Original Article

Comparative evaluation of fracture resistance of simulated immature teeth restored with apical plugs of mineral trioxide aggregate, Biodentine, and bone cement: An *in vitro* study

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ABSTRACT

Aim: This *in vitro* study aimed to compare the fracture resistance of simulated immature permanent teeth restored with apical plugs of mineral trioxide aggregate (MTA), Biodentine, and bone cement.

Methods: Forty-eight single-rooted human maxillary central incisors were selected and decoronated 6 mm above and 9 mm below the cementoenamel junction to simulate the immature teeth. Based on weight and homogeneity, the samples were distributed into three experimental groups ($n = 12$) and one control group ($n = 12$). In all the experimental group samples, a peeso reamer size 5 was stepped out 1 mm beyond the apex to enlarge the apices to a diameter of 1.5 mm. Apical plugs of MTA Plus (Prevest DenPro Limited, India), Biodentine (Septodont, France), and Bone cement (Surgical Simplex P, Stryker, Australia) were placed to 4 mm, and obturation was done using gutta-percha and AH Plus® sealer (Dentsply DeTrey, Konstanz, Germany). The force was applied at 45° angulation until fracture, using the universal testing machine. The results were analyzed using a one-way analysis of variance followed by Tukey's *post hoc* test at a 95% confidence level.

Results: The Biodentine group showed a statistically higher fracture resistance value than the MTA Plus and bone cement group ($P = 0.014$ and $P = 0.016$, respectively). No statistically significant difference was reported between MTA Plus and the bone cement group.

Conclusion: Within the limitations of this study, using Biodentine as an apical plug increases the fracture resistance of immature teeth. Bone cement can be used as a viable alternative to MTA.

Keywords: Apexification, Biodentine, bone cement, fracture resistance, immature teeth, mineral trioxide aggregate

INTRODUCTION

The maxillary anterior teeth are most commonly affected by dental trauma in young adolescents between 8 and 12 years of age.[1] These traumatic injuries often result in pulpal necrosis, halting root development and producing an immature open apex. Cervical root fractures occur at a rate ranging from 28% to 77% in immature teeth and are dependent on the stage of root development.[2]

Apexification has long been the treatment of choice for immature teeth with open apices. Historically, calcium hydroxide was used since it induces a hard tissue barrier at the open apex with a success rate of 64%–95%.[3] However, it was reported that prolonged use of calcium hydroxide for up to 18 months weakens the dentinal walls, causing vulnerable root fractures.[4]

Mineral trioxide aggregate (MTA) is a gold standard for apexification, considering the drawbacks of calcium

Submitted: 18-Mar-2022 **Revised:** 17-Jul-2022
Accepted: 28-Aug-2022 **Available Online:** 27-Mar-2023

Access this article online	
Website: www.endodontologyonweb.org	Quick Response Code
DOI: 10.4103/endo.endo_21_22	

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How to cite this article: Gudapati S, Satish RK, Sajjan GS, Varma KM, Kumar VS, Kumar MS. Comparative evaluation of fracture resistance of simulated immature teeth restored with apical plugs of mineral trioxide aggregate, Biodentine, and bone cement: An *in vitro* study. Endodontology 2023;35:30-4.

hydroxide. The success rates of one-step apexification using MTA range from 81% to 100%.[5] MTA is a calcium silicate-based material with properties such as biocompatibility, least cytotoxicity,[6] low solubility,[7] and the capacity to endure a moist environment.[8] However, it has drawbacks such as extended setting time, discoloration potential, and poor handling properties.[7,9] Recently, MTA Plus (Prevest DenPro Limited, India) was formulated with a mixing gel as an agent to improve its washout resistance.

