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Original Article

Short-term Effect of Four Root Filling Materials on the Flexural Strength of Human Root Dentin

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Abstract

Background: This study aimed to assess the effects of calcium hydroxide, Biodentine, calcium-enriched mixture (CEM) cement, and mineral trioxide aggregate (MTA) on root dentin flexural strength after a 30-day exposure period.

Methods: This in vitro experimental study evaluated 25 freshly extracted sound human incisors with no caries or restorations. The apical 5 mm and the coronal two-thirds of the crowns were cut such that all samples had 10 mm length. Dentin samples (n=20 in each group) were then exposed to 2 mm thickness of calcium hydroxide, Biodentine, CEM cement, MTA, or saline (control) in petri dishes for 30 days. Finally, dentin samples were subjected to a three-point bending test after the intervention, and the flexural strength data were analyzed using one-way ANOVA, Tukey's test, and *t* test.

Results: Thirty-day exposure to all four biomaterials decreased the flexural strength of root dentin ($P<0.05$). The four groups were significantly different in terms of the flexural strength of root dentin ($P=0.001$). The flexural strength of root dentin was significantly lower following exposure to calcium hydroxide ($P=0.003$), Biodentine ($P=0.011$), CEM cement ($P=0.001$), and MTA ($P=0.007$) compared to saline. The reduction in strength following exposure to calcium hydroxide was higher than that in Biodentine, CEM cement, and MTA groups ($P<0.05$) while the latter three were not significantly different in this respect ($P>0.05$).

Conclusions: In general, all four tested biomaterials decrease the dentin strength although this reduction is more prominent by calcium hydroxide.

Keywords: Root canal filling materials, Mineral trioxide aggregate, Biodentine, CEM cement, Calcium hydroxide, Dentin, Flexural strength

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Highlights

- Thirty-day exposure of root canal dentin to calcium hydroxide, Biodentine, CEM cement and MTA significantly decreased the flexural strength.
- The reduction in strength following exposure to calcium hydroxide was higher than that in Biodentine, CEM cement, and MTA groups while the latter three were not significantly different in this respect.

Background

Root canal treatment is a commonly performed dental procedure for preserving teeth with necrotic or infected pulp tissue. Tooth fracture is a common clinical complication in endodontically treated teeth, which often necessitates tooth extraction (1). Irrigating solutions, intracanal medicaments, and root filling materials affect the properties of dentin, making it more susceptible to fracture (2).

Considering the extensive use of new products in the root canal treatment of teeth, some concerns still exist regarding their adverse effects on dental structures, especially dentin. Materials with minimal or no adverse effects are obviously preferred and have gained more popularity.

Calcium hydroxide is the most commonly used intracanal medicament and pulp capping agent due to its high pH, optimal antibacterial properties, and the induction of hard tissue formation (3,4). It is applied into the root canal for short or long periods of time, is used in combination with some sealers (5), and its broad-spectrum antibacterial activity is responsible for its successful application (6,7). This is directly related to the release of hydroxide ions from calcium hydroxide and their diffusion into the dentin (7). Long-term root filling with calcium hydroxide is widely performed for young, immature, traumatized teeth or those with extensive periapical lesions. Calcium hydroxide may remain in the root canals of such teeth for 2-3 months or 2-3 years. It remains in the root canal of immature teeth for longer periods of time to induce the formation of an apical

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barrier in a process called apexification. However, it has been reported that long-term use of calcium hydroxide may weaken the root structure and lead to fracture of immature teeth (8).

Limited studies have focused on changes in the fracture strength of dentin in response to exposure to endodontic materials. For instance, Rosenberg et al (9) evaluated the effect of calcium hydroxide on the microtensile strength of the dentin of maxillary incisors and showed that it weakened the dentin structure by 23%-43.9%.

