Journal of Dental Sciences 20 (2025) 1532–1538

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journal homepage: www.e-jds.com

Journal of Dental Sciences

Original Article

In vitro comparison of fracture strength of maxillary incisors with the simulated external root resorption cavities repaired with BioMTA or Biodentine

Tufan Ozasir*, Birgul Ozasir, Nagihan Aribal, Derin Bugu Yuzer, Baris Kandemir, Kamran Gulsahi

Department of Endodontics, Faculty of Dentistry, Baskent University, Ankara, Turkey

Received 1 December 2024; Final revision received 17 December 2024
Available online 27 December 2024

KEYWORDS
Biodentine;
BioMTA;
External root resorption;
Fracture resistance

Abstract *Background/purpose:* Treatment of external root resorption is performed by root canal treatment and repair of the resorptive area with biocompatible materials. Our study aimed to compare the fracture strengths of teeth with simulated external resorption repaired with BioMTA or Biodentine.

Materials and methods: Sixty extracted human maxillary incisors were used in the study. The root canals were instrumented with Ni–Ti rotary instruments and obturated with single cone technique using corresponding gutta-percha cone and root canal sealer. The teeth were embedded in acrylic blocks. Fifteen of them served as negative control group. Simulated external resorption cavities were opened with burs on the approximal surfaces of the remaining teeth. Fifteen of them were assigned randomly as positive control group. The remaining teeth were randomly divided into two groups, the cavities were filled with BioMTA in one group and with Biodentine in the other group and then subjected to fracture strength test. The force at which fracture occurred was evaluated by analysis of variance at 0.05 significance level.

Results: Biodentine showed significantly higher fracture strength than BioMTA. There was no difference between the negative control group and the Biodentine and BioMTA group. The positive control group showed significantly lower values than the other groups.

Conclusion: Both Biodentine and BioMTA may be used to repair external root resorption, while Biodentine is more durable.

* Corresponding author. Department of Endodontics, Faculty of Dentistry, Baskent University, 82. Sk., No:26, Ankara, 06490, Turkey.
E-mail address: tozasir@gmail.com (T. Ozasir).

https://doi.org/10.1016/j.jds.2024.12.019

Introduction

Dental root resorption is a pathological condition that progresses with odontoclast activity, characterized by the loss of dental hard tissues, which can be aggressive enough to lead to the loss of the relevant tooth if left untreated. Under normal conditions, non-collagenous structures such as the odontoblast layer of the root wall and pre-dentin as well as the pre-cementum and periodontal ligament on the root surface protect the root against internal and external root resorption.[1] It is known that the cells responsible for resorption cannot adhere to non-mineralized tissue surfaces.[2] Many mechanical, thermal and chemical factors can irritate and damage the protective barriers and initiate mineralization, in result, osteoclast migration to the area occurs with the release of pro-inflammatory cytokines and resorption processes begin.[2,3] While the most common causes are orthodontic treatment, dental trauma and intracanal whitening procedures; external root resorption may develop due to dental factors such as routine and advanced periodontal treatments, tooth extractions, restorative treatments, traumatic dental injuries, as well as non-dental causes such as herpes zoster virus and bisphosphonate use.[2,4] The resorption process, which causes almost no clinical symptoms, is usually detected incidentally on radiographs. Cone-beam computed tomography (CBCT) images can provide key information about the resorption area and surrounding anatomical structures.[2,5,6] Treatment is usually carried out by root canal treatment and surgical intervention, reaching the resorptive area and repairing it with filling materials. In cases of advanced resorption, extraction of the tooth is also an option.[2,7] Treatment options are determined depending on the size of the resorption, accompanying clinical symptoms such as pain and swelling, and the amount of mobility of the tooth due to periodontal damage. The chosen treatment option is often case-specific, depending on the clinician's experience and opinion of such cases.[7]

Calcium silicate-based materials have many uses in endodontics, including the repair of root resorptions, due to their superior sealing abilities and biocompatibility.[8] Mineral trioxide aggregate (MTA) is a commonly used material for dental root resorptions and perforations.[9] In addition to its biocompatibility and sealing properties, its inhibitory effect on osteoclasts, high pH and adequate radiopacity are its advantages, while problems such as causing discoloration, difficulty in handling, and long hardening time are some of its disadvantages.[10] BioMTA (Cerkamed, Stalowa Wola, Poland) is considered a modified calcium silicate cement containing hydroxyapatite and nanoceramic particles. It aims to reduce the long hardening time of MTA and increase its hardness.[11] Biodentine (Septodont, Saint Maur-des-Fossés, France), another calcium silicate formulation, has been suggested as an alternative to MTA, showing a shorter initial setting time, and higher compressive strength and micro-hardness than MTA.[12] To our knowledge, there is no fracture strength study conducted using BioMTA in the literature to date. Hence, this *in vitro* study questioned whether there was an effect on root fracture strength between BioMTA and Biodentine applied to simulated external resorption cavities. Our null hypothesis was that there was no difference between the materials used in terms of their effect on root fracture resistance.

