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Effect of Conservative Access Cavity Preparation on the Fracture Resistance of Endodontically Treated Molars

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ABSTRACT

Introduction: This study aimed to evaluate the influence of different access cavity designs (conservative versus traditional) and the impact of thermocycling and load cycling on the fracture resistance of endodontically treated molars.

Materials and Methods: In this in vitro investigation, sixty extracted human molars were selected and allocated into six groups based on access cavity design and subsequent thermocycling (1000 cycles between 5 °C and 55 °C) and load cycling (200,000 axial cycles at 80 N) protocols. Root canal treatment was performed on all specimens using standardized endodontic procedures. Fracture resistance was subsequently assessed using a universal testing machine.

Results: The mean fracture resistance of the teeth with conservative access cavity preparation was significantly higher than that of traditional preparation ($P = 0.044$). Furthermore, the application of thermocycling and load cycling significantly reduced fracture resistance across all tested groups ($P < 0.05$).

Conclusion: These findings underscore the critical roles of access cavity design and simulated functional aging conditions in determining the long-term structural durability of endodontically treated teeth.

Keywords: Root canal therapy; Fracture resistance; Load cycling; Thermocycling; Access cavity Preparation.

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Introduction

The principal objective of root canal therapy is the retention of teeth compromised by infection or trauma, achieved through microbial load reduction, comprehensive cleaning and shaping of the root canal system, followed by complete obturation and coronal restoration [1]. A critical determinant in the success of endodontic treatment is the meticulous design and execution of the access cavity [2]. The configuration of the access cavity profoundly influences the efficacy of canal instrumentation, debridement, orifice localization, and the ultimate quality of the coronal restoration. Moreover, an appropriately designed access cavity is integral to the long-term prognosis of endodontically treated teeth by preserving their inherent fracture resistance [3]. Excessive removal of tooth structure, particularly during conventional access cavity preparation, can structurally compromise the tooth, thereby increasing its susceptibility to fracture under masticatory forces. This concern is especially pertinent for endodontically treated teeth, which often exhibit diminished fracture resistance compared to vital counterparts, a phenomenon potentially attributable to alterations in dentin properties, such as reduced hardness [4]. Challenges in restoring the function, aesthetics, and structural integrity of such teeth frequently arise from substantial dentinal tissue loss incurred during access preparation [5–7]. The quantity of remaining dentin is arguably the most decisive factor governing the fracture resistance and longevity of endodontically treated teeth [8–10].

Preservation of anatomical entities, including marginal ridges, cusps, and the pulp chamber roof, is paramount. Pericervical dentin, defined as the dentin located approximately 4 mm coronal and 6 mm apical to the alveolar bone crest, plays a crucial role in the dissipation of occlusal forces and the maintenance of tooth integrity [11,12]. Clark and Khademi emphasized the significance of preserving 0.5–3 mm of the pulp chamber roof to minimize cuspal deflection and mitigate fracture risk [13]. Consequently, more conservative access cavity designs have gained popularity, including the Contracted Endodontic Cavity, Truss Access Cavity, and Ninja Access [14]. Although the philosophy of minimally invasive endodontics (MIE) is increasingly embraced in contemporary clinical practice, robust evidence substantiating its widespread efficacy remains limited. Therefore, the present study was designed to compare the fracture resistance of endodontically treated molars prepared with conservative versus traditional access cavity designs, following exposure to simulated thermal and cyclic loading conditions. This investigation aims to provide clinically pertinent insights for optimizing both the mechanical performance and longevity of endodontically treated dentition.

