Original Article

The effect of preparation design on fracture resistance of endodontically treated maxillary premolars restored with lithium disilicate computer-aided design/computer-aided manufacturing endocrowns: An *in vitro* study

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Abstract

Purpose: This study aimed to assess the effect of preparation design on fracture resistance (FR) of endodontically treated maxillary premolars restored with lithium disilicate (LDS) endocrowns fabricated by the computer-aided design/computer-aided manufacturing (CAD/CAM) technology.

Materials and Methods: In this *in vitro*, experimental study, 30 sound maxillary premolars were randomly assigned to three groups ($n = 10$) of control (no preparation), endocrown preparation with butt-joint design without ferrule, and endocrown preparation with ferrule (shoulder design with 1 mm height). After restoration fabrication and cementation, the teeth underwent thermocycling, were mounted with 45° angle, and subjected to compressive load in a universal testing machine to measure their FR. The mode of failure was also determined under a stereomicroscope. Data were analyzed using one-way ANOVA and Tukey's test ($\alpha = 0.05$).

Results: The shoulder group showed the highest FR (1768.98 ± 386.1 N). The difference in FR was statistically significant among the three groups ($P < 0.05$). Pairwise comparisons revealed that the shoulder group had significantly higher FR than the butt-joint ($P = 0.001$) and control ($P = 0.009$) groups. However, the difference in FR between the butt-joint and control groups was not significant ($P = 0.75$). The mode of failure was not significantly different among the three groups ($P > 0.05$).

Conclusions: Preparation design had a significant effect on FR of endodontically treated maxillary premolars restored with LDS CAD/CAM Endocrowns, such that addition of a short axial wall in shoulder group significantly increased the FR of endocrowns.

Keywords: Computer-aided design/computer-aided manufacturing; endocrowns; endodontically treated premolars; flexural strength; lithium disilicate; preparation design

INTRODUCTION

Reconstruction of endodontically treated teeth that have lost a large portion of their coronal structure is a

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clinical challenge.[1] The risk of biomechanical failure of endodontically treated teeth is much higher than that of vital teeth. The main reason for reduction of stiffness and fracture resistance (FR) of endodontically treated teeth is the lost integrity of tooth structure due to caries, trauma, or extensive access cavity preparation rather than dehydration and physical changes in dentin structure. Such biomechanical changes in endodontically treated teeth compromise their long-term prognosis and challenge the process of tooth restoration.[2] The survival of endodontically treated teeth depends on tooth type, amount of residual tooth structure, type of restorative material, treatment technique, and interactions between the tooth structure, restorative material, and oral cavity.[3]

There is no agreement on the best procedure for restoring endodontically treated teeth. However, fabrication of post and core and crown is a commonly practiced technique for this purpose.[2] In the past, it was believed that this treatment would reinforce the remaining tooth structure. However, more recent studies found that intracanal posts could only enhance the retention of crown, and postspace preparation further weakens the residual tooth structure and increases the risk of tooth fracture or root perforation.[4]

More conservative treatment approaches have grown in popularity as adhesive dentistry has advanced. The efficacy of conventional post and core restorations is a matter of question in conservative dentistry; therefore, endocrowns were introduced as a possible alternative for restoration of endodontically treated teeth.[5]

Ceramic endocrown is a monolithic ceramic restoration. Tooth preparation for an endocrown requires a circumferential butt margin and a central retention cavity in the pulp chamber. This design benefits from the available pulp chamber surface to ensure retention and stability of restoration with the help of adhesive bonding.[6] Tooth preparation for an endocrown follows the decay-oriented design concept, which requires minimally invasive tooth preparation.[7] In endocrown restoration, macro-retentive design is not necessary given that sufficient tooth surface is available for bonding.[2] Endocrowns have recently gained increasing attention due to their advantages such as maximum preservation of tooth structure, decreased need for additional retention, fewer procedural steps, and saving time and cost.[5] A strong bonding between the indirect restoration and tooth structure increases the durability and longevity of restoration.[8]

