. The teeth were then cleaned and scaled for removing any dental deposits and/or calculus. At the level of cement-enamel junction and under water coolant, all teeth were decoronated using isomet saw (Isomet, Buehler; Ltd., Lake, Bluff, IL). The length of all roots was standardized in 16 mm by coronal surface grinding. Then all samples were stored at the room temperature in a sterile normal saline solution.

2.4. Root canal instrumentation

An endodontic explorer was used for locating the orifice of the root canal. Patency and working length of each canal was determined by passing the #15 Flex-o-File (Maillefer, Johnson City, TN, USA) to the anatomical foramen. This length was reported, and the final working length was established 1 mm short of this reported length. All teeth were irrigated with 5.25% Sodium hypochlorite solution by a 27-gauge needle, 2 mL between each file size. The canals were then cleaned and shaped by using the step-back method and #50 Flex-o-File was used as the master apical file. The canals were then flared to #70.

The instrumented root canals were then dried with the paper points and obturated by gutta-percha (Henry Schein, Melville, NY) and AH26 sealer (Dentsply, Konstanz, Germany) by using the lateral condensation technique. To verify proper obturation, all obturated teeth were radiographed (Fig. 1a). The samples showing insufficient obturation were re-obturated until proper form, fill and density were seen. IRM (Dentsply, York, PA-USA) was used to seal the coronal surfaces of the canals. The roots were wrapped in moist gauze and stored for 1 week at 100% humidity and 37 °C.

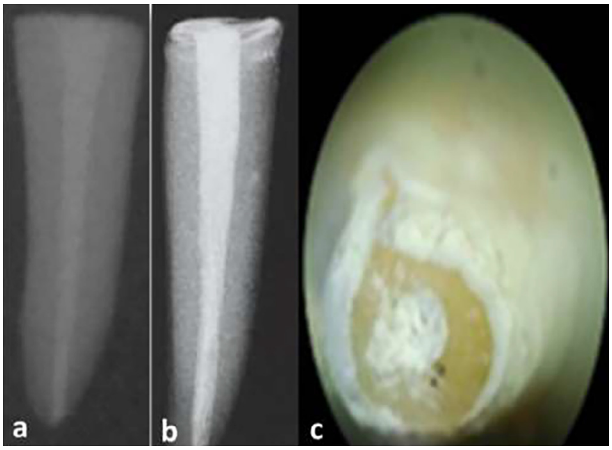

Fig. 1 (a) Photo-radiograph showing an obturated sample. (b) Photo-radiograph showing a sample after root-end resection. (c) Photograph showing a sample after filling with ProRoot MTA.

2.5. Root-end resection

Under water coolant, resection of 3 mm of the apical end of each root was performed perpendicular to the long axis of the root using a carbide bur (KOMET, Santo André, São Paulo, Brazil) mounted on a high speed hand piece (Fig. 1b).

Root-end cavity preparation, 3 mm in depth and 0.8 mm diameter was prepared in each sample using an ultrasonic tip (Ultrasonic tip, E32D NSK, Tochigi, Japan) powered by an ultrasonic device (Piezon Master, EMS, Nyon, Switzerland) at a frequency of 32 KHz. A periodontal probe was used to measure the preparation depth.

2.6. Sample grouping

The prepared teeth were randomly divided into 2 equal experimental groups according to the tested root-end filling materials; Group 1: Mineral Trioxide Aggregate (N = 10 teeth) and Group 2: Biodentine (N = 10 teeth).

To avoid any possible bias, all samples were coded throughout the study

2.7. Root-end filling

Gray ProRoot MTA was mixed according to the manufacturer's instructions and used to fill the prepared root-end cavity in group 1. After drying of the root-end cavity with paper points, ProRoot MTA was dispensed into the root end cavity using MTA carrier and compacted using a small plugger (Dentsply, York, PA-USA). Any excessed material was removed and the surface of the root was cleaned with a moist piece of gauze (Fig. 1c).