Materials and methods

This study was conducted in the Department of Endodontics, Faculty of Dentistry, Baskent University, Turkey. The study protocol was approved by the Baskent University Non-invasive Clinical Research Ethics Committee (Project no: D-KA18/15). G Power 3.1.9. 2 Package program (Heinrich Heine University, Dusseldorf, Germany) was used in the statistical power analysis of the study. Assuming 20—35 % standard deviation of fracture strength values,[9] it was calculated that 15 samples were required for each group with 90 % power and 0.05 error level ($\alpha = 0.05$, $1-\beta = 0.90$, effect size of 1.104).

Sixty single-rooted human maxillary central teeth without caries extracted for periodontal, orthodontic or prosthetic reasons were selected. After the teeth were examined clinically and radiographically, those with cracks or fractures in the crown and root, and those with anatomical complications in the root canals were excluded from the study. Care was taken to ensure that the average crown and root lengths of the teeth were the same, approximately 22 mm. The extracted teeth were kept in 0.1 % thymol solution for 48 h and then kept in distilled water at 4 °C until use. The endodontic access cavity for the teeth was prepared with diamond round burs under water cooling. The working length was determined with a #10 K-file to be 0.5 mm shorter of the apical foramen. Biomechanical preparation of the root canals was performed with Protaper Next (Dentsply Maillefer, Ballaigues, Switzerland) rotary files according to the manufacturer's instructions, up to the X5 finishing file, with copious irrigation with 2.5 % NaOCl solution between each file. Final irrigation protocol was 5 ml 17 % ethylenediaminetetraacetic acid (Ultradent, South Jordan, UT) to remove the smear layer, followed by 5 ml distilled water to remove the remaining solutions in the root canal system. The root canals were dried with paper points then obturated with X5 gutta-percha cones and AH Plus sealer (Dentsply De Trey, Konstanz, Germany) with single-cone technique. Excess gutta-percha was cut away from the canal orifice with a heated plugger. The access cavity was filled with condensable light-curing composite (3M/ESPE, St Paul, MN, USA) using Clearfill SE bond system (Kuraray Noritake Dental, Tokyo, Japan). The teeth were kept in a 100 % humid environment and 37 °C for 24 h to allow the sealer to set. The samples were dipped 6 mm of vax from the apical, then embedded in acrylic blocks up to this level. Afterwards the wax was removed, and the samples placed back into the blocks with silicone impression material (Zhermack, Rovigo, Italy) to simulate the periodontal ligament. The teeth were randomly divided into four groups (n = 15). Group 1 had no other treatment and served as negative control group. In other groups, standardized simulated resorption cavities were prepared on the approximal surface with a 3 mm diameter diamond round bur, 3 mm below the cemento-enamel junction (CEJ), under water cooling, to imitate external root resorption (Fig. 1). The teeth in positive control

Figure 1 Schematic representation of simulated external root resorption.

group (Group 2) did not receive any further treatment. In accordance with the manufacturer's recommendations, BioMTA (Cerkamed) for group 3 and Biodentine (Septodont) for group 4 were prepared and applied to the resorption cavities as repairing materials. To allow the setting reactions of the materials, the teeth were kept in a humid environment for 5 min in group 3 and 12 min in group 4.

For the fracture strength test, a force of 1 mm/s was applied to the samples placed in the Universal Testing Machine (Lloyd LR30K, Fareham, UK) at an angle of 135° with the long axis of the teeth until the fracture occurred. Fig. 2 schematically shows the preparation of samples and the application of the fracture strength test. The force values at which the fracture occurred were recorded in Newton.

Statistical analysis

The Statistical Package for Social Sciences (SPSS) version 25 (IBM Corp, Armonk, NY, USA) was used in the evaluations and the limit of statistical significance was set to 0.05. The suitability of maximum load values to normal distribution was examined with the Shapiro–Wilk test. ANOVA, a parametric test, was used as the maximum load values showed normal distribution. If any, the group(s) causing the statistically significant difference were examined with the Tukey test.