Preservation of sound coronal and radicular tooth structure, especially in the cervical region, is imperative to create a ferrule effect for optimal biomechanical behavior of restored teeth. Ferrule refers to parallel dentinal walls that extend from the restoration margin towards the coronal region. This area is surrounded by the restoration and exerts a protective effect by decreasing the stress applied to the tooth and root, which is referred to as the "ferrule effect."[9]

Premolars has small bonding area and inappropriate crown/root ratio compared with molar teeth, which make them susceptible to fracture.[3] Evidence shows that addition of ferrule to cavity preparation design can increase the available surface area for bonding and enhance the stability of restoration.[10] Using a minimum of 0.5 mm ferrule significantly increases the cyclic fatigue resistance of teeth restored with full-coverage all-ceramic restorations supported by a fiber post and resin core. Furthermore, evidence shows that using a ferrule, compared with an intracanal post alone, significantly increases the FR.[10] However, using a ferrule design in preparation of premolars for an endocrown restoration has not been previously investigated.

It has been reported that premolars restored with endocrown restorations have higher susceptibility to fracture than molars. The possible reason for this finding may be smaller bonding surface area and higher coronal height of premolars. Furthermore, premolars receive more amounts of horizontal (off-axial) forces than molars, which can compromise their FR after restoration.[5] All these parameters further highlight the significant role of preparation design, restorative material, and cementation and bonding techniques in FR of endodontically treated premolars. Since premolars are subjected to shear in addition to tensile forces in the oral cavity, and considering their unique anatomy, they may require a unique customized restoration protocol.[1]

The computer-aided design/computer-aided manufacturing (CAD/CAM) technology has undergone great advances in the recent years such as decreased cost of the hardware, more user-friendly software, faster fabrication, more precise preparation in terms of anatomical form and dimensions, and precise marginal fit.[11] At present, CAD/CAM systems can be used chairside for automatic fabrication of ceramic restorations, particularly endocrowns (mono-block core and crown).[5]

Ceramic materials, especially lithium disilicate (LDS) ceramics have improved mechanical (flexural strength, hardness, toughness, and FR) and optical (translucency, opalescence, and shine) properties.[10] Ceramic materials used for the fabrication of CAD/CAM endocrowns should have optimal esthetics and strength.[12] Highly rigid materials such as LDS can well tolerate occlusal stresses.[13] Moreover, using only one material for fabrication of endocrown decreases stress accumulation due to different properties of different materials.[14] Moreover, in endocrown restorations, only one interface exists between the one-piece restoration and tooth, which minimizes the risk of adhesive failure.[2]

Considering the significance of this topic and gap of information, this study aimed to assess the effect of preparation design on FR of endodontically treated maxillary premolars restored with LDS endocrowns fabricated by the CAD/CAM technology. The null hypothesis was that the FR of the two groups with different preparation designs would not be significantly different.

MATERIALS AND METHODS

This *in vitro*, experimental study was conducted on 30 sound extracted maxillary premolars. The study was approved by the ethics committee of Islamic Azad University (IR.IAU.DENTAL.REC.1399.079). The sample size was calculated to be nine in each group according to a study by Al-Shibri and Elguindy[15] assuming $\alpha = 0.05$, $\beta = 0.2$, mean standard deviation of FR to be 353 N, and effect size of 0.6, using one-way ANOVA power analysis of PASS 11 (NCSS, Kaysville, Utah, USA). To increase the statistical power of the study, 10 teeth were assigned to each group.