According to the manufacturer's instructions, Biodentine was mixed and used to fill the root-end cavity preparations in group 2.

2.8. Evaluation of sealability

The sealability of the tested materials was evaluated using the fluid filtration method described by Derkson et al. (1986) and as shown in Fig. 2.

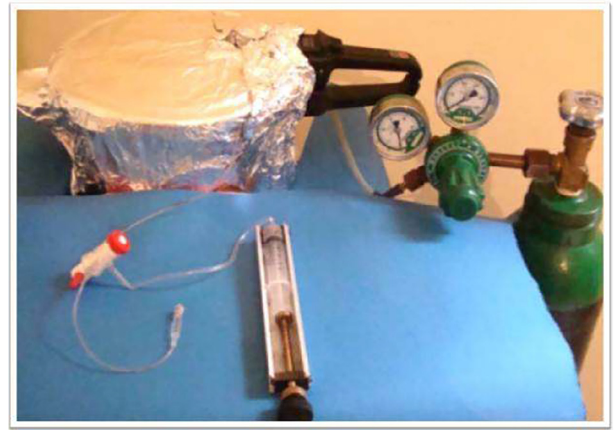

Fig. 2 Photograph showing the fluid filtration device.

All samples were measured after assembly of the measuring device as follows: each root was coated by cyanoacrylate adhesive except its apical cut aspect, to have a leak proof surface.

The root was fitted from its coronal part to the syringe with a light cure glass-ionomer except its apical 3 mm. All points of connection in the system were closed with epoxy resin. Also the base of the syringe, in which the samples were fixed, was closed as well to have a leak proof closed system. Five successive measures were taken for each sample along 10 min at 2 min intervals. These measures were averaged and converted from mm/1 min to μL/min.

Each sample was evaluated at three different tested periods (one day, one week and one month after setting).

2.9. Statistical analysis

The obtained data were represented as mean and standard deviation (SD) values of apical leakage for the tested materials at different tested periods.

Leakage data showed non-parametric distribution, so non-parametric tests were used for the comparisons. Mann-Whitney U test was applied to compare between the groups. Kruskal-Wallis test was used to compare between more than two groups. Friedman's test was used to evaluate the effect of time in comparison with more than two follow up times. Wilcoxon signed-rank test was used for assessment of the effect of time in comparison with two follow up times. Dunn's test was applied for pair-wise comparison when Kruskal-Wallis test or Friedman's test had significant results. The significance level was set at $P \leq .05$. IBM® SPSS® Statistics Version 20 for Windows (IBM® Corporation, NY, USA) was applied for the statistical analysis.

3. Results

3.1. Longitudinal data for leakage values of the tested root-end filling materials

In group 1, the sealing ability of ProRoot MTA as a root-end filling material was affected by time. The leakage mean values of ProRoot MTA samples were 0.80 ± 0.63, 1.40 ± 0.52 and 0.60 ± 0.52 after one day, one week and one month, respectively (Fig. 3).

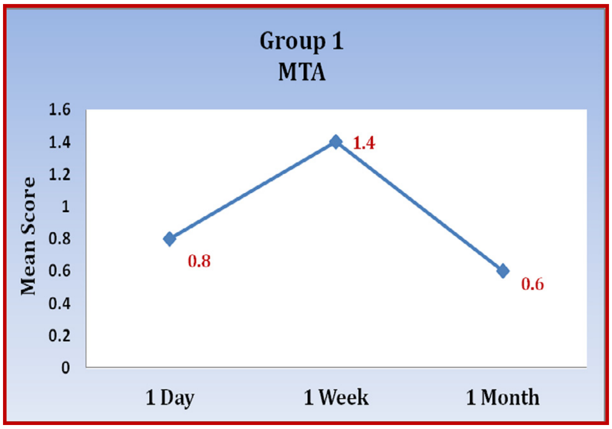

Fig. 3 Line chart showing the mean values of leakage for ProRoot MTA samples as a root-end filling material at different time intervals.