Mineral trioxide aggregate (MTA) is a silicate-based cement introduced in 1993 as a root-end filling material (10). Since then, it has been commonly applied as apical plug and for root perforation repair, pulp capping, pulpotomy, treatment of root resorption, and root filling (10,11). It is composed of several oxides combined with some other hydrophilic components, which are crystalized in the presence of moisture. The main components of MTA include tricalcium silicate, tricalcium aluminate, tricalcium oxide, and silicate oxide (12). The hydration of powder results in the formation of a colloidal gel, which is solidified within a few hours. Evidence indicates that MTA provides a better seal compared to amalgam, intermediate resin material, and super ethoxy benzoic acid, and better adapts to the prepared root end dentinal wall (13). The pH of the freshly mixed MTA is alkaline similar to that of calcium hydroxide (14). A limited body of research has addressed the effect of MTA on root dentin strength. For example, White et al (15) reported a 33% reduction in bovine dentin strength following the application of MTA for 5 weeks. Based on the findings of another study, immature teeth filled with MTA were stronger than those filled with calcium hydroxide (16).

Calcium-enriched mixture (CEM) cement has clinical applications similar to those of MTA while with a different chemical composition (17). It has a high alkaline pH level and releases calcium hydroxide (18). It can also produce hydroxyapatite crystals using endogenous and exogenous ions. It has biocompatibility similar to that of MTA whereas superior working time and handling properties. However, it causes no staining and has a shorter setting time in comparison with MTA (18). It has a film thickness, flow, and sealing ability comparable to those of MTA (17) but with lower cytotoxicity (19,20). In addition, its antibacterial activity is comparable to that of hydroxide apatite while higher than that of MTA (21). It is also used as a root-end filling material (22) and for pulp capping, pulpotomy, internal root resorption repair, and furcal perforation repair (23,24). Moazami et al (25) showed that long-term use of CEM cement caused a reduction in dentin strength although this reduction was compensated in the long term.

Biodentine is another silicate-based cement introduced in 2009 for dentin replacement. It can be used for root perforations, pulp capping, apexification, root resorption, and root-end filling in endodontic surgery (26), and is supplied in the form of a powder and liquid. The powder is composed of tricalcium silicate (as its main constituent), calcium carbonate (filler), zirconium oxide (opaquer), dicalcium silicate, calcium oxide, and iron oxide. Its liquid form is composed of an aqueous solution of water-soluble polymers, along with calcium chloride (for decreasing the setting time). The physical properties of Biodentine (e.g., its flexural strength, modulus of elasticity, and Vickers hardness number) are higher than those of MTA. Biodentine is denser than MTA and has less porosities. It is also alkaline. Rajasekharan et al (27) confirmed that Biodentine is neither cytotoxic nor genotoxic. In general, Biodentine is believed to have superior physical and biological properties compared to other tricalcium cements such as MTA.

MTA and calcium hydroxide are frequently used in immature traumatized teeth for inducing apical closure. The intertubular and peritubular dentin in such teeth have not developed well. Andreasen et al (28) reported that the proteolytic activity of calcium hydroxide can weaken the tooth structure by 50% and lead to its fracture. MTA also has similar proteolytic activity.

Given that no previous study has compared the effects of Biodentine, calcium hydroxide, CEM cement, and MTA on the flexural strength of dentin, this study sought to evaluate and compare the effects of these materials on dentin flexural strength.

Materials and Methods

This in vitro, experimental study investigated 25 freshly extracted sound mature human incisors with no caries or restoration.

The teeth were stored in saline for hydration prior to the experiment. The sample size was calculated to be 20 samples in each group assuming alpha =0.05, 80% power, standard deviations of 24 and 39 for calcium hydroxide and MTA, and 10% error according to a study by Moazami et al (25).