Materials and Methods

Data source and study design

This in vitro study received ethical approval from the Institutional Review Board of Zahedan University of Medical Sciences (IR.ZAUMS.REC.1403.315). This study was also conducted in accordance with the Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) 2021 guidelines. Sixty human first and second mandibular molars, freshly extracted from adult patients (age range: 18–25 years) for orthodontic or periodontal indications upon clinicians' prescription, were collected following informed consent in accordance with the Declaration of Helsinki. Ten samples per group has been widely used to determine the sample size in in vitro studies using human teeth. Based on the results of the study by Saberi et al. [14], $\alpha = 0.05$, and $\beta = 0.2$, the sample size of ten specimens per group was approved. Selected teeth featured mature apices, were devoid of caries, restorations and abnormal morphology, and exhibited no pre-existing cracks or marginal involvement. Subsequent to debridement using manual scalers, all specimens were stored in 0.5% chloramine-T solution at 4 °C for one month.

Digital radiographs were acquired in both buccolingual and mesiodistal projections using a standardized film holder (Dentsply DeTrey GmbH, Konstanz, Germany). The anatomical crown height, from the most occlusal aspect to the cementoenamel junction (CEJ), was meticulously measured on all four axial surfaces. Occlusal buccolingual and mesiodistal dimensions were recorded using a digital caliper (Digimatic 500; Mitutoyo, Kanagawa, Japan). Teeth were systematically allocated into experimental groups to ensure homogeneity in tooth morphology and dimensions, thereby minimizing potential confounding variables. The teeth were allocated into 6 groups (10 per group): Intact teeth without load cycling and thermocycling (I), Traditional access cavity without load cycling and thermocycling (T), Conservative access cavity without load cycling and thermocycling (C), Intact teeth with load cycling and thermocycling (I+LTC), Traditional access cavity with load cycling and thermocycling (T+LTC) and Conservative access cavity with load cycling and thermocycling (C+LTC). Cavity preparation, root canal therapy and restoration.

Access cavities were prepared by a single experienced endodontist. A long, 1-mm diameter diamond fissure bur (No. 856; Intensiv SA, Montagnola, Switzerland) was utilized in a high-speed air turbine handpiece under copious water and air coolant to prevent desiccation. The occluso-pulpal distance was predetermined radiographically to ensure minimal iatrogenic dentin removal. For conservative access cavities (C group), emphasis was placed on minimal removal of tooth structure to preserve coronal strength while ensuring adequate access to the canal orifices. For traditional access cavities (T group), established guidelines for complete deroofing of the pulp chamber and straight-line access were followed (Figure 1.A). The conservative access was initiated within the mesial aspect of the central groove, extending distally and apically only as necessary to deroof the pulp chamber and facilitate straight-line access to the canals (Figure 1.B).

Following exposure of the canal orifices, a size 15 K-file (MANI, Inc., Tochigi, Japan) was employed to confirm canal patency (typically two mesial canals and one distal canal in mandibular molars). Gates-Glidden drills (sizes 1–3; MANI, Inc.) were used in a slow-speed handpiece to flare the coronal aspects of the canal entrances without prior irrigation. The working length was established by advancing a size 15 K-file to the apical foramen and subsequently retracting it by 1 mm. Cleaning and shaping of the root canals were performed using Dia-PT nickel-titanium rotary files (DPT; DIA-Dent, Cheongwon, Korea) according to the manufacturer's prescribed protocol. Between the use of each rotary file, the canals were irrigated with 2 mL of 5.25% sodium hypochlorite (NaOCl). Final irrigation consisted of 2 mL of 17% ethylenediaminetetraacetic acid (EDTA) for 1 minutes, followed by a terminal rinse with 2 mL of 0.9% saline solution. After thorough drying with sterile paper points, the canals were obturated using the lateral condensation technique with gutta-percha points (Dentplus, Diadent Group International, Chungcheongbuk-do, Korea) and AH26 root canal sealer (Dentsply DeTrey GmbH, Konstanz, Germany). Excess gutta-percha was removed from the pulp chamber using a heated instrument, and the coronal gutta-percha was vertically compacted. The pulp chamber was subsequently cleaned with alcohol-soaked cotton pellets to remove any residual sealer. For all groups except the intact groups (I and I+LTC), the dentin and enamel walls of the access cavities were etched with 37% phosphoric acid gel (Morva Etch, Morvabon, Tehran, Iran) for 30 seconds on enamel and 15 seconds on dentin, followed by thorough rinsing with water and gentle air-drying. Two coats of a dental bonding agent (MASTER-DENT, Ultimate Bond, Dentonics, Inc., PA, USA) were applied, gently air-thinned for 5 seconds to evaporate the solvent, and light-polymerized according to the manufacturer's instructions using a calibrated LED curing unit. The access cavities were then restored with a micro-hybrid composite resin (GRADIA DIRECT, GC Corporation, Tokyo, Japan) using an incremental layering technique. Each increment was light-polymerized as per the manufacturer's guidelines. Occlusal anatomy was carefully replicated. The root surfaces of all teeth were coated with a uniform layer of molten utility wax up to the CEJ. Each tooth was then embedded in a custom mold containing auto-polymerizing acrylic resin (Acropars 200, Marlic Medical Industries Co., Tehran, Iran). After complete polymerization of the acrylic resin, the teeth were carefully removed from the molds. The wax was eliminated using hot water, and the resultant space, mimicking the periodontal ligament space, was filled with a light-body polyvinylsiloxane impression material (Spidex, Coltene/Whaledent, Altstätten, Switzerland) to simulate the periodontal ligament. The teeth were then reinserted into the acrylic blocks and were stored in 0.9% physiological saline solution at 4 °C to prevent dehydration and preserve their biomechanical properties.