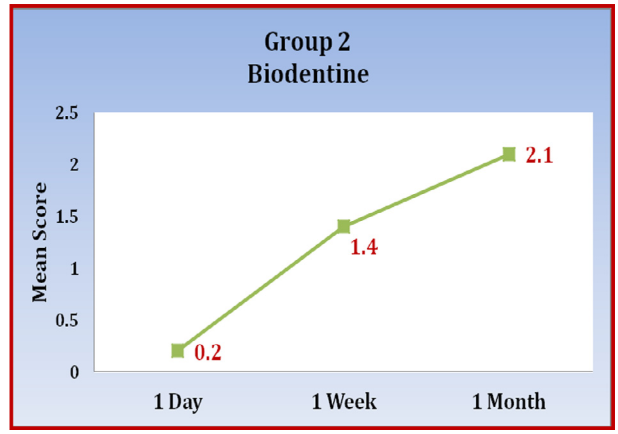

Fig. 4 Line chart showing the mean values of leakage for Biodentine samples as a root-end filling material at different time intervals.

Statistically, there was a significant change in sealing ability scores by time ($P = .003$). Pair-wise comparisons between the follow-up times revealed a statistically significant increase in sealing ability scores after 1 week followed by a significant decrease in sealing ability scores from 1 week to 1 month. However, there was no difference ($P < .05$) between sealing ability scores reported from 1 day to 1 month.

In group 2, the sealing ability of Biodentine as a root-end filling material was affected by time. The leakage mean values of Biodentine samples were 0.20 ± 0.42, 1.40 ± 0.52 and 2.10 ± 0.57 after one day, one week and one month, respectively (Fig. 4).

Statistically, there was a significant change in sealing ability scores by time ($P < .001$). Pair-wise comparisons between the follow-up times revealed a statistically significant increase in sealing ability scores after 1 week as well as from 1 week to 1 month.

3.2. Comparison of the leakage values of the two tested root-end filling materials at the three time intervals

The leakage values at each specific time interval were not consistent among the two tested materials.

At one day interval, ProRoot MTA samples showed a higher mean leakage value reaching 0.80 ± 0.63 when compared to Biodentine samples which was 0.20 ± 0.42. This difference in leakage values was not significant ($P = .052$).

At one week interval, both materials showed an increased degree of leakage mean value to be 1.40 ± 0.52 with no significant difference ($P = 1.000$).

At one month interval, ProRoot MTA samples showed a decreased leakage mean value reaching 0.60 ± 0.52, while Biodentine samples showed further increase in the leakage mean value to be 2.10 ± 0.57. This difference in leakage values between the two tested materials was significant ($P < .001$, Fig. 5).

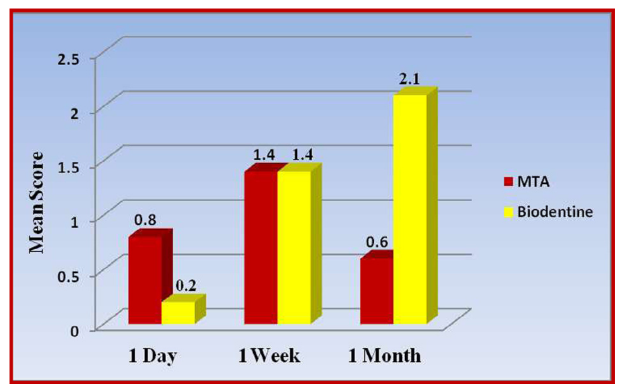

Fig. 5 Histogram showing the mean values of leakage for ProRoot MTA and Biodentine as root-end filling materials at three time intervals.

4. Discussion

The successful root canal therapy aims to eliminate the microorganisms from the root canal and to fill the intra-canal space for prevention of the possible apical pathosis caused by the bacterial colonization. Conventional endodontic treatment is unsuccessful curing in some clinical cases; hence the surgical endodontic intervention is a mandatory procedure. Root-end resection and root-end filling are the common surgical procedures when the conventional endodontic treatment fails.