The apical 5 mm and the coronal two-thirds of the crowns were cut using a high-speed diamond bur (D&Z, Wiesbaden, Germany) under water coolant such that all samples had a length of 10 mm. Next, a 2.5 mm drill (D&Z, Wiesbaden, Germany) was used parallel to the root canal longitudinal axis to widen the canal. Moreover, a medium-size trephine bur (Meisinger, Düsseldorf, Germany) was used to standardize the external diameter of the samples. Dentin cylinders with 2.5 and 5.5 mm internal and external diameters and 10 mm length were obtained as such. These cylinders were then longitudinally divided into four segments with a diamond disc (JOTA, Hirshensprungstrasse, Switzerland). Next, the samples were randomly divided into five groups (n=20). Samples in each group were placed in petri dishes, and the dentin surface was subjected to root filling materials as follows:

- Group 1: Petri dish containing 2 mm thickness of creamy calcium hydroxide (Merck, Darmstadt,

Germany);
- Group 2: Petri dish containing 2 mm thickness of CEM cement (BioniqueDent, Tehran, Iran);
- Group 3: Petri dish containing 2 mm thickness of MTA (Dentsply, Tulsa, OK, USA);
- Group 4: Petri dish containing 2 mm thickness of Biodentine (Septodont, Lancaster PA, France);
- Group 5: Four petri dishes containing saline as the control group.

All materials were prepared according to the manufacturer's instructions. The samples remained in petri dishes for 30 days (29). Distilled water was added to petri dishes every 3-4 days in order to hydrate the samples. All dishes were stored at 37°C and 100% humidity. After the completion of the storage period, each sample was rinsed with water. Dentin cylinders were then subjected to a three-point bending test using an Instron universal testing machine (Fantam, Mashhad, Iran). Each dentin cylinder was subjected to load application to its center point. The load was applied at a crosshead speed of 1 mm/s. The load at fracture was recorded in Newton and converted to megapascal (MPa).

The obtained data were analyzed using SPSS (SPSS Inc., IL, the USA) version 20. The effect of the type of root filling material on the flexural strength of dentin was evaluated using one-way ANOVA and Kruskal-Wallis tests for normally and non-normally distributed data, respectively. In the case of the presence of a significant difference, Tukey's test or independent *t* test was applied for pairwise comparisons, and $P < 0.05$ was considered statistically significant.

Results

Table 1 presents the flexural strength of root dentin following exposure to root filling materials. According to the t-test, the flexural strength of root dentin following exposure to calcium hydroxide ($P = 0.003$), Biodentine ($P = 0.011$), CEM cement ($P = 0.001$), and MTA ($P = 0.007$) was significantly lower than that of saline.

According to one-way ANOVA test results, the four groups significantly differed in terms of the flexural strength of root dentin ($P = 0.001$). Table 2 provides the pairwise comparisons of the flexural strength of the groups. The results demonstrated that dentin exposed to calcium hydroxide had significantly lower flexural strength in comparison with dentin exposed to Biodentine, CEM cement, and MTA ($P < 0.05$). Dentin flexural strength was nearly the same in Biodentine, CEM cement, and MTA groups ($P > 0.05$).

Discussion

This study assessed the effects of calcium hydroxide, Biodentine, CEM cement, and MTA on dentin flexural strength after a 30-day exposure period. The results revealed that 30-day exposure to all the aforementioned biomaterials decreased the flexural strength of root dentin. Importantly, the reduction in strength following exposure to calcium hydroxide was greater than that in Biodentine, CEM cement, and MTA groups while the latter three were not significantly different in this regard. Some previous studies confirmed the weakening effect of calcium hydroxide on dentin (19,30), which is in agreement with our findings. For instance, Moazami et al (25) reported that calcium hydroxide, MTA, and CEM cement decrease dentin strength. However, dentin samples in the CEM cement group regained their lost strength after one week. Thus, CEM cement was found to be the most suitable biomaterial in terms of preserving dentin strength. The reduction in dentin strength in calcium hydroxide, MTA, and CEM cement groups was attributed to the destruction of dentin protein structures as the result of the alkalinity of these compounds. Similarly, White et al (15) evaluated the effect of calcium hydroxide, sodium hypochlorite,

Table 1. Maximum Force Means (in Newton) of the Five Groups (2 mm thickness) Required to Cause Dentin Fracture

Biomaterial	Mean	Standard Deviation	Minimum	Maximum
Calcium hydroxide	109.6	16.958	78.80	143.20
Biodentine	130.9	9.06012	115.40	146.00
CEM cement	124.2	15.90043	95.50	158.80
MTA	126.55	17.29650	90.10	152.70
Control	140.58	13.511	106.00	170.60

Note. CEM: Calcium enriched mixture; MTA: Mineral trioxide aggregate.

