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Research Article

COMPARISON OF THE EFFECTS OF TREATMENT OF SIMULATED ROOTS WITH OPEN APEX WITH TWO DIFFERENT CALCIUM SILICATE ROOT FILLING MATERIALS ON FRACTURE RESISTANCE

Öznur DİŞLİ [1]*, Büşranur YAVUZ[2], Tuğrul ASLAN[2], İpek ERASLAN AKYÜZ[2]

1 Mir Dental Clinic, Şanlıurfa, TÜRKİYE
2 Department of Endodontics, Faculty of Dentistry, Erciyes University, Kayseri, TÜRKİYE
*Correspondence: ipekemamak@hotmail.com

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ABSTRACT

Objective: This study aimed to compare the fracture resistance (FR) of simulated immature maxillary incisors in apexification and regeneration treatment protocols using BioMTA+ and Well Root PT materials.

Material and Methods: Fifty-five extracted maxillary incisors of similar dimensions were selected and standardized. After simulating open apices and preparing root canals under laboratory conditions, the specimens were randomly divided into five experimental groups (n=11). The first group received apexification with BioMTA+, the second group received regeneration with BioMTA+, the third group received apexification with Well Root PT, and the fourth group underwent regeneration with Well Root PT. The fifth group served as the control group. The FR of all specimens was measured using a universal testing machine.

Results: The Kruskal-Wallis test revealed no statistically significant difference in fracture resistance among the five groups ($p = 0.559$). Although the BioMTA+ and Well Root PT groups showed a trend toward increased FR compared to the control group, these differences were not statistically significant ($p = 0.607$ and $p = 0.298$, respectively).

Conclusion: BioMTA+ and Well Root PT materials showed similar biomechanical performance in simulated immature teeth treated with apexification or regeneration procedures.

Keywords: Apexification, Mineral trioxide aggregate, Regeneration, Tooth Fractures

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INTRODUCTION

Traumatic dental injuries are common, especially in preschool, school-aged children, and young adults, accounting for approximately 5% of all traumatic injuries (1). These injuries often result from falls, sports activities, bicycle accidents, or traffic accidents (2, 3). Epidemiological data suggest that approximately one-quarter of school-aged children, particularly those between the ages of 6 and 9, have experienced at least one dental trauma (4, 5). During this period, permanent teeth are not yet fully developed. Consequently, root development may be halted when trauma occurs, and dentinal walls may remain thin (6). These characteristics create additional challenges in the treatment process, necessitating different approaches to protect the affected teeth.

Apexification is frequently used in treating immature permanent teeth, particularly those with traumatic pulp necrosis or infected root canal systems. Calcium hydroxide ($Ca(OH)_2$) was first introduced into clinical use by Kaiser in 1964 due to its potential to stimulate physiological apical closure in immature teeth (7). An alternative approach to calcium hydroxide apexification is creating an artificial apical barrier using mineral trioxide aggregate (MTA), which enables rapid and reliable root canal closure (8). However, another treatment option for immature teeth that have lost vitality is regenerative endodontic procedures, which aim to restore pulp tissue vitality (9). Currently, apexification with MTA or regenerative endodontic approaches is considered a prominent, clinically valid, and preferable option for treating non-vital immature permanent teeth (10).

Regenerative endodontic procedures aim to restore pulp vitality by harnessing the biological potential of stem cells, growth factors, and the host's signaling molecules. These procedures promote continued root maturation, thickening of dentinal walls, and deposition of new hard tissue, which may enhance the long¬term fracture resistance of immature teeth (6,9). Understanding these underlying biological mechanisms is essential for evaluating the clinical outcomes of regenerative approaches compared to traditional apexification.

Calcium silicate-based root canal filling materials are available in various physical forms today. These materials are available in powder-liquid mixtures as well as pre-mixed putty forms. For example, Bio MTA+ (CERKAMED, Poland) is available in powder and liquid forms, whereas Well Root PT (Vericom Co., Korea) is used in a pre-mixed putty form. Both materials have clinical applications in apexification and regenerative endodontic treatments.

MTA in powder-liquid form increases tooth resistance to root fractures long term (11). However, the inability to achieve complete homogeneity due to mixing during preparation and application is a significant limitation of this form. On the other hand, putty materials offer the advantage of being readily available and provide clinically favorable properties, such as resistance to bonding in acidic environments (12). However, data on the effects of both forms on root fracture resistance (FR) are still limited, and the existing literature does not provide sufficient evidence on this topic.