The ideal root-end filling material has a good adherence to dentinal walls, a bioactive promotion of healing and a periradicular tissue tolerance (Jou and Pertl, 1997).

However Biodentine has similar properties to those of ProRoot MTA, calcium hydroxide is produced during the setting of Biodentine cement (Butt et al., 2014). Therefore, this study evaluated the sealing ability of both Gray ProRoot MTA and Biodentine as root-end filling materials because the manufacturer of each material claims its superior features in clinical performance.

It is well known that Biodentine is recommended as an endodontic repair material due to its good sealing ability, short setting time, high compressive strengths, biocompatibility and biomineralization properties.

In dentistry, the microleakage evaluation could be performed by various methods and devices such as fluid filtration, dye extraction, dye penetration, bacterial and protein leakage models. New alternative methods are introduced recently such as artificial caries, radioactive isotopes, scanning electron microscopy, neutron activation analysis, and electrical conductivity (Gogna et al., 2011).

The fluid filtration system is widely used in the literature for microleakage evaluation. This technique evaluates the sealing ability of different restorative and endodontic sealers (Bates et al., 1996; Tang et al., 2002; Fridland et al., 2003). Therefore this method has gained popularity in endodontic for the evaluation of apical or coronal microleakage (Yoshimura et al., 1990).

In the present study, fluid filtration method described by Derkson et al. (1986) was employed. This method, as the dye extraction technique, depends upon the quantitative measurements of liquid passage within interfaces therefore both techniques gave similar results in a previous study (Camps and Pashley, 2003).

The fluid filtration method has several advantages when compared to the other techniques used for microleakage evaluation. These advantages include; the samples are not destroyed as that with dye penetration, no tracer is needed, no intermediate materials as in bacterial penetration or radioactive studies are required. Moreover, the fluid filtration method gives very accurate results due to the automatic recording of very small volumes, so avoiding any possible operator bias.

Ten minutes monitoring of the air bubble at 2 min interval was selected to assure regular movement of the air bubble. A small measurement time may lead to misinterpretation.

The pressure used in this study (20 Psi) was relatively higher than the average pressure (15 Psi) used by Bashisha et al. (1998). The 20 Psi pressure seems to be far too high because it corresponds to a 1406 cm H_2O pressure. Under clinical conditions, a root-end filling material is subjected to pressure due to local bleeding, tooth function and post-operative swelling (Taschieri et al., 2004).

The results of the present study showed that both ProRoot MTA and Biodentine exhibited microleakage, but there was a difference in the leakage value at different time intervals.

After one day, Biodentine was superior with regard to sealing ability; however, the difference was not statistically significant. This was in agreement with the results of other studies which concluded that Biodentine exhibited best sealing ability followed by MTA when evaluated at 24 h (Khandelwal et al., 2015; Malhotra and Hegde, 2015) and at 48 h after setting (Pathak, 2015; Sinkar et al., 2015).

The difference in microleakage seen in Biodentine in comparison to ProRoot MTA when evaluated at 1 day after setting could be attributed to the formation of calcium or phosphate rich crystalline deposits that increases over time and minimizes the gap between the tooth and the root-end filling material (Lee, 2000; Byakod et al., 2012). The relatively high leakage of ProRoot MTA observed during the initial 24 h can be due to the longer setting time of MTA (Sarkar et al., 2005).

Therefore the setting time is one of the most clinically determinant factors (Han and Okiji, 2011). Biodentine has a rapid setting time that decreases the risk of dislodgement and contamination of the root-end filling materials (Ishikawa et al., 1997). Moreover, the handling property is another important feature of the root-end filling materials. In contrast to the difficult manipulation of MTA, due to its grainy nature and its poor consistency, Biodentine is relatively easily handled and easily condensed.