Table 2. Pairwise Comparisons of the Flexural Strength of the Groups

Group I	Group J	Mean Difference (I-J)	P Value	95% Confidence Interval	
				Lower Bound	Upper Bound
Calcium hydroxide	Biodentine	-21.28500[a]	0.000	-34.3534	-8.2166
Calcium hydroxide	CEM cement	-14.63000[a]	0.020	-27.6984	-1.5616
Calcium hydroxide	MTA	-16.94500[a]	0.004	-30.0134	-3.8766
Biodentine	CEM cement	6.65500	0.619	-6.4134	19.7234
Biodentine	MTA	4.34000	0.887	-8.7284	17.4084
CEM cement	MTA	-2.31500	0.988	-15.3834	10.7534

Note. CEM: Calcium enriched mixture; MTA: Mineral trioxide aggregate.
[a] Tukey's post-hoc test.

and MTA on dentin strength and hardness and reported a reduction in dentin strength after 5 weeks of exposure to the materials. They concluded that such a decline was owing to the alkaline effect of materials and the subsequent destruction of dentin proteins. In another study, Sahebi et al (29) explained that the reduction in dentin strength following exposure to MTA and CEM cement can be due to the gradual release of calcium hydroxide and the subsequent destruction of dentin proteins because of its alkaline pH. Similar to our study, the reduction in strength caused by MTA and CEM cement in their study was less than that caused by calcium hydroxide, which can be due to the lower amount of released calcium hydroxide from MTA and CEM cement compared to the use of pure calcium hydroxide.

In some studies on the strength and fracture resistance of dentin following exposure to biomaterials, the researchers filled the entire root canal with the respective root filling material and then applied force while some others, similar to the present study, applied force on dentin cylinders, which can yield different results. Some studies claim that the filling of the root canal with MTA increases its fracture resistance (32,33). Such controversial results can be due to differences in methodology. Our methodology was similar to that of Moazami et al (25) and Sahebi et al (29), both reporting a decrease in dentin strength following exposure to biomaterials, which is in line with our findings. They further (25) explained that filling the weak root canals with materials with a modulus of elasticity similar to that of dentin yields a higher strength compared to empty root canals. However, similar to our study, the samples were rinsed prior to load application in order to eliminate all the filling material residues, and the load was applied to dentin cylinders rather than a filled root canal (25).

According to our findings, Biodentine caused a reduction in dentin strength although the magnitude of this decline was less than that of the other three materials and had no statistically significant difference with MTA and CEM cement groups. This reduction can be due to the alkalinity of Biodentine and the destruction of dentin proteins. Sawyer et al (34) evaluated the effect of Biodentine and MTA on the flexural strength of dentin and concluded that they both decrease the flexural strength of dentin, which is in accordance with our study findings.

Considering the current findings and those of similar previous studies regarding the effect of calcium hydroxide, Biodentine, CEM cement, and MTA on root dentin strength, it seems that long-term use of calcium hydroxide and the filling of the entire root canal with calcium hydroxide paste increase the risk of root fracture compared to the application of other three root filling materials. On the other hand, the entire canal length is not filled with calcium silicate-based cements in vital pulp therapy or apical plug placement; instead, they are applied with 3-4 mm height, which decreases the risk of root fracture in their application. Nonetheless, further studies with longer exposure time and longer follow-ups are required to better elucidate this issue. Eventually, this study had an in vitro design, which limits the generalizability of results to the clinical setting. Thus, future clinical studies are needed to cast a final judgment in this respect.

Conclusions

In general, it appears that all four tested biomaterials decreased the dentin strength although this reduction was more prominent by calcium hydroxide.

Conflict of Interest Disclosures

The authors declare that there is no conflict of interests.

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Ethical Statement

The study was approved by the Ethics Committee of Hamadan University of Medical Sciences (IR.UMSHA.REC.1397.61).

