Comparison of Push-Out Bond Strength of Three Calcium Silicate Cements to Dentin

Üç Kalsiyum Silikat Esaslı Simanın Dentine Bağlanma Dayanımının Karşılaştırılması

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Geliş Tarihi/*Received:* 15.09.2015
Kabul Tarihi/*Accepted:* 22.02.2016

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ABSTRACT Objective: To compare the push-out bond strength of ProRoot MTA (PRM), Biodentine (BD) and BioAggregate (BA) to root dentin. **Material and Methods:** Twenty extracted mandibular premolar teeth were used. Serial slices of 1.00 ± 0.05 mm thickness were obtained from the middle third of the roots by sectinon vertically to the long axis using a water-cooled diamond blade on a cutting machine. The specimens were prepared with Gates Glidden burs (sizes 4, 5 and 6) to obtain a standard diameter of 1.3 mm. A total of 60 slices were randomly divided into three groups (n = 20). The root slices were filled with PRM, BD and BA cements. The push-out bond strengths were measured by using a universal testing machine. Force was applied to the fillings with a 1-mm diameter cylindrical stainless steel plunger, at a speed of 1 mm/min. Stereomicroscopic images were obtained at 25× magnification to determine the type of bond failure. Data were analysed using one-way analysis of variance and post hoc Tukey tests. A chi-square test was used to determine if there were any significant association between the type of material and type of failure. **Results:** PRM and BD each had higher bond strength values than BA ($p<0.001$). **Conclusion:** Since the push-out bond strength of ProRoot MTA and Biodentine are higher than BioAggregate, their usage in clinical applications can be advised if seen necessary.

Key Words: Calcium silicate; mineral trioxide aggregate

ÖZET Amaç: ProRoot MTA (PRM), Biodentine (BD) ve BioAggregate (BA) simanların kök dentinine bağlanma dayanımını karşılaştırmaktır. **Gereç ve Yöntemler:** 20 adet çekilmiş alt premolar diş kullanıldı. Köklerin orta üçlüsünde 1,00 ± 0,05 mm kalınlıklarında diskler elde etmek için kökün uzun aksına dik olacak şekilde su soğutma altında elmas bıçaklar kullanılarak kesildi. Elde edilen diskler, çaplarını 1.3 mm standardize etmek için 4, 5 ve 6 numaralı Gates Glidden frezleri kullanılarak genişletildi. Toplam 60 örnek rastgele 3 gruba ayrıldı (n:20). Diskler ProRoot MTA, Biodentine ve BioAggragate simanları ile dolduruldu. Universal test cihazı kullanılarak örneklere itme testi uygulandı. Kuvvetler dakikada 1 mm hızla ve çapı 1 mm olan paslanmaz çelik pistonlarla dolgu materyallerinin üzerine uygulandı. Bağlanma dayanımının başarısızlık tiplerini belirlemek için 25 büyütme altında stereomikroskopta incelendi. İstatistiksel analiz için one-way ANOVA ve post hoc Tukey testi kullanıldı. Başarısızlık tipleri arasındaki farkı belirlemek için Ki-Kare testi yapıldı. **Bulgular:** Gruplar arasında anlamlı fark vardı. ProRoot MTA ve Biodentine ile doldurulan örneklerin bağlanma dayanımı BioAggregate'dan daha yüksek bulundu. **Sonuç:** ProRoot MTA ve Biodentine'in kök dentinine bağlantısı BioAggregate'dan daha iyi olduğu için klinik uygulamalar sırasında kullanımları gerekli görüldüğünde tavsiye edilebilir.

Anahtar Kelimeler: Kalsiyum silikat; mineral trioksid agregat

Turkiye Klinikleri J Dental Sci 2016;22(1):29-34

doi: 10.5336/dentalsci.2015-47969

Mineral trioxide aggregate (MTA) was introduced to endodontics in 1993.[1] Studies have reported MTA's various favourable properties, including low cytotoxicity, high biocompatibility and good sealing ability.[2-5] It is used in several applications, such as root end fillings, direct pulp capping and the closure of the apex in immature teeth; it is also used as a coronal barrier and canal paste in the treatment of root resorptions.[6-8]