To address the shortcomings of MTA, Biodentine (Septodont, France) was introduced, which was specifically designed as a dentine replacement material. Biodentine has similar properties to MTA but with higher compressive strength, a shorter setting time of 9–12 min,[10] better handling characteristics, no staining, and biomineralization properties.[11] Biodentine has the ability to improve its strength over time, which is a distinct edge over MTA.[12]

Bone cement (Surgical Simplex P, Stryker, Australia) is a potentially new economical repair material that has been recently introduced in dentistry. It is widely used in orthopedic surgery, mainly for prosthesis fixation, stabilizing compressive vertebral fractures, or filling bone defects.[13] It is a polymethyl methacrylate-based material packaged as a powder and a liquid mixed together at the time of application. Its properties such as faster setting time of 8–10 min,[14] good load-bearing capacity, and better marginal adaptation[15] make it ideal for use as a repair material for various endodontic treatments.[16,17] Bone cement exhibits low cytotoxicity compared to MTA.[15]

The fracture resistance of immature teeth repaired with MTA and Biodentine apical plugs has been extensively studied. There are no available studies that evaluated the effect of apexification with bone cement on root fracture. The present study was designed to compare the fracture resistance of simulated immature permanent teeth restored with apical plugs of MTA, Biodentine, and bone cement. The null hypothesis of the present study was there would be no significant difference in the fracture resistance of simulated immature permanent teeth restored with apical plugs of MTA, Biodentine, and bone cement.

MATERIALS AND METHODS

Sample size calculation

Forty-eight extracted human maxillary central incisors were selected for the study. The sample size was estimated based on the pilot study results by projecting the power as 0.80, effect size = 0.371, and significance level as = 0.05. The collected samples were immersed in a 5.25% sodium hypochlorite (NaOCl) *(*Cerkamed Medical Company, Stalowa, Poland) solution for 30 min to remove the soft-tissue debris. Preoperative radiographs were exposed to confirm the presence of straight roots and a single canal. All the teeth were examined under ×4, and samples with caries, fractures, and developmental disturbances were excluded from the study. After exclusion, the samples were stored in distilled water until use.

The samples were decoronated 6 mm above and 9 mm below the cementoenamel junction (CEJ) using a diamond-coated disc to obtain a standardized length of 15 mm. The mesiodistal and buccolingual dimensions of the samples were measured using a digital caliper (Mitutoyo Absolute Digimatic Calliper Series 500, Mitutoyo Corp., Kawasaki, Japan) to maintain uniformity. The weights of the samples were measured with a sensitive precision balance (CY513, ACZET Prolab, India). Based on weight and homogeneity, the samples were distributed into three experimental groups (n = 12) and one control group (n = 12).

The control group samples (Group 1) were left intact without instrumentation.

Access cavity preparation, cleaning, and shaping

In all the experimental groups, the access cavity was prepared using Endo Access bur size 2 (Dentsply, Maillefer, Tulsa, USA) and biomechanical preparation was performed with ProTaper Gold rotary Ni-Ti files (Dentsply Maillefer, Switzerland) up to F5 (tip size 50 with a taper of 0.05). After every instrumentation, the canals were irrigated with 2 ml of 3% NaOCl, using a 30-gauge side-vented needle (RC Twents, Prime Dental Products, Mumbai, India).

Simulation of immature teeth with open apex:

All the samples were sequentially instrumented with peeso reamers sizes 1–4 (Mani Inc., Tochigi, Japan) to simulate the open apices. Finally, a peeso reamer size 5 was stepped out 1 mm beyond the apex to enlarge the apices to a standardized diameter of 1.5 mm.[18] The root canals were then irrigated with 5 ml of 3% NaOCl (Prime dental Pvt Ltd., India) and a final rinse of 5 ml of 17% ethylenediaminetetraacetic acid (Orikam Healthcare India Pvt Ltd., Gurugram, India). Finally, the root canals were flushed with 5 ml of normal saline and dried using paper points. All the samples were stabilized in floral foam before obturation to prevent extrusion of the materials.

Obturation of root canals

Group 2 (MTA Plus): MTA Plus was mixed at a powder to liquid ratio of 3:1. It was placed into the canal with a messing gun and compacted as a 4 mm apical plug with hand pluggers (Dentsply Maillefer, Germany).

Group 3 (Biodentine): A capsule of Biodentine powder was mixed with liquid according to the manufacturer's recommendations for 30 s with an amalgamator and condensed as a 4 mm apical plug using hand pluggers.

Group 4 (Bone Cement): Bone cement was mixed according to the manufacturer's instructions with a powder and liquid ratio of 2:1. The mixture was carried with hand pluggers and placed as a 4 mm apical plug, in a dough-like consistency.