References

1. Driscoll CO, Dowker SE, Anderson P, Wilson RM, Gulabivala K. Effects of sodium hypochlorite solution on root dentine composition. J Mater Sci Mater Med. 2002;13(2):219-23. doi: 10.1023/a:1013894432622.
2. Blaser PK, Lund MR, Cochran MA, Potter RH. Effect of designs of Class 2 preparations on resistance of teeth to fracture. Oper Dent. 1983;8(1):6-10.
3. Yoshiba K, Yoshiba N, Iwaku M. Histological observations of hard tissue barrier formation in amputated dental pulp capped with alpha-tricalcium phosphate containing calcium hydroxide. Endod Dent Traumatol. 1994;10(3):113-20. doi: 10.1111/j.1600-9657.1994.tb00535.x.
4. Zmener O, Pameijer CH, Banegas G. An in vitro study of the pH of three calcium hydroxide dressing materials. Dent Traumatol. 2007;23(1):21-5. doi: 10.1111/j.1600-9657.2005.00447.x.
5. Holland R, de Souza V. Ability of a new calcium hydroxide root canal filling material to induce hard tissue formation. J Endod. 1985;11(12):535-43. doi: 10.1016/s0099-2399(85)80199-0.
6. Brännström M, Vojinovic O, Nordenvall KJ. Bacteria and pulpal reactions under silicate cement restorations. J Prosthet Dent. 1979;41(3):290-5. doi: 10.1016/0022-3913(79)90009-x.
7. Fisher FJ, McCabe JF. Calcium hydroxide base materials. An investigation into the relationship between chemical structure and antibacterial properties. Br Dent J. 1978;144(11):341-4. doi: 10.1038/sj.bdj.4804093.
8. Andreasen JO. Treatment of fractured and avulsed teeth. ASDC J Dent Child. 1971;38(1):29-31 passim.
9. Rosenberg B, Murray PE, Namerow K. The effect of calcium hydroxide root filling on dentin fracture strength. Dent Traumatol. 2007;23(1):26-9. doi: 10.1111/j.1600-9657.2006.00453.x.
10. 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):591-5. doi: 10.1016/s0099-2399(06)80271-2.
11. Nakamichi I, Iwaku M, Fusayama T. Bovine teeth as possible substitutes in the adhesion test. J Dent Res. 1983;62(10):1076-