A review of the existing literature reveals no studies directly comparing the effects of different formulations of BioMTA+ and Well Root PT materials on FR in simulated roots with open apices. Therefore, our study aimed to comparatively evaluate the impact of these two different calcium silicate-based materials on root FR, depending on their formulations, within the context of apexification and regenerative endodontic protocols used to treat traumatized immature teeth. The study's null hypothesis was that the type of material used and the treatment method would not result in a statistically significant difference in root FR.

MATERIALS AND METHODS

Sample Size Determination

The present in vitro study was approved by the Erciyes University Clinical Research Ethics Committee (code 2024/250). Based on a previous study (13), an estimated effect size of 0.48, a Type I error rate (α) of 0.05, and a statistical power of 0.80 were used, which indicated that a minimum of 11 specimens per group was required.

Sample Selection

This study involved 55 mature upper incisors extracted for periodontal reasons. Preoperative periapical radiographs were taken to verify the presence of previous root canal treatment and to detect any canal resorption or calcification. Tooth dimensions were measured with a digital caliper, and only specimens with mesiodistal and buccolingual sizes close to the average values were included in the study. Each tooth with similar root lengths was preserved in saline solution before use. Any remaining tissue on the root surface was removed using periodontal curettes before the commencement of the study.

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Canal Preparation and Filling Protocols

The teeth were prepared using water-cooled, high-speed instruments, separating them from the cementoenamel junction. The roots were prepared 11 mm from the cementoenamel junction to simulate an open apex. The root canals were prepared with Protaper Next rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland) up to size #50. Peeso reamers (#1 and #6; Dentsply Maillefer) were used to simulate immature teeth, with the #6 reamer protruding 1 mm beyond the apex (14).

After each file change, the canals were irrigated with 3 mL of 2.5% sodium hypochlorite (NaOCl), and the solution was left in place for approximately one minute. After the preparation, the final irrigation protocol consisted of 3 mL of 17% EDTA for 1 minute, followed by a 30-second irrigation with 5 mL of distilled water.

In the regeneration groups, Spongostan® (Ferrosan Medical Devices, Denmark) was inserted into the root canal using a hand plugger (Dentsply Sirona, Ballaigues, Switzerland) to simulate a blood clot and condensed to a depth of 3–4 mm below the cementoenamel junction. Root filling materials used were BioMTA+ (powder-liquid form) and Well Root PT (pre-mixed putty form).

Experimental Groups and Test Protocol

Fifty-five teeth were randomly divided into five groups (n=11). Group 1: The root canal was filled with BioMTA+ to the cemento-enamel junction using a hand plugger (Dentsply Sirona, Ballaigues, Switzerland). Group 2: Regenerative endodontic treatment procedure was performed, and BioMTA+ was condensed to 4 mm below the cementoenamel junction with a hand plugger (Dentsply Sirona, Ballaigues, Switzerland). Group 3: The root canal was filled with Well Root PT, following the same procedure as in Group 1. Group 4: Well Root PT was condensed, similar to the procedure used in Group 2. Group 5 (Control): Untreated teeth.

All root canal orifices were sealed with light-cured composite resin (3M ESPE, USA). The specimens were then incubated at 37 °C under 100% humidity for one week. The 0.2–0.3 mm-thick polyvinylsiloxane (Coltene/Whaledent AG, Switzerland) was applied to the roots to mimic the periodontal ligament, and the teeth were embedded in acrylic resin 2 mm below the cementoenamel junction (14).

Fracture Resistance

The FR of the specimens was measured with a universal testing machine (Autograph AG-X, Shimadzu, Tokyo, Japan). A compressive load was applied vertically to the coronal surfaces of the roots at a crosshead speed of 1 mm/min until failure occurred. The load at which each specimen fractured was measured in Newtons (N). The FR test setup is shown in Figure 1.



Figure 1. Fracture resistance test setup showing specimen positioning and vertical loading.

Statistical Analysis

The statistical evaluation was performed with IBM SPSS Statistics version 23 (IBM Corp., Armonk, NY, USA). The suitability of the measurement values for the normal distribution was evaluated using the Shapiro-Wilk test. The Kruskal-Wallis Test was used to compare non-normally distributed measure values across groups. Analysis results are presented as mean ± standard deviation and median (minimum - maximum). The significance level was set at $p < 0.05$.

Table 1. Comparison of fracture resistance values of groups (N).