Load cycling, thermocycling and fracture resistance assessment

All specimens were mounted vertically in a parallelometer to ensure standardized alignment for load application and dispatched to a specialized laboratory for load cycling, thermocycling, and fracture resistance assessment. Specimens were mounted in custom fixtures within a chewing simulator (CS-4, SD Mechatronik GmbH, Feldkirchen-Westerham, Germany). They were subjected to 200,000 axial load cycles at a force of 80 N, with a 1 mm vertical displacement and a frequency of 2 Hz. All specimens remained submerged in distilled water at room temperature throughout the load cycling procedure (Figure 2). Following load cycling, these samples underwent thermocycling in a specialized thermocycling device (Vafaei Industrial Co., TC300, Tehran, Iran) for 1,000 cycles. Each cycle consisted of immersion in water baths maintained at 5 °C and 55 °C, with a dwell time of 30 seconds in each bath and a transfer time of 10 seconds between baths (Figure 3). The settings and sequence of aging procedures were selected based on the previous similar study [14]. After load and thermo cycling, all specimens were stored in distilled water at room temperature for 24 hours.

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The fracture resistance of each specimen was determined using a universal testing machine (Zwick/Roell Z050, Zwick GmbH & Co. KG, Ulm, Germany). A compressive load was applied parallel to the long axis of the tooth using a 6-mm diameter spherical stainless-steel antagonist. The crosshead speed was maintained at 0.5 mm/min until fracture occurred. The indenter was positioned to simultaneously contact both the buccal and lingual cusps surrounding the central fossa. To reduce stress concentration and create the appearance of a food layer, a 0.2 mm thick layer of tin foil was positioned between the teeth and the indenter. The peak force (in Newtons, N) required to cause fracture was recorded. Fracture was defined as the point of a sudden drop in the load-displacement curve (Figure 4). Throughout the process, the specimens were in distilled water at room temperature.

Statistical Analysis

Analysis of variance (ANOVA) was used to compare the study variables between the groups. A post hoc LSD test was used to determine which pairs were different when the ANOVA results showed a significant difference between the study groups. Normality of data was assessed using the Kolmogorov–Smirnov test. The statistical analysis was performed using IBM SPSS Statistics version 24 (IBM Corp., Armonk, NY, USA); statistical significance was set at a P-value of 0.05.