Results

Descriptive statistics for the data (mean, standard deviation, minimum & maximum values) are shown in Table 1 and Fig. 3. The conformity of maximum load values to normal distribution was examined using the Shapiro–Wilk test. One-way analysis of variance (ANOVA) showed statistically significant differences between the groups. Tukey test was used to determine which groups had statistically significant differences. The positive control group showed the lowest values among the groups which is statistically significant ($P < 0.001$).

The difference between Biodentine and BioMTA groups was found to be statistically significant ($P < 0.05$). The difference between the negative control group and the BioMTA group was not significant ($P = 0.307$), and the Biodentine group also did not have a significant difference with the negative control group ($P = 0.552$).

Discussion

The present study aimed to evaluate the differences in the fracture strength of teeth with repaired simulated external root resorption cavities with two different calcium silicate-based materials in an *in vitro* environment. The teeth repaired with Biodentine showed higher fracture resistance. This result is consistent with the findings of previous studies comparing fracture strength of Biodentine and different silicate-based materials on various experimental methods.[4,8,9] Materials with an elasticity modulus close to

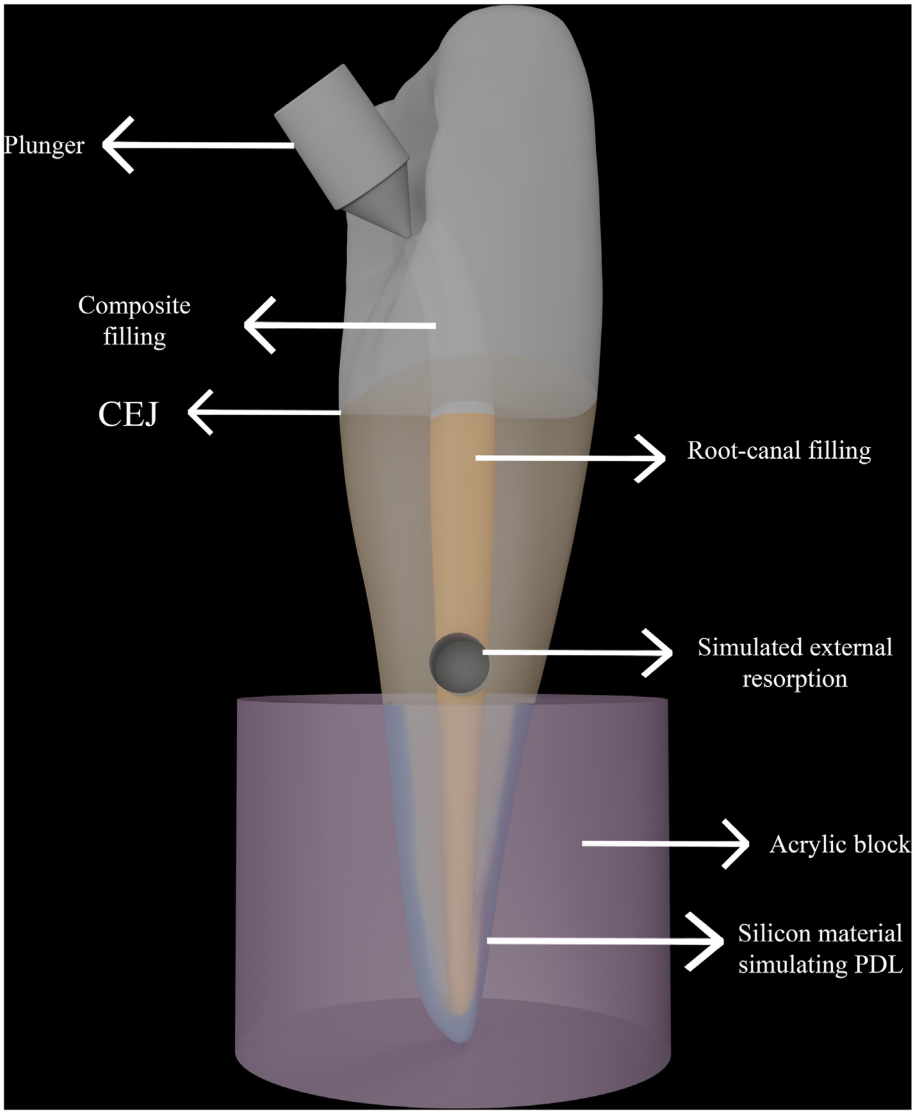

Figure 2 Schematic representation of experimental study design Abbreviations: CEJ, Cemento-enamel junction; PDL, Periodontal ligament.