At one week interval, both ProRoot MTA and Biodentine had an increased degree of leakage mean value with no significant difference. For Biodentine, the increased leakage value after one week may be attributed the formation of a high pH solution containing Ca^{2+}, OH^{-}, and silicate ions with formation of calcium silicate hydrated gel (CSH) that precipitates on the cement particles, whereas calcium hydroxide nucleates (Lenander-Lumikari and Loimaranta, 2000).

At one month interval, ProRoot MTA samples showed a decrease in leakage mean value, while the Biodentine samples showed further increase and this difference was statistically significant. These results are in accordance with other studies which concluded that MTA has a better long-term sealing ability than Biodentine (Gandolfi et al., 2010; Camilleri et al., 2013). This improvement in the sealing ability of ProRoot MTA by time is due to its hydrophilic properties and formation of an interfacial layer between the dentin and MTA. This interfacial layer decreases the risk of marginal percolation and enhances long-term clinical success (Guven et al., 2014). In addition, further hydration of MTA powder by moisture increases the compressive strength and decreases leakage (Kubo et al., 2005). Sarkar et al. (2005) added that MTA has the ability to precipitate hydroxyapatite crystals in the presence of moisture and minimizing leakage. Also, the small particle size of MTA increases the surface available for hydration and induces greater early strength (Sarkar et al., 2005; Camilleri, 2007; Camilleri et al., 2013).

Regarding Biodentine, an increase in the alkalinity of the surrounding medium is observed due to release of calcium hydroxide and formation of a solid network. An interaction between the calcium silicate based cements and the phosphate ions of saliva results in formation of apatite deposits with increasing the sealability of the material as reported before (Lenander-Lumikari and Loimaranta, 2000; Camilleri, 2008). Moreover, Han and Okiji (2011) recorded that biomineralization ability of Biodentine is more than MTA, with a wider calcium and silicon rich layer at material dentine interface.

The relatively higher leakage values in this study compared to other studies (Butt et al., 2014; Chhaparwal et al., 2017) could be attributed to the high pressure used. In the fluid filtration method, several factors can affect the results such as; the diameter of the tube, the length of the bubble, and the measurement time.

5. Conclusion

Although the sealing ability of ProRoot MTA is superior to Biodentine, Biodentine could be considered as an acceptable alternative to ProRoot MTA in the peri-radicular surgeries. Further comparative studies on the biocompatibility of ProRoot MTA and Biodentine as root-end filling materials are recommended.

Conflict of interest

The authors declare no conflict of interests.

Ethical statement

All author approved the writing and submission of this article and none of them has any conflict of interests. This article did not published elsewhere before in any form.

Acknowledgements

None.

Funding

This research did not receive any grant from funding agencies in the commercial, public, or not-for-profit sectors.

References

Apaydin, E.S., Shabahang, S., Torabinejad, M., 2003. Hard-tissue healing after application of fresh or set MTA as root-end filling material. J. Endod. 30, 21–24.

Asawaworarit, W., Yachor, P., Kijsamanmith, K., Vongsavan, N., 2016. Comparison of the apical sealing ability of calcium silicate-based sealer and resin-based sealer using the fluid-filtration technique. Med. Princ. Pract. 25, 561–565.

Bates, C.F., Carnes, D.L., Del Rio, C.E., 1996. Longitudinal sealing ability of mineral trioxide aggregate as root-end filling material. J. Endod. 22, 575–578.

Bernabé, P.F.E., Holland, R., Morandi, R., De Souza, V., Nery, M.J., Otoboni, J.A.F., et al, 2005. Comparative study of MTA and other materials in retrofilling of pulpless dogs' teeth. Braz. Dent. J.16, 149–155.

Bashisha, W.S., Di Fiore, P.M., Liller, D.A., Lautenshhlager, E.P., Pashley, D.H., 1998. Microleakage of endodontically treated teethrestored with posts. J. Endod. 24, 703–708.