The uniformity and thickness of the apical plugs were verified using radiographs. After 24 h, the remaining part of the root canals were obturated with F5 master gutta-percha point and AH Plus® sealer (Dentsply DeTrey, Konstanz, Germany) using a cold lateral compaction technique. Excess material was seared off and condensed using hand pluggers up to the CEJ. The orifice of the root canal space was restored using composite resin (Filtek Z350 XT Universal Restorative, 3M ESPE, USA). Postobturation radiographs were obtained to ensure consistent fillings without voids. The samples were stored in an incubator for 1 month at 37° and 100% relative humidity.

Periodontal ligament simulation

Periodontal ligament (PDL) simulation was performed as described by Soares *et al*.[19] The samples were coated with molten wax of 0.2–0.3 mm thickness and 2 mm below the CEJ. The samples were mounted in molds filled with self-cure acrylic resin (DPI-RR Cold cure, India). After resin polymerization, the samples were removed from the molds, and the wax was removed and replaced with elastomeric material (Reprosil, DENTSPLY Caulk, USA). The samples were reinserted back into the molds, and excess material was removed using a scalpel blade.

Fracture resistance evaluation

A jig was used to stabilize the acrylic blocks at an angle of 45°. Fracture resistance was evaluated using the universal testing machine (UTM) (Instron Corp., Canton, MA, USA). A sharpened conical tip of 2 mm diameter was used to apply a compressive force on the palatal surface of the tooth 3 mm above the CEJ at a crosshead speed of 1 mm/min. The fracture moment was determined when a sudden drop in force occurred, as observed on the testing machine display. The values were recorded in Newtons (N).

Statistical analysis

Data were analyzed using a IBM SPSS Statistics for Windows, version 23 (IBM Corp., Armonk, N.Y., USA). One-way analysis of variance was used to compare the difference in forces at which the fracture of roots occurred. Tukey's *post hoc* test was used for pair-wise comparisons. The level of significance was set at $P < 0.05$.

RESULTS

The mean values of fracture resistance (in Newtons) and standard deviation are shown in Table 1. Tukey's *post hoc* test results for multiple group comparisons are shown in Table 2. The mean fracture resistance values were higher in all the experimental groups when compared with the control group (Group 1), with a statistically significant difference ($P < 0.05$).

In experimental groups, the mean fracture resistance values were significantly higher in Group 3 (1032.36 ± 101.79 N) when compared to Group 2 (826.37 ± 182.34 N) and Group 4 (829.07 ± 198.15 N). In this present study, the mean fracture resistance values were similar for Group 2 (826.36 ± 182.33 N) and Group 4 (829.06 ± 198.14 N), and the difference between them was not statistically significant.

DISCUSSION

Maxillary central incisors are particularly vulnerable to trauma at a young age due to their location and are prone to pulpal necrosis, which prevents root closure.[4] It is impossible to completely seal the open apex using gutta-percha and sealer without penetrating beyond the apex. The fracture resistance of the teeth is influenced by the thickness of the dentine. Therefore, the reinforcing material selected should be biocompatible, easy to manipulate, and adhere consistently to the dentinal walls.

Standardization is a crucial element in evaluating the difference in fracture resistance among the groups. The buccolingual, mesiodistal, and weights of the teeth were measured in this study, and no significant differences were identified. Despite the fact that extreme care was taken in standardizing experimental tooth dimensions, natural teeth might have variations in dentine, enamel, and cementum thickness.

All experimental groups outperformed the control group in the current study suggesting that root canal obturation significantly improved the fracture resistance of immature teeth. The present study results show that Group 3 exhibited significant fracture resistance compared with Group 2 and Group 4. El-Ma'aita *et al*. postulated that Biodentine particles are finer than MTA, allowing for better permeability and stable anchorage into dentine tubules.[20] Han and Okiji concluded that Biodentine had a high calcium and silicon ion uptake, resulting in larger tag-like structures at the material–dentine interface than MTA.[21]

Table 1: Mean fracture values for all groups measured in Newtons along with their respective standard deviations.

Group	Mean	*N*	SD	*F*	*P*
Group 1	613.6833	12	136.46984	13.821	0.000*
Group 2	826.3667	12	182.33933		
Group 3	1032.3583	12	101.78548		
Group 4	829.0667	12	198.14627		

*Significant at $P<0.05$, SD: Standard Deviation

Table 2: Pair wise comparisons of four groups for fracture resistance (Newtons) by Tukey's post hoc test.