Results

In this study, 60 extracted mandibular first and second molars were divided into six groups to evaluate their fracture resistance. The groups were: Intact teeth without load cycling and thermocycling (I), Traditional access cavity without load cycling and thermocycling (T), Conservative access cavity without load cycling and thermocycling (C), Intact teeth with load cycling and thermocycling (I+LTC), Traditional access cavity with load cycling and thermocycling (T+LTC) and Conservative access cavity with load cycling and thermocycling (C+LTC). Normality of data was assessed using the Kolmogorov–Smirnov test, which confirmed a normal distribution (P = 0.79). Therefore, ANOVA was used to analyze the data and compare fracture resistance across groups. Table 1 shows the mean and standard deviation of fracture resistance in the groups. The highest fracture resistance was observed in the I group with a mean of 3117 N, while the lowest was in the T+LTC group with the mean of 1560 N. ANOVA showed a statistically significant difference between the groups (P = 0.001). A post-hoc LSD test was therefore carried out to determine which groups had a significant difference from the others. This test revealed that the I+LTC group had significantly higher fracture resistance than that of the T+LTC (P = 0.001) and C+LTC (P = 0.029) groups. Furthermore, the C+LTC had significantly higher resistance compared to the T+LTC group (P = 0.044). The fracture resistance of the I group was significantly higher than that of T group (P = 0.009). In addition, the C group had significantly higher fracture resistance than the T group (P = 0.033). However, no significant difference was observed between the I and C groups (P > 0.05).

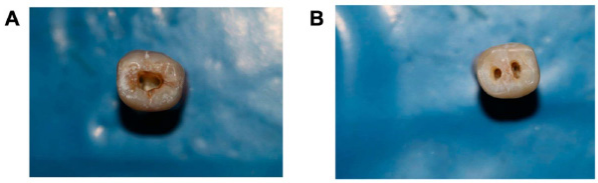


Figure 1. **A:** Traditional access cavity. **B:** Conservative access cavity.

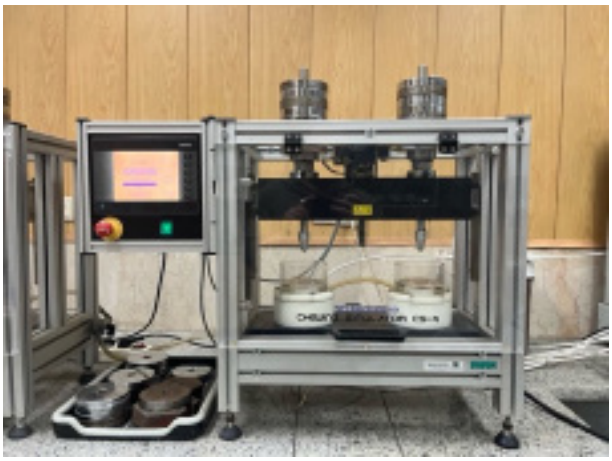


Figure 2. Load cycling device.



Figure 3. Thermocycling device.



Figure 4. Universal testing machine.

Table 1. Mean and standard deviation of fracture resistance (N) in the study groups.

Access Cavity Type	*Fracture resistance*		*P value*
(mean ± SD)	*Fracture resistance*		*0.001**
(min-max)			
I	*3117.3 ± 782.06*	*1574.03 - 4126.7*	
T	*2077.9 ± 487.6*	*1395.1 - 2730.9*	
C	*2802.04 ± 423.6*	*1972.7 - 3130.3*	
I + LTC	*2840.8 ± 1404.9*	*378 - 4964.2*	
T + LTC	*1560.1 ± 691.1*	*457.8 - 2943.2*	
C + LTC	*1985.4 ± 953.2*	*985.4 - 3793.4*	

*Statistically significant / I: Intact / T: Traditional access cavity / C: Conservative access cavity / LTC: Load and thermo cycling.