Butt, N., Talwar, S., Chaudhry, S., Nawal, R.R., Yadav, S., Bali, A., 2014. Comparison of physical and mechanical properties of MTA and Biodentine. Ind. J. Dent. Res. 25, 692–697.

Byakod, P.S., Astagi, P.B., Sakri, M., 2012. Electrical and dye leakage comparison of three different root end materials: a comparative in vitro study. Ind. J. Dent. Edu. 5, 13–21.

Camileri, J., Pittford, T.R., 2006. Mineral trioxide aggregate: a review of the constituents and biological properties of the material. Int. Endod. J. 39, 747–754.

Camilleri, J., 2007. Hydration mechanisms of mineral trioxide aggregate. Int. Endod. J. 40, 462–470.

Camilleri, J., 2008. Characterization and chemical activity of portland cement and two experimental cements with potential for use in dentistry. Int. Endod. J. 41, 791–799.

Camilleri, J., Formosa, L., Damidot, D., 2013. The setting characteristics of mta plus in different environmental conditions. Int. Endod. J. 46, 831–840.

Camps, J., Pashley, D., 2003. Reliability of the dye penetration studies. J. Endod. 29, 592–594.

Chhaparwal, S., Ballal, N.V., Menezes, N.D., Kamath, S.U., 2017. Effect of chelating agents on sealing ability of Biodentine and mineral trioxide aggregate. Saudi Endod. J. 7, 16–22.

Derkson, G.D., Pashley, D.H., Derkson, M.E., 1986. Microleakage measurement of selected restorative materials: a new in vitro method. J. Prosthodont. Dent. 56, 435–440.

Estrela, C., Holland, R., Estrela, C.R., Alencar, A.H., Sousa-Neto, M. D., Pécora, J.D., 2014. Characterization of successful root canal treatment. Braz. Dent. J. 25, 3–11.

Felippe, W.T., Felippe, M.C.S., Rocha, M.J.C., 2006. The effect of mineral trioxide aggregate on the apexification and periapical healing of teeth with incomplete root formation. Int. Endod. J. 39, 2–9.

Fridland, M., Rosado, R., Eng, C., 2003. MTA solubility and porosity with different water-to-powder ratios. J. Endod. 29, 814–817.

Gandolfi, M.G., Van Landuyt, K., Taddei, P., Modena, E., Van Meerbeek, B., Prati, C., 2010. Environmental scanning electron microscopy connected with energy dispersive x-ray analysis and raman techniques to study proroot MTA and calcium silicate cements in wet conditions and in real time. J. Endod. 36, 851–857.

Gogna, R., Jagadis, S., Shashikal, K., 2011. A comparative in vitro study of microleakage by a radioactive isotope and compressive strength of three nano-filled composite resin restorations. J. Conserv. Dent. 14, 128–131.

Guven, Y., Tuna, E.B., Dincol, M.E., Aktoren, O., 2014. X-ray diffraction analysis of MTA-plus, MTA-angelus and diaroot bioaggregate. Eur. J. Dent. 8, 211–215.

Han, L., Okiji, T., 2011. Uptake of calcium and silicon released from calcium silicate–based endodontic materials into root canal dentine. Int. Endod. J. 44, 1081–1087.

Hassanien, E.E., Abu-Seida, A.M., Hashem, A.A., Khanbash, S.S., 2015. Histologic Evaluation of Furcation Perforation Treated with Mineral Trioxide Aggregate and Bioaggregate. Asian J. Anim. Sci. 9, 148–156.

Holland, R., Mazuqueli, L., Souza, V., Murata, S.S., Junior, E.D., Suzuki, P., 2007. Influence of the type of vehicle and limit of obturation on apical and periapical tissue response in dogs' teeth after root canal filling with MTA. J. Endod. 33, 693–697.

Ishikawa, K., Miyamoto, Y., Takechi, M., Toh, T., Kon, M., Nagayama, M., 1997. Non-decay type fast-setting calcium phosphate cement: hydroxyapatite putty containing an increased amount of sodium alginate. J. Biomed. Mater. Res. 36, 393–399.