Like any material, calcium silicate cements (CSCs) have several disadvantages, such as long setting times, difficulties in manipulation, and the risk of tooth discolouration.[8] Because of these disadvantages, the original formulation was modified to improve the material's physicochemical and mechanical properties.[9] The main components of MTA are tricalcium silicate, bismuth oxide, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, and calcium sulphate dehydrate; in the dental market, PRM is its commercial form. According to the manufacturer, the recommended setting time for MTA is 4 h. BA is a material similar to MTA, modified so as to contain no aluminium; this modification precludes cytotoxic effects.[10] It contains tricalcium silicate, dicalcium silicate, calcium phosphate, and monobasic and amorphous silicon dioxide. Additionally, tantalum pentoxide is replaced with bismuth oxide in conventional MTA to provide radiopacity.[11] BD consists of tricalcium silicate, calcium carbonate, zirconium oxide, a setting accelerator that contains calcium chloride, and a water-reducing agent. BD can be called a dentin replacement material; it can be used as a base material under composite restorations, with the advantages of good sealing ability, resistance to high compressive strengths, a short setting time, and good biocompatibility, bioactivity and biomineralisation properties.[12-15]

The ability to prectule microleakage through the pulp and periradicular tissues and be resistant to various forces are some of the principal properties that a repair material should ideally possess; the ability of such a material to adapt to dentin walls, as well as its bond strength, are also very important.[9,16] Adhesion of any dental material to dentin can be evaluated through the use of tensile, shear, and push out strength tests.[17] Push out tests area a frequently used in endodontics, as they provide more reliable results than the conventional shear test; by using this method, more realistic specimens are obtained with parallel fractures.[18-21] The aim of this study was to compare the push-out bond strength of PRM, BD, and BA to root dentin. The null hypothesis states that there are no significant differences among the three in terms of push out bond strength.

MATERIAL AND METHODS

SAMPLE PREPARATION

Twenty single rooted permanent mandibular premolar teeth that had been extracted for orthodontic reasons were used in the present study. Each teeth had fully formed apex and lacked both root resorption and previous endodontic treatment. Teeth were stored in tap water containing 0.1% thymol until they were used in the study. A standard length of 11 mm was obtained by sectioning the tooth at the cementoenamel junction with a diamond saw. Serial slices of 1.00 ± 0.05 mm thickness were obtained from the middle third of the roots by sectioning vertically to the long axis, using a water cooled diamond blade on a cutting machine (Isomet 1000; Buehler, Lake Bluff, NY, USA). A total of 60 root dentin slices were drilled with Gates Glidden burs (Dentsply Maillefer, Ballaigues, Switzerland) sizes 4, 5, and 6 to obtain standardised cavites with 1.3 mm diameters. All slices were irrigated 5 ml of distilled water and dried on paper points. The specimens were then randomly divided into three groups (n = 20).

Different CSCs (ProRoot MTA, Biodentine, and DiaRoot BioAggregate cements) were prepared according to manufacturer' instructions, placed inside the root canal space of the slices, and compacted with an endodontic plunger. A scalpel was used to remove any excess material. The specimens were then covered with serum soaked gauze and incubated for 7 days at 37 °C and 100% humidity, in order to achieve complete setting. The specimens in each group were stored separately in plastic containers. The humid environment was maintained inside the container by replacing wet gauze every day.

PUSH-OUT TEST

A universal testing machine (Instron, Norwood, MA, USA) was used to measure push-out bond strength. Force was applied on the fillings with a 1-mm diameter cylindrical stainless steel plunger at a 1 mm/min speed. The maximum load needed to achieve filling failure was recorded in newtons. The data obtained were converted to megapascals (Mpa) by using the following formula: newtons / (2π rh), where π indicate the constant, and r and h the canal radius and the thickness of the root slice, both in millimetres.

STEREOMICROSCOPY ANALYSIS

Stereomicroscopic images were obtained at 25× magnification to determine the type of bond failure. Categorisation of the type of failure was than performed, in terms of one of three types namely, adhesive failure between MTA and dentin, cohesive failure within MTA, or mixed failure.

STATISTICAL ANALYSIS

IBM SPSS statistics software 20.0 was used in this study to undertake statistical analyses. Push out strength data were analysed using one-way analysis of variance (ANOVA) and post hoc Tukey tests ($p < 0.05$). A chi-square test was used to determine if there were any significant association between material type and failure type.