Table 1 Descriptive statistics of fracture resistance values (in newtons) of experimental groups (n = 15).

		Mean ± SD	Min-Max
Group 1	Negative control	372.45 ± 126.19 [a]	147.72—626.76
Group 2	Positive control	87.65 ± 30.68 [b]	33.42—142.72
Group 3	BioMTA	311.13 ± 109.02 [ac]	129.27—566.05
Group 4	Biodentine	418.81 ± 89.55 [ad]	305.10—572.96

Abbreviations: SD, standard deviation; Min, minimum load value; Max, maximum load value.
Different superscript letters mean statistically significant difference ($P < 0.05$).

dentin, such as MTA, behave similarly to dentin tissue and resist fracture by absorbing and distributing the incoming forces.[13] Aslan et al.[13] reported in their finite element analysis study that the stress values in teeth repaired with MTA were higher than in samples treated with Biodentine. The reason why Biodentine showed higher fracture resistance and lower stress values may be that it is closer to dentin than MTA in terms of elastic modulus.[4,14]

However, BioMTA has some differences in content from the traditional MTA composition, which may affect the physical properties of the material. Table 2 summarizes the ingredients of BioMTA and Biodentine used in our study. BioMTA powder contains hydroxyapatite components, nanoparticle structures, and its liquid contains calcium catalyst that accelerates the initial setting reaction.[15] Since root dentin also contains hydroxyapatite, it can be

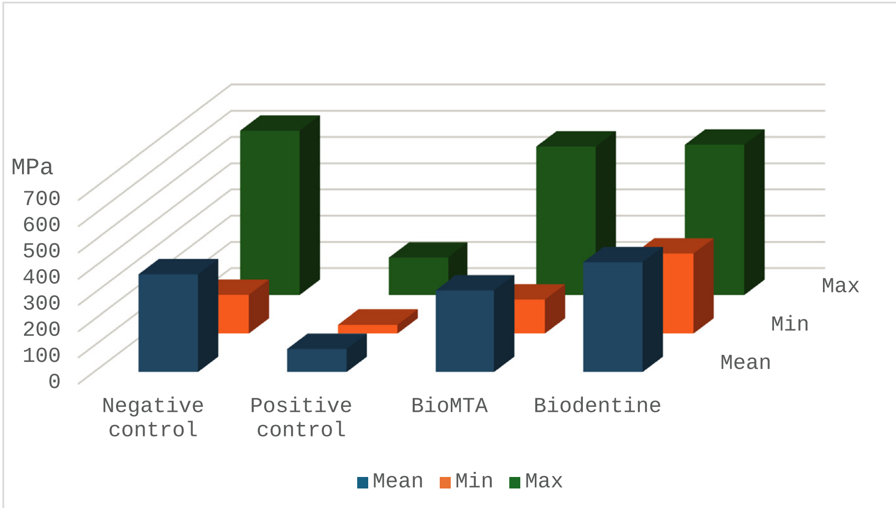

Figure 3 Graphical representation of the fracture strength values of the experimental groups Abbreviations: MPa, megapascal; Min, Minimum load value; Max, Maximum load value.

Table 2 Composition of BioMTA and Biodentine.

	Powder	Liquid
BioMTA (Cerkamed)	Calcium oxide Hydroxyapatite Oxides of silicon iron Aluminium Sodium Potassium Bismuth Magnesium Zirconium Calcium phosphate	Purified water Calcium catalyst
Biodentine (Septodont)	Tricalcium silicate Calcium carbonate Zirconium oxide Dicalcium silicate Calcium oxide Iron oxide	Aqueous solution of a hydro-soluble polymer with calcium chloride

thought that the material containing hydroxyapatite is actually advantageous in terms of bonding to dentin, which has a polar structure because of the Ca^{2+} ions.[16] However, in a study examining the chemical compositions of Biodentine and BioMTA,[17] the apatite content of BioMTA was found to be less than enamel and dentin, and the calcium content was found to be less than Biodentine. According to the results of the mentioned study, Biodentine was more successful than BioMTA in terms of adhesion to dentin. Strong adhesion to dentin may also increase fracture strength,[17] which Biodentine gave better results in our study. The shear bond strength of BioMTA is also in question because of its nanoparticle content.[11] Although small particle size seems to be advantageous in adhesion to dentin at first glance, the shear bond strength of nanoparticle composites was found to be lower than the ones with microhybrid structure.[18] Falakaloğlu et al.[11] compared the micro-shear bond strength of silicate-based materials and reported that they did not reach optimum bond values (17—20 Megapascal) in any of the samples applied with BioMTA. Nanoparticle-containing calcium silicate cements, namely BioMTA, need to be further investigated in this regard, but this structure may be a reason for the lower fracture strength seen in our study compared to Biodentine.