Jou, Y.T., Pertl, C., 1997. Is there a best retrograde filling material? Dent. Clin. North. Am. 41, 555–561.

Khandelwal, A., Karthik, J., Nadig, R.R., Jain, A., 2015. Sealing ability of MTA and biodentine as the root end filling material, using two different retro preparation techniques – an in vitro study. Int. J. Contemp. Dent. Med. Article ID: 150115.

Kubo, C.H., Gomes, A.P.M., Mancini, M.N.G., 2005. *In vitro* evaluation of apical sealing in root apex treated with demineralization agents and retrofiled with mineral trioxide aggregate through marginal dye leakage. Braz. Dent. J. 16, 149–155.

Lee, E.S., 2000. A new mineral trioxide aggregate root end filling technique. J. Endod. 26, 764–765.

Lenander-Lumikari, M., Loimaranta, V., 2000. Saliva and dental caries. Adv. Dent. Res. 14, 40–47.

Malhotra, S., Hegde, M.N., 2015. Analysis of marginal seal of proroot MTA, mta angelus biodentine, and glass ionomer cement as root-end filling materials: an in vitro study. J. Oral. Res. Rev. 7, 44–49.

Muliyar, S., Abdul Shameem, K., Thankachan, R.P., Francis, P.G., Jayapalan, C.S., Abdul Hafiz, K.A., 2014. Microleakage in endodontics. J. Int. Oral Health. 6, 99–104.

Negm, A.M., Hassanien, E.E., Abu-Seida, A.M., Nagy, M.M., 2017. Biological evaluation of a new pulp capping material developed from Portland cement. Exp. Toxicol. Pathol. 69, 115–122.

Pathak, S., 2015. Comparative evaluation of sealing ability of root end filling materials: in-vitro study. Int. J. Dent. Med. Res. 1, 48–52.

Sarkar, N.K., Caicedo, R., Ritwik, P., Moiseyeva, R., Kawashima, I., 2005. Physicochemical basis of the biologic properties of mineral trioxide aggregate. J. Endod. 31, 97–100.

Shabahang, S., Torabinejad, M., Boyne, P., Abedi, H., McMillan, P., 1999. A comparative study of root end induction using osteogenic protein-1, calcium hydroxide and mineral trioxide aggregate in dogs. J. Endod. 25, 1–5.

Sinkar, R.C., Sanjay, S.P., Nitin, P.J., Vandana, J.G., 2015. Comparison of sealing ability of proroot MTA, retromta, and biodentine as furcation repair materials: An ultraviolet spectrophotometric analysis. J. Conserv. Dent. 18, 445–1448.

Soundappan, S., Sundaramurthy, J.L., Raghu, S., Natanasabapathy, V., 2014. Biodentine versus mineral trioxide aggregate versus intermediate restorative material for retrograde root end filling: an in vitro study. J. Dent. (Tehran) 11, 143–149.

Tang, H.M., Torabinejad, M., Kettering, J.D., 2002. Leakage evaluation of root-end filling materials using endotoxin. J. Endod. 28, 5–7.

Taschieri, S., Del Fabbro, M., Francetti, L., Testori, T., 2004. Effect of root-end resection and root-end filling on apical leakage in the presence of core-carrier root canal obturation. Int. Endod. J. 37, 477–482.

Unal, G.C., Maden, M., Isidan, T., 2010. Repair of furcal iatrogenic perforation with mineral trioxide aggregate: Two years follow-up of two cases. Eur. J. Dent. 4, 475–481.

von Arx, T., 2011. Apical surgery: a review of current techniques and outcome. Saudi Dent. J. 23, 9–15.

Yoshimura, M., Marshall, F.J., Tinkle, J.S., 1990. In vitro quantification of the apical sealing ability of retrograde amalgam fillings. J. Endod. 16, 5–12.