RESULTS

Table 1 showed the mean and standard deviations of the groups. Statistically significant differences were found among the groups, according to the results of the ANOVA test ($p < 0.001$). The PRM and BD groups exhibited higher mean values of push-out bond strength than the BA group ($p<0.001$). No statistically significant difference could be found between PRM and BD ($p=0.181$) in terms of mean bond strength. Differences among the bond failure modes of the groups were not statistically significant according to the results of the chi-square test ($p=0.780$) (Table 2). While a majority of the samples exhibited an adhesive type failure, some exhibited cohesive and mixed failure types (Figure 1).

TABLE 1: The mean push out bond strength in MPA of three different materials.

Groups	N	Mean(Mpa)	SD
ProRoot MTA	20	10.7a	±2.1
Biodentine	20	9.2a	±2.7
Bioaggregate	20	2.6b	±1.2

Different superscript letters indicate significant differences between the groups ($P^{<}$ .05). Same superscript letters indicate no significant differences (p>.05); SD: Standart deviation.

TABLE 2: Bond failure was of the adhesive type in the majority of samples; however, some samples exhibited cohesive and mixed failure patterns.

	Adhesive	Cohesive	Mix	Total
ProRoot MTA	10	6	4	20
Biodentine	11	4	5	20
BioAggregate	8	5	7	20

Different superscript letters indicate significant differences between the groups ($P^{<}$ .05). Same superscript letters indicate no significant differences (p>0.05).

DISCUSSION

Many studies have evaluated the clinical usage and, biological and physical characteristics of CSC materials.[10,17,22] These materials gained importance in endodontics, since they have used in hard-to-cope areas such as external root surface resorptions and apical plug-in resected teeth. Therefore, they should have properties such as biocompatibility, stability after setting, adherence to dentin, resist-

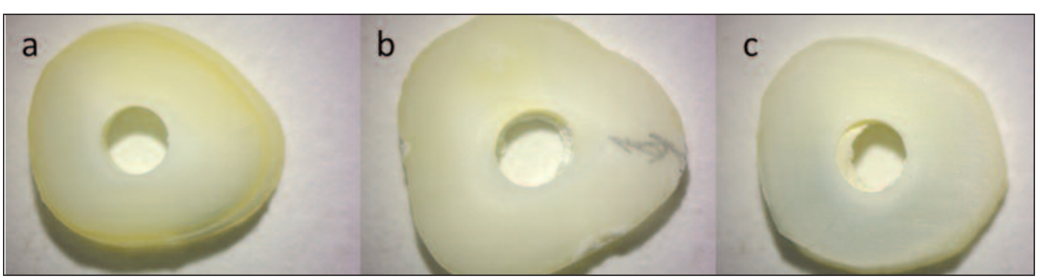

FIGURE 1: Stereomicroscop images of the failure modes from representative samples. Adhesive type **(a)**, cohesive type **(b)** and mix type **(c)** failure patterns.

ance to dislodging forces and the rendering of a good seal to prevent bacterial leakage and the passage of tissue fluids.[23] Some formulation modifications have been performed to improve their properties, as in the examples of BA and BD. This study was designed to assess the push-out bond strength of the adherence of three CSC to canal dentin.

Gancedo-Caravia and Garcia-Barbero have reported that the push-out strength of CSC increased in the presence of moisture.[16] In the present study, the specimens were incubated for 7 days at 37 °C at 100% humidity, to allow the materials to set completely; this was done on the understanding that CSCs have a long setting time. In previous studies, after the root canal slices were prepared with the Gates Glidden, or post-drilling, they were obturated with CSC.[24,25] In the present study we used similar method with previous studies.[24,25]

The selection of mixing and compaction techniques relates to the chemical, physical, and biological characteristics of the CSCs used. When CSCs are mixed, a slurry paste forms that is difficult to handle and compact inside the root canal spaces, without voids.[26] The use of a lentulo, manual files, pluggers, and ultrasonic activation are some of the techniques used to apply CSCs to root canals.[27-29] When hand condensation is combined with indirect ultrasonic activation, improvements can be made to the compaction of CSCs and their adaptation to dentin by appling compressive forces; these improvements derive from the reorganisation of particles and the escape of entrapped air.[29] On the other hand, El-Ma'aita et al. have reported on manual compaction results in denser root canal fillings, compared to those rendered through ultrasonic activation.[26] Yet another study compared ultrasonic and hand condensation methods in terms of their effects on the adaptation of CSCs in simulated root canals and found that ultrasonic activation causes more voids and poorer adaptation.[28] Namazikhah et al. and Nekoofar et al. each state that voids may actually not pose a problem for the optimal setting, since they act as water passages through CSCs.[30,31] In the current study, standardised root slices were filled with PRM, BD and BA cements, using a plugger.