The powder/liquid ratio is another factor that affects the physical properties of the materials, including setting time.[19] The long setting time of the traditional MTA formulation caused risks such as contamination and cement washout before bonding to the dentin in cases requiring surgical approach such as root resorption.[20] Therefore, in our study, we waited for the recommended initial hardening time of the materials to be suitable for the clinical situation and performed the fracture strength tests. Coagulia et al.[20] reported the initial setting of BioMTA as 5 min; that is 1 min longer than the manufacturer's stated time (4 min). Considering that this is a reasonable amount of time in practice, we waited 5 min for the BioMTA to set in our study. In the study,[20] the time they determined for Biodentine to harden was 27.5 min, which is more than twice the manufacturer's stated time of 12 min. They also reported that when they prepared the mixture with the powder-liquid ratio recommended by the manufacturer, the resulting material was not suitable for work and used 1 drop more liquid. Since the powder-liquid ratio recommended by the manufacturer has changed and the 12-min waiting time is more reasonable in the practical environment, we found it appropriate to wait 12 min for the Biodentine to set in our study. The liquids of both calcium silicate-based materials we used in our study contain formulas that accelerate initial setting. But unlike BioMTA liquid, Biodentine liquid contains a water-soluble polymer, which reduces the amount of water required for the material to set.[21]

Low water/cement ratio increases the compressive strength of silicate-based materials.[12] This increased physical property of Biodentine may also promote fracture strength. Biodentine also differs from the traditional MTA formulation and BioMTA in terms of its powder content. It contains 15 percent calcium carbonate in its powder.[22] It leads to hydroxyapatite clustering, more calcium release, creating a less porous structure and increasing adaptation to root dentin.[21] Calcium carbonate in Biodentine also accelerates hardening by inducing the formation of calcium silicate hydrate. Therefore, it is possible that mechanical strength occurs quickly; it has been reported[22] that the exothermic reaction reaches its peak in 30 min. Considering that it takes about 2 h for BioMTA to fully set,[11] this may be a reason for its lower fracture strength than Biodentine.

One of the physicochemical properties that affects the sealing ability of dental materials is solubility. For solid materials, solubility can be defined as the dissolution of a material in a certain amount of solvent.[12] Biodentine has been reported[20,23] to have high solubility that does not comply with ISO 6876.[24] While no difference was found on the 30th day in their study, Torres et al.[23] found Biodentine to be the silicate cement with the highest dissolution value on the 7th day. Consistent with this result, Coaguila et al.[20] also reported that Biodentine showed high solubility. Conversely, they also found that BioMTA gained mass after 24 h.[20] The high solubility of Biodentine was attributed to its polycarboxylate content by Torres et al.[23] The polycarboxylate content used to facilitate the manipulation and application of the material may have a surfactant effect and increase its solubility.[23] Biodentine solubility peaks on the 7th day in distilled and deionized water and volumetric loss peaks on the 30th day.[20,23] Although Biodentine seems to be disadvantageous compared to BioMTA in terms of solubility, its effect may be limited on the fracture strength test due to the method of our study.

The fact that calcium silicate-based materials show volumetric changes within 7—30 days due to dissolution may be a limitation of our study.[12,20,23] With more samples and repeated measurements, especially on the 7th and 30th days, further fracture strength studies can be planned using calcium silicate-based repair materials. Although attempts were made to mimic the clinical situation, the *in vitro* study design can be considered another limitation for this study.

As a difference that should be emphasized, in our study, the negative control group was designed differently from some other resorption studies.[4,8—10] In general, teeth without any treatment in the root canal system, intact roots are used as the negative control group. However, in practice, root canal treatment is applied in the treatment approach in cases of external resorption.[1,25] Since root canal treatment was also applied in the experimental groups, the negative control group was created by only applying root canal treatment to the teeth to interpret the effect of only simulated cavities and repair materials on the teeth as a variable.

In conclusion, the results of the present study support the view that Biodentine shows better microarchitectural properties and is a root dentin substitute. Within the limitations of the study, it is concluded that both BioMTA and Biodentine may be used as a root repair material in external resorption cases, and Biodentine is more durable than BioMTA. Further research conducted with more samples and long-term follow-up measurements are needed.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

This study was approved by Baskent University Institutional Review Board (Project no: D-KA18/15) and supported by Baskent University Research Fund.

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