81. doi: 10.1177/00220345830620101501.
12. Camargo CH, Bernardineli N, Valera MC, de Carvalho CA, de Oliveira LD, Menezes MM, et al. Vehicle influence on calcium hydroxide pastes diffusion in human and bovine teeth. Dent Traumatol. 2006;22(6):302-6. doi: 10.1111/j.1600-9657.2005.00326.x.
13. Islam I, Chng HK, Yap AU. X-ray diffraction analysis of mineral trioxide aggregate and Portland cement. Int Endod J. 2006;39(3):220-5. doi: 10.1111/j.1365-2591.2006.01077.x.
14. Bogen G, Kuttler S. Mineral trioxide aggregate obturation: a review and case series. J Endod. 2009;35(6):777-90. doi: 10.1016/j.joen.2009.03.006.
15. White JD, Lacefield WR, Chavers LS, Eleazer PD. The effect of three commonly used endodontic materials on the strength and hardness of root dentin. J Endod. 2002;28(12):828-30. doi: 10.1097/00004770-200212000-00008.
16. Hatibović-Kofman S, Raimundo L, Zheng L, Chong L, Friedman M, Andreasen JO. Fracture resistance and histological findings of immature teeth treated with mineral trioxide aggregate. Dent Traumatol. 2008;24(3):272-6. doi: 10.1111/j.1600-9657.2007.00541.x.
17. Asgary S, Eghbal MJ, Parirokh M. Sealing ability of a novel endodontic cement as a root-end filling material. J Biomed Mater Res A. 2008;87(3):706-9. doi: 10.1002/jbm.a.31678.
18. Asgary S, Shahabi S, Jafarzadeh T, Amini S, Kheirieh S. The properties of a new endodontic material. J Endod. 2008;34(8):990-3. doi: 10.1016/j.joen.2008.05.006.
19. Asgary S, Moosavi SH, Yadegari Z, Shahriari S. Cytotoxic effect of MTA and CEM cement in human gingival fibroblast cells. Scanning electronic microscope evaluation. N Y State Dent J. 2012;78(2):51-4.
20. Mozayeni MA, Milani AS, Alim Marvasti L L, Asgary S. Cytotoxicity of calcium enriched mixture cement compared with mineral trioxide aggregate and intermediate restorative material. Aust Endod J. 2012;38(2):70-5. doi: 10.1111/j.1747-4477.2010.00269.x.
21. Asgary S, Akbari Kamrani F. Antibacterial effects of five different root canal sealing materials. J Oral Sci. 2008;50(4):469-74. doi: 10.2334/josnusd.50.469.
22. Asgary S, Eghbal MJ, Ehsani S. Periradicular regeneration after endodontic surgery with calcium-enriched mixture cement in dogs. J Endod. 2010;36(5):837-41. doi: 10.1016/j.joen.2010.03.005.
23. Fallahinejad Ghajari M, Asgharian Jeddi T, Iri S, Asgary S. Direct pulp-capping with calcium enriched mixture in primary molar teeth: a randomized clinical trial. Iran Endod J. 2010;5(1):27-30.
24. Zarrabi MH, Javidi M, Jafarian AH, Joushan B. Histologic assessment of human pulp response to capping with mineral trioxide aggregate and a novel endodontic cement. J Endod. 2010;36(11):1778-81. doi: 10.1016/j.joen.2010.08.024.
25. Moazami F, Sahebi S, Jamshidi D, Alavi A. The long-term effect of calcium hydroxide, calcium-enriched mixture cement and mineral trioxide aggregate on dentin strength. Iran Endod J. 2014;9(3):185-9.
26. Malkondu Ö, Karapinar Kazandağ M, Kazazoğlu E. A review on biodentine, a contemporary dentine replacement and repair material. Biomed Res Int. 2014;2014:160951. doi: 10.1155/2014/160951.
27. Rajasekharan S, Martens LC, Cauwels RG, Verbeeck RM. Biodentine™ material characteristics and clinical applications: a review of the literature. Eur Arch Paediatr Dent. 2014;15(3):147-58. doi: 10.1007/s40368-014-0114-3.
28. Andreasen JO, Farik B, Munksgaard EC. Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. Dent Traumatol. 2002;18(3):134-7. doi: 10.1034/j.1600-9657.2002.00097.x.
29. Sahebi S, Nabavizadeh M, Dolatkhah V, Jamshidi D. Short term effect of calcium hydroxide, mineral trioxide aggregate and calcium-enriched mixture cement on the strength of bovine root dentin. Iran Endod J. 2012;7(2):68-73.
30. Eghbal MJ, Asgary S, Baglue RA, Parirokh M, Ghoddusi J. MTA pulpotomy of human permanent molars with irreversible pulpitis. Aust Endod J. 2009;35(1):4-8. doi: 10.1111/j.1747-4477.2009.00166.x.
31. Doyon GE, Dumsha T, von Fraunhofer JA. Fracture resistance of human root dentin exposed to intracanal calcium hydroxide. J Endod. 2005;31(12):895-7. doi: 10.1097/01.don.0000194542.02521.af.
32. Sarkar NK, Caicedo R, Ritwik P, Moiseyeva R, Kawashima I. Physicochemical basis of the biologic properties of mineral trioxide aggregate. J Endod. 2005;31(2):97-100. doi: 10.1097/01.don.0000133155.04468.41.
33. Amini Ghazvini S, Abdo Tabrizi M, Kobarfard F, Akbarzadeh Baghban A, Asgary S. Ion release and pH of a new endodontic cement, MTA and Portland cement. Iran Endod J. 2009;4(2):74-8.
34. Sawyer AN, Nikonov SY, Pancio AK, Niu LN, Agee KA, Loushine RJ, et al. Effects of calcium silicate-based materials on the flexural properties of dentin. J Endod. 2012;38(5):680-3. doi: 10.1016/j.joen.2011.12.036.