Discussion

The findings of this in vitro investigation indicate that conservative access cavity designs contribute to the preservation of tooth structure, thereby enhancing fracture resistance and potentially reducing the incidence of crack propagation in endodontically treated molars. This aligns with the principle that minimally invasive techniques may improve the long-term prognosis of root canal treatment [15]. Traditional access techniques, which involve more extensive removal of tooth structure, were shown to significantly diminish fracture resistance [16]. This reduction is likely due to compromised biomechanical integrity and altered stress distribution patterns within the remaining tooth structure when subjected to occlusal forces [17]. Conservative access designs are hypothesized to facilitate a more favorable distribution of functional stresses, thereby contributing to enhanced fracture resistance. These findings are congruent with previous research emphasizing the critical role of preserved tooth structure in determining the fracture resistance of endodontically treated teeth. Gluskin et al. highlighted that conservative endodontic approaches aid in preserving more tooth structure, thereby enhancing fracture resistance [15]. The utilization of modern technologies, such as dental operating microscopes and advanced imaging, can aid clinicians in executing conservative preparations with greater precision, further preserving tooth structure and potentially minimizing post-treatment fractures [18]. MIE underscores the preservation of coronal tooth structure by minimizing the dimensions of the access cavity, occasionally at the expense of achieving traditional straight-line access [19]. Technological advancements, such as enhanced magnification systems, novel endodontic instruments, and sophisticated imaging modalities, have facilitated the implementation of conservative cavity designs without ostensibly compromising therapeutic efficiency [20,21]. Nevertheless, a significantly reduced access size may potentially impede irrigation efficacy, thorough canal

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instrumentation, and obturation quality, thereby possibly increasing the incidence of procedural complications [22]. The application of load cycling and thermocycling, simulating the dynamic oral environment characterized by repetitive mechanical and thermal stresses, consistently led to a reduction in fracture resistance across all groups. These aging processes are known to induce material fatigue and propagate microcracks within the tooth structure [23]. Consequently, the cumulative effect of these stresses negatively impacts the long-term structural stability of root-filled teeth. While not directly assessed as a primary variable in this study, the choice of restorative material can also influence outcomes. Previous literature suggests that ceramic materials, owing to their favorable mechanical compatibility with tooth structure and high resistance to thermal and mechanical degradation, may offer superior performance in maintaining fracture resistance. Furthermore, restorative materials possessing an elastic modulus similar to that of natural dentin are considered beneficial for prolonging treatment longevity [24].

The combined effect of thermal and mechanical stresses, as simulated in this study, likely contributes to reduced structural integrity via microcrack initiation and propagation. This underscores the importance of protecting endodontically treated teeth from excessive or repeated occlusal loading [25]. Morresi et al., have reported that thermal and mechanical cycling can induce material fatigue and diminish the structural resistance of teeth [23]. Despite the array of proposed access designs, the optimal approach that harmonizes structural preservation, procedural facility, and therapeutic efficacy remains a subject of ongoing investigation. Notably, the cumulative effect of functional stresses, such as those induced by thermal cycling, occlusal loading, and the intraoral environment (e.g., pH fluctuations), on the fracture resistance of endodontically treated teeth require further investigation. Limitations of this in vitro study include the use of extracted teeth, which may not perfectly replicate the clinical behavior of teeth in vivo within the complex biological environment of the oral cavity (e.g., oblique forces and saliva). The simulation of the periodontal ligament, while attempted, may not fully capture its dynamic shock-absorbing properties. Furthermore, the specific parameters chosen for load cycling and thermocycling represent only one possible aging scenario. In addition, the results of the I+LTC and T+LTC groups should be interpreted with caution due to the high variability of fracture resistance of the samples. Future studies should address these challenges.

Conclusion

Within the limitations of this in vitro investigation, it was demonstrated that both the design of the endodontic access cavity and the application of thermocycling and load cycling significantly influence the fracture resistance of endodontically treated mandibular molars. Conservative access cavities, by preserving a greater volume of tooth structure, resulted in significantly higher fracture resistance compared to traditional access cavity designs. Furthermore, thermomechanical aging through combined load cycling and thermocycling consistently reduced the fracture strength across all tested groups. These findings underscore the clinical importance of adopting minimally invasive endodontic approaches to maximize tooth structure preservation and highlight the need to consider the cumulative effects of mechanical and thermal stresses on the long-term prognosis of endodontically treated teeth.

Conflict of Interest

There is no conflict of interest to declare.

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