It remains controverisal whether or not leaving the smear layer intact is advantageous in endodontics. It has been suggested that the smear layer may block the dentinal tubules and therefore preclude bacterial or toxin penetration; it has also been suggested, however, that the smear layer leads to the possibility of infection and microleakage, and so it must be removed.[32-34] On the other hand, this smear layer prevents medicaments from penetrating the dentinal tubules and killing bacteria within. Additionally, the smear layer also reduces the adaptability of filling materials and their penetration into the canal walls, thus reducing sealing ability.[35,36] Still, other studies report that smear layer removal prior to CSC application has a negative effect on the CSC's sealing ability.[37,38] Uyanık et al. evaluated the effect of different irrigation methods on the sealing capacity of CSC; they conclud that the use of MTAD and EDTA causes an increase in the leakage of CSC. In yet another study, CSC exhibited higher leakage when the smear layer was removed prior to CSC application.[39,40] Having considered all these matters, we decided that in the current study, the smear layer would be left intact.

Guneser et al. showed that the bond strength of White PRM was weaker than that BD. In addition, Ma'atta et al. have reported that the bond strength of Biodentine was stronger than that of PRM; they attribute this to the fact that the particle size of BD was small and has better capacity for penetration into dentinal tubules.[41,42] Shokouhinejad et al. showed that the bond strength of BA was weaker than that of PRM or Endosequence, in a study evaluating the bond strength of those materials as root repair materials.[43] Ertas et al. evaluated the push-out bond strength of PRM, Angelus MTA, and calcium-enriched mixture (CEM) cement; they found PRM to have the greatest strength.[25] They explained that this comparatively greater strength could be attributed to its different formulation.[25]

The results of the current study indicated that the push-out bond strength of BA was lower than PRM and BD. This difference might stem from the presence of different chemical components in each CSC; some are present in PRM and BD, for example, but not in BA. These results align with those of previous studies.[24,44,45] Han and Okiji stated that the higher retention in White MTA and BD groups might be explained by the tag-like structure forms in the adjacent root canal dentin; Liu et al. indicated that the addition of tricalcium aluminate improves the strength of CSC. In the absence of $Ca_3\ Al_2O_6$ the strength of a CSC may be attenuated.[12,24,46]

Shokouhinejad et al. have showed that following push-out testing, the mode of failure is mainly of an adhesive nature.[17] Ertas et al. have stated that the mode of failure does not significantly differ among PRM, Angelus MTA, and CEM cement.[25] In the current study, the bond failures observed in all experimental groups generally occured at the CSC-dentin interface (i.e., adhesive type). However, differences among the bond failure groups were not significant.

CONCLUSION

Within the limitations of the present study, the clinical usage of ProRoot MTA and BioDentine may be advised since their push-out bond strength to root canal dentin are higher than that of BioAggregate.