Group	Fracture Resistance (N) Median (min-max)	Test Statistics	p value*
Group 1	863.89 (16 - 1126.36)	-	-
Group 2	750.91 (99.06 - 1745.05)	-	-
Group 3	806.77 (147.87 - 1058.05)	2.994	0.559
Group 4	905.46 (54.65 - 1444.04)	-	-
Group 5	729.48 (258.68 - 1078.09)	-	-

Group 1: Apexification with BioMTA+; Group 2: Regeneration with BioMTA+; Group 3: Apexification with Well-Root PT; Group 4: Regeneration with Well-Root PT; Group 5: Control group; *Kruskal-Wallis Test

RESULTS

The Kruskal-Wallis test results indicated no statistically significant difference in FR among the five groups ($p = 0.559$). Although there was a trend toward increased FR in

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all experimental groups compared to the control group, this increase was not statistically significant. When the treatment protocols were compared, although higher FRs were achieved in the experimental groups compared to the control group, these differences were not statistically significant ($p = 0.607$). In pairwise comparisons of the root canal filling materials used, no significant difference was found between the BioMTA+ and Well Root PT groups and the control group ($p = 0.298$). Post-hoc pairwise comparisons were not made since there was no statistically significant difference between the groups ($p>0.05$). The distribution of FR values across the groups is presented in Table 1, and boxplot representations of these values are presented in Figure 2.

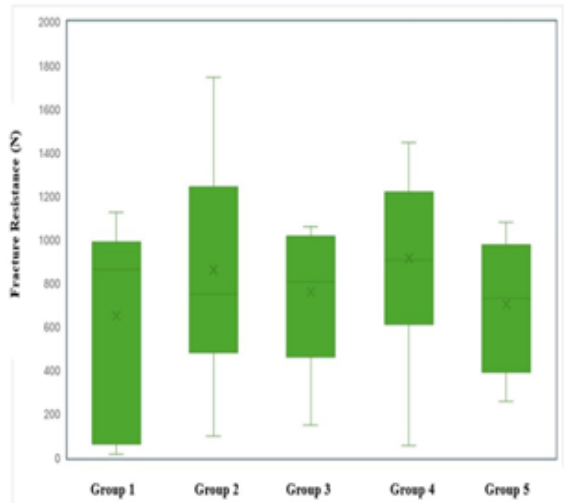

Figure 2. Boxplot showing fracture resistance (N) values for all groups.

DISCUSSION

In this study, upper incisors, which are prone to trauma, were used. The apices were enlarged using Peeso reamers #6 to simulate open-apex root morphology. This method has been previously reported in the literature as a reliable method for creating open apices (13) and was applied in the current study to ensure consistency. The 0.2–0.3 mm-thick polyvinylsiloxane layer used to simulate the periodontal ligament was selected based on previous studies (11, 13).

Due to their high biocompatibility properties, calcium silicate-based materials are frequently preferred today for both apexification and regenerative endodontic applications (15). These materials aid the healing process of periapical tissues, positively influence biological mechanisms, and provide a strong seal by penetrating dentinal tubules (16, 17). Based on this scientific basis, we used calcium silicate-containing Bio MTA+ and Well Root PT materials in the present study. However, there are significant differences in the structural properties of the two materials. Bio MTA+ is prepared and applied as a powder-liquid mixture, similar to the traditional MTA formulation. Well Root PT, on the other hand, offers practicality in clinical applications thanks to its pre-mixed, ready-to-use form (17). In a study by Alnassar et al., it was reported that the rapid setting properties of Well-Root PT provide significant advantages, particularly in pulpotomy procedures performed on immature teeth (18). Compared to Bio MTA, both materials demonstrated similar clinical success; however, it was emphasized that Well-Root PT's rapid setting properties make it more practical in specific clinical scenarios. In terms of clinical application, while user-dependent variations can be observed during the preparation of the powder-liquid form of Bio MTA+, the pre-mixed form of Well-Root PT reduces application time, particularly in pediatric patients, and is easier to handle (18).

The study's primary objective was to compare the fracture resistance of these two materials in teeth treated with apexification and regenerative treatments. Results showed increased fracture resistance in all experimental groups compared to the control group; however, the differences were not statistically significant. The similar performance may be due to the effects of the materials' mechanical and chemical properties on dentin bonding and stress distribution. In particular, mechanical and biochemical processes such as calcium ion release, hydroxyapatite formation on dentin, and micromechanical bonding can directly influence FR. These mechanisms may have led to similar FR results by optimizing the post-application integration of the materials with dentin and the stress distribution across the root wall. Therefore, mechanical and biochemical interactions are critical in explaining similar FR performance.