(I) group	(J) group	Mean Difference (I-J)	Standard Error	Significance
Group 1	Group 2	-212.68333*	65.03008	0.011*
	Group 3	-418.67500*	65.03008	0.000*
	Group 4	-215.38333*	65.03008	0.010*
Group 2	Group 1	212.68333*	65.03008	0.011*
	Group 3	-205.99167*	65.03008	0.014*
	Group 4	-2.70000	65.03008	1.000
Group 3	Group 1	418.67500*	65.03008	0.000*
	Group 2	205.99167*	65.03008	0.014*
	Group 4	203.29167*	65.03008	0.016*
Group 4	Group 1	215.38333*	65.03008	0.010*
	Group 2	2.70000	65.03008	1.000
	Group 3	-203.29167*	65.03008	0.016*

*Significant at $P<0.05$

During the setting of Biodentine, the compressive strength increases with time, reaching 300 MPa after 1 month, which is comparable to the compressive strength of natural dentine (297 MPa).[22] Grech *et al*. found that a low water/powder ratio and manipulating the material with an amalgamator improved the compressive strength of Biodentine.[23] All these factors might have contributed to the superior strength of Biodentine.

The present study reported that Group 2 and Group 4 showed similar fracture resistance values. The good marginal seal of bone cement to the dentine wall despite acrylic polymerization shrinkage can be explained by the fact that the volume of cement increases to a maximum during polymerization before reducing slightly.[24,25]

Badr assessed the sealing characteristics and cytotoxic effects of bone cement, MTA, and amalgam. The research resulted in the interesting finding that bone cement and MTA adapt better to dentinal walls than amalgam. Furthermore, bone cement exhibited a similar cytotoxic effect on fibroblast cells as MTA.[15]

Due to the minimal amount required for apical plugs, the heat produced during the setting of bone cement appears to have no deleterious consequences. *In vitro* and *in vivo* studies have been conducted on the heat produced by curing bone cement. According to these studies, the highest temperature reached was 48°. However, the temperature rise was in the range of 3°–17° with no adverse effects.[24] High and Russell suggested that the volume of bone cement used as retrograde filling material is relatively small and because the tooth is nonvital, it would act as a heat sink to dissipate the heat generated during acrylic polymerization.[26] This mechanism can be applicable when bone cement is used as an apical plug. All these factors make bone cement a potentially viable alternative to MTA.

The marginal adaption of MTA is inextricably linked to the material constitution. MTA powder is composed of fine calcium silicate hydrophilic particles that imbibe water during hydration, forming a calcium silicate hydrate colloidal gel. This gel expands during solidification within 4 h.[27] Despite this, MTA did not outperform Biodentine in terms of fracture resistance.

PDL is necessary for stress dispersion in root canals and may affect fracture patterns.[19] To simulate the PDL, silicone-based impression material was used to prevent the stress concentration in one area, and instead disperse the force all over the surface of the root.

Mechanical tests, like fracture resistance, investigate tooth performance in high-intensity load scenarios.[28] UTM was used to evaluate the fracture resistance of teeth. The load was applied at an angle of 45°, as it replicates the typical contact angle between the anterior teeth in Class I occlusion.[29] Future research with varying velocities and angulations is needed to precisely depict the natural forces that cause trauma.

In necrotic immature teeth, root dentinogenesis is halted. Hence, depending on the stage of root development, the thin root dentinal wall has incompletely developed peritubular and intertubular dentine with increasing tubular density toward the cementum.[30] The apices were enlarged to a diameter of 1.5 mm to simulate Cvek's root development stage 3. Mature teeth used in this study might resemble the morphology of immature teeth, but they may not exactly simulate tissue composition and physical characteristics.

Modified bone cements are being introduced by adding fillers, adhesives, antibiotics, and nanoparticles that make it well suited as an endodontic repair material. Further research is warranted to assess the interface integrity and osteoconductive properties of the bone cement.

CONCLUSION

Within the limitations of this present study, it was concluded that using Biodentine as an apical plug improved the fracture resistance of immature teeth. Bone cement can be used as a potential alternative to MTA.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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