REFERENCES

1. Lee SJ, Monsef M, Torabinejad M. Sealing ability of a mineral trioxide aggregate for repair of lateral root perforations. J Endod 1993;19(11):541-4.
2. Mozayeni MA, Milani AS, Marvasti LA. Cytotoxicity of calcium enriched mixture cement compared with mineral trioxide aggregate and intermediate restorative material. Aust Endod J 2012;38(2):70-5.
3. Mozayeni MA, Salem Milani A, Alim Marvasti L, Mashadi Abbas F, Modaresi SJ. Cyctotoxicity of cold ceramic compared with MTA and IRM. Iran Endod J 2009;4(3):106-11.
4. Fischer EJ, Arens DE, Miller CH. Bacterial leakage of mineral trioxide aggregate as compared with zinc-free amalgam, intermediate restorative material, and Super- EBA as a root-end filling material. J Endod 1998;24(3): 176-9.
5. Torabinejad M, Pitt Ford TR, McKendry DJ, Abedi HR, Miller DA, Kariyawasam SP. Histologic assessment of mineral trioxide aggregate as a root-end filling in monkeys. J Endod 1997;23(4):225-8.
6. Vossoughhosseini S, Lotfi M, Shahmoradi K, Saghiri MA, Zand V, Mehdipour M, et al. Microleakage comparision of glass-ionomer and White mineral trioxide aggregate used as a coronal barrier in nonvital bleaching. Med Oral Pathol Oral Cir Bucal 2011;16(7):1017-21.
7. Salem Milani A, Rahimi S, Borna Z, Jafarabadi MA, Bahari M, Deljaver AS. Fracture resistance of immature teeth filled with mineral trioxide aggregate or calcium enriched mixture cement: an exvivo study. Dent Res J (Isfahan) 2012;9(3):299-304.
8. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review--Part III: clinical pplications, drawbacks, and mechanism of action. J Endod 2010;36(3): 400-13.
9. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review-Part I: chemical, physical, and antibacterial properties. J Endod 2010;36(1):16-27.
10. De-Deus G, Canabarro A, Alves G, Linhares A, Sene MI, Granjeiro JM. Optimal cytocompatibility of a bioceramic nanoparticulate cement in primary human mesenchymal cells. J Endod 2009;35(10):1387-90.
11. Zhang H, Pappen G, Haapasalo M. Dentin enhances the antibacterial effect of mineral trioxide aggregate and bioaggregate. J Endod 2009;35(2):221-4.
12. Han L, Okiji T. Uptake of calcium and silicon released from calcium silicate-based endodontic materials into root canal dentine. Int Endod J 2011;44(12):1081-7.
13. Koubi G, Colon P, Franquin JC, Hartmann A, Richard G, Faure MO, et al. Clinical evaluation of the performance and safety of a new dentine substitute, Biodentine, in the restoration of posterior teeth-a prospective study. Clin Oral Investig 2013;17(1):243-9.
14. Laurent P, Camps J, De Méo M, Déjou J, About I. Induction of specific cell responses to a Ca(3) SiO(5)-based posterior restorative material. Dent Mater 2008;24(11):1486-94.
15. Laurent P, Camps J, About I. Biodentineinduces TGF-b1 release from human pulp cells and early dental pulp mineralization. Int Endod J 2012;45(5):439-48.
16. Gancedo-Caravia L, Garcia-Barbero E. Influence of humidity and setting time on the push-out strength of mineral trioxide aggregate obturations. J Endod 2006;32(9):894-6.
17. Shokouhinejad N, Nekoofar MH, Iravani A, Kharrazifard MJ, Dummer PM. Effect of acidic environment on the push-out bond strength of mineral trioxide aggregate. J Endod 2010;36 (5):871-4.
18. Hong ST, Bae KS, Baek SH, Kum KY, Shon WJ, Lee W. Effects of root canal irrigants on the push-out strength and hydration behaviour of acceleratedmineral trioxide aggregate in its early setting phase. J Endod 2010;36(12):1995-9.
19. Saghiri MA, Shokouhinejad N, Lotfi M, Aminsobhani M, Saghiri AM. Push-out bond strength of mineral trioxide aggregate in the presence of alkaline pH. J Endod 2010;36(11): 1856-9.
20. Shahi S, Rahimi S, Yavari HR, Samiei M, Janani M, Bahari M, et al. Effects of various mixing techniques on push-out bond strengths of white mineral trioxide aggregate. J Endod 2012;38(4):501-4.
21. Drummond JL, Sakaquchi RL, Racean DC, Wozny J, Steinberg AD. Testingmode and surface treatment effects on dentin bonding. J Biomed Mat Res 1996;32(4):533-41.
22. Torabinejad M, Parirokh M. Mineral trioxide aggregate: a comprehensive literatüre review--part II: leakage and biocompatibility investigations. J Endod 2010;36(2):190-202.
23. Kayahan MB, Nekoofar MH, Kazandağ M, Canpolat C, Malkondu O, Kaptan F, et al. Effect of acid-etching procedure on selected physical properties of mineral trioxide aggregate. Int Endod J 2009;42(11):1004-14.
24. Alsubait SA, Hashem Q, AlHargan N, AlMohimeed K, Alkahtani A. Comperative evaluation of push-out bond strength of ProRoot MTA, bioaggregate and biodentine. J Contemp Dent Pract 2014;15(3):336-40.
25. Ertas H, Kucukyılmaz E, Ok E, Uysal B. Push-out bond strength of different mineral trioxide aggregates. Eur J Dent 2014;8(3):348-52.
26. El-Ma'aita AM, Qualtrough AJ, Watts DC. A micro-computed tomography evaluation of mineral trioxide aggregate root canal fillings. J Endod 2012;38(5):670-2.