Similarly, a study by Jang et al. reported that there were no significant differences in physical and mechanical properties, such as flowability, surface pH, and cell viability, between various calcium silicate-based cements, including Well-Root PT, and that the pre-mixed materials generally exhibited similar performance (19). These data reinforce the observations in our study, demonstrating that the physical and mechanical properties of BioMTA+ and Well-Root PT after application are clinically comparable.

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Regarding physical properties, both materials exhibit high impermeability, low solubility, and a capacity for chemical bonding with dentin (15, 20). Dawood et al. reported that calcium silicate-based cements resist microleakage and exhibit low solubility (15). Another study reported that these materials maintain bond strength even in acidic environments (21). These findings suggest that the physical stability of BioMTA+ and Well Root PT is broadly similar.

From a chemical perspective, both materials provide antibacterial activity by creating a high pH and can establish micromechanical and chemical bonds with dentin. Torabinejad et al. reported that MTA and its derivatives increase the mechanical strength of the interface by bonding with dentin through hydroxyapatite formation and promote mineralization through calcium ion release (22). These data support the safe use of both materials in clinical applications from physical and chemical perspectives.

This study not only compared BioMTA+ and Well Root PT materials but also evaluated the effects of apexification and regeneration procedures on root FR. Findings showed an increase in FR in both treatment groups compared to the control group; however, these differences were not statistically significant. The literature suggests that apexification offers functional protection by creating a rigid barrier at the apical portion of the root; however, since it does not increase root wall thickness, it may not eliminate the long-term risk of fracture (23). Regenerative procedures, conversely, can increase root wall thickness by promoting root development and theoretically reduce the risk of fracture (24). Although the mean fracture strength was higher in the regeneration group than in the apexification group, the difference was insignificant, possibly due to the limited sample size and the fact that in vitro conditions do not fully reflect the clinical setting. However, the data obtained demonstrate that regenerative treatments offer biologically and mechanically potential benefits. Future in vivo studies with larger samples and a direct comparison of the long¬term biomechanical effects of these two approaches will contribute to improving clinical protocols.

Nevertheless, the authors acknowledge certain limitations of the present study. The small sample size may have limited the statistical power to detect subtle group differences. As this was an in vitro study, the results may not precisely replicate the oral environment's complex biological and mechanical conditions, such as functional loading, humidity, and thermal cycling. Additionally, Spongostan® was used to simulate the blood clot in regenerative procedures; however, it lacks cells, growth factors, and signaling molecules present in a natural clot, which may affect tissue regeneration and root maturation. Therefore, the findings should be interpreted cautiously, and further in vivo investigations are warranted to validate these results under clinical conditions.

The similarity of the materials' chemical structures, curing mechanisms, and biomechanical behavior may have resulted in equivalent results in terms of root FR. Our findings are consistent with similar results reported in the literature; moreover, there are studies with parallel results (18, 25). Türker et al. compared different calcium silicate-based materials and reported no significant difference between the groups (25). In conclusion, despite the formulation differences, BioMTA+ and Well Root PT materials exhibit equivalent biomechanical effects on tooth FR by creating similar structural integrity after curing. These findings demonstrate that mechanical, chemical, and physical properties are crucial in root FR.

The findings of this study suggest that regeneration treatments can be effective biologically and mechanically. Regenerative treatments that specifically support root development are thought to reduce the long-term fracture risk by thickening the root walls. Filling only the apical portion of the root during regeneration may increase FR by preserving greater flexibility in the coronal region. However, the lack of statistical significance in this difference may be due to the limited sample size and the fact that in vitro conditions do not fully reflect the actual clinical environment. Therefore, more detailed comparisons of these parameters in future in vitro and in vivo studies will help improve understanding of the clinical success of calcium silicate-based materials.

CONCLUSION

Within the limitations of this study, BioMTA+ and Well-Root PT demonstrated comparable effects on the FR of simulated immature teeth. Although both treatment protocols tended to increase FR compared to the control group, these differences were not statistically significant. These findings indicate that either material may be a reliable option in clinical practice, emphasizing the need for validation through larger-scale, long¬term in vivo studies.

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The authors declare that they have no conflicts of interest related to this study.

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Authorship contributions

Concept: TA, ÖD, BY; Design: ÖD, BY; Data collection or processing: TA, İEA, BY; Analysis and interpretation: TA; Literature search: ÖD, BY; Writing: İEA, BY.

Data availibity statement

The datasets used and/or analyzed in this study are available from the corresponding author upon reasonable request.

Declaration of competing interest

The authors declare that they have no relevant or material interests related to this study.

Ethics

This in vitro study was approved by the Erciyes University Clinical Research Ethics Committee (2024/250).

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