27. Bogen G, Kuttler S. Mineral trioxide aggregate obturation: a review and case series. J Endod 2009;35(6):777-90.

28. Aminoshariae A, Hartwell GR, Moon PC. Placement of mineral trioxide aggregate using two different techniques. J Endod 2003;29 (10):679-82.

29. Yeung P, Liewehr FR, Moon PC. A quantitative comparison of the fill density of MTA produced by two placement techniques. J Endod 2006;32(5):456-9.

30. Namazikhah MS, Nekoofar MH, Sheykhrezae MS, Salariyeh S, Hayes SJ, Bryant ST, et al. The effect of pH on surface hardness and microstructure of mineral trioxide aggregate. Int Endod J 2008;41(2):108-16.

31. Nekoofar MH, Haddad DC, Nodle J, Aseeley Z. Water content of ampoule packaged with ProRoot MTA. Int Endod J 2009;42(6):205-10.

32. Timpawat S, Vongsavan N, Messer HH. Effect of removal of the smear layer on apical microleakage. J Endod 2001;27(5):351-3.

33. Meryon SD, Brook AM. Penetration of dentine by three oral bacteria in vitro and their associated cytotoxicity. Int Endod J 1990;23(4):196-202.

34. Oksan T, Aktener BO, Sen BH, Tezel H. The penetration of root canal sealers into dentinal tubules. A scanning electron microscope study. Int Endod J 1993;26(5):301-5.

35. Sen BH, Wesselink PR, Türkün M. The smear layer: a phenomenon in root canal therapy. Int Endod J 1995;28(3):141-8.

36. Torabinejad M, Handysides R, Khademi AA, Bakland LK. Clinical implications of the smear layer in endodontics: a review. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002;94(6):658-66.

37. Yildirim T, Er K, Taşdemir T, Tahan E, Buruk K, Serper A. Effect of smear layer and root-end cavity thickness on apical sealing ability of MTA as a root-end filling material: a bacterial leakage study. Oral Surg Oral Med Oral Pathol Radiol Endod 2010;109(1):67-72.

38. Yan P, Peng B, Fan B, Fan M, Bian Z. The effects of sodium hypochlorite (5.25%), chlorhexidine(2%), and glyde file prep on the bond strength of MTA-dentin. J Endod 2006;32(1):58-60.

39. Uyanik MO, Nagas E, Sahin C, Dagli F, Cehreli ZC. Effects of different irrigation regimens on the sealing properties of repaired furcal perforations. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;107(3):e91-5.

40. Yildirim T, Oruçoğlu H, Cobankara FK. Long-term evaluation of the influence of smear layer on the apical sealing ability of MTA. J Endod 2008;34(12):1537-40.

41. Guneser MB, Akbulut MB, Eldeniz AU. Effect of various endodontic irrigants on the push-out bond strength of biodentine and conventional root perforation repair materials. J Endod 2013;39(3):380-4.

42. El-Ma'aita AM, Qualtrough AJ, Watts DC. The effect of smear on the push-out bond strength of root canal calcium silicate cements. Dent Mater 2013;29(7):797-803.

43. Shokouhinejad N, Razmi H, Nekoofar MH, Sajadi S, Dummer PM, Khoshkhounejad M. Push-out bond strength of bioceramic materials in a synthetic tissue fluid. J Dent (Tehran) 2013;10(6):540-7.

44. Hashem AA, Wanees Amin SA. The effect of acidity on dislodgement resistance of mineral trioxide aggregate and bioaggregate in furcation perforations: an in vitro comperative study. J Endod 2012;38(2):245-9.

45. Saghiri MA, Garcia-Godoy F, Gutmann JL, Lotfi M, Asatourian A, Ahmadi H. Push-out bond strength of a nano-modified mineral trioxide aggregate. Dent Traumatol 2013:29(4):323-7.

46. Liu WN, Chang J, Zhu YQ, Zhand M. Effect of tricalcium aluminate mixtures: setting time, mechanical strength and biocompatibility. Int Endod J 2011;44(1):41-50.