Collection of teeth and eligibility criteria

Thirty sound maxillary premolars extracted for periodontal problems or orthodontic treatment were collected. Soft-tissue residues and calculus were removed from the surface of root and crown by a hand scaler. The teeth belonged to patients between 18 and 25 years who consented to the use of their extracted teeth for research purposes. The teeth had completely formed roots and were inspected under a stereomicroscope (SMZ 1000, Nikon, Japan) at ×25 magnification to ensure absence of coronal or radicular cracks or caries. Furthermore, all teeth had normal anatomy and had no anomaly. The length and mesiodistal width of the teeth were measured by a caliper, and teeth with almost similar dimensions (maximum of 10% standard deviation from the mean) were selected. The teeth were disinfected in 0.5% chloramine T solution at 23°C and were then stored in saline (for a maximum of 3 months).[16,17]

Grouping of teeth

The teeth were randomly assigned to three groups ($n = 10$) such that the three groups were standardized in terms of dimensions. To calculate tooth dimensions, according to Eakle *et al*.,[18] the maximum buccolingual and mesiodistal dimensions of teeth in their occlusal third were measured by a caliper and multiplied. According to the obtained number, the three groups were standardized to have equal number of each size. Accordingly, the effect of tooth size as a confounder was eliminated.[1] The three groups were as follows:

- Group 1 (control): This group included sound maxillary premolars with no preparation
- Group 2 (butt-joint): The teeth in this group underwent endodontic treatment, received an endocrown preparation with a butt-joint margin with no ferrule and were restored with endocrowns
- Group 3 (shoulder): The teeth in this group underwent endodontic treatment, received an endocrown preparation with 1 mm shoulder and ferrule, and were restored with endocrowns.

Endodontic treatment of teeth

An access cavity was prepared with a diamond fissure bur (Dentsply, USA) with 3 mm × 2 mm dimensions.[19] Next, a #15 stainless steel file (Mani, Japan) was introduced into the canal until its tip was visible at the apex; 1 mm was subtracted from this length to calculate the working length. Root canal shaping was conducted by the step-back technique up to master K-file #30. The canals were flared using #1, 2 and 3 Gates-Glidden drills (Mani, Japan). The root canals were rinsed with saline and 2.5% NaOCl after using each file with standardized pressure.[16] After shaping, the root canals were dried with paper points, and #30 gutta-percha (Meta, Wisconsin, USA) dipped in AH Plus sealer (Dentsply DeTrey, Konstanz, Germany) was inserted into the canal. The root canals were filled with gutta-percha by lateral compaction technique using a #2 spreader (Mani, Japan) and #20 accessory cones. Excess gutta-percha was removed by a heated instrument at 0.5 mm below the cementoenamel junction (CEJ). The remaining gutta-percha was condensed by a plugger.[16]

Tooth preparation for endocrown restoration

In Groups 2 and 3, the teeth were cut at 2 mm above the CEJ from the proximal region using a diamond disc under copious coolant to create a circular butt margin in all specimens.[20] To prepare the pulp chamber, all root canals were sealed with Filtek Z350XT flowable composite (3M ESPE, St. Paul, MN, USA) such that 3 mm space remained from the pulp chamber depth to the cavo-surface margin. Next, all retentive areas and undercuts were removed, and axial pulp chamber walls were prepared by a tapered diamond bur (Dentsply, USA) with 10° divergence. [Figure 1]

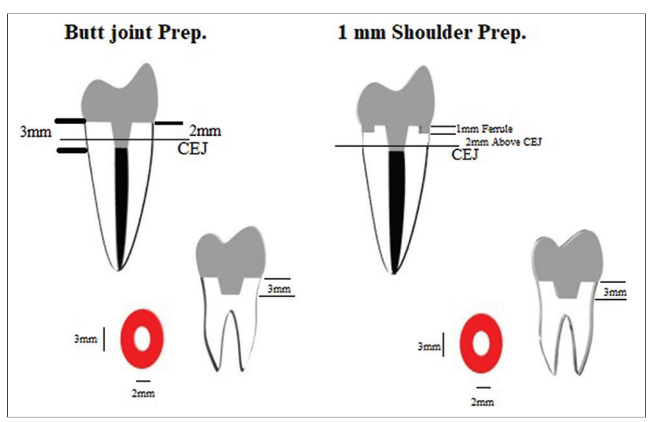

Figure 1: Schematic diagram of preparation designs of endocrowns in two study groups

In Group 3, a flat-end tapered diamond bur was used to create a shoulder with 1 mm width and a ferrule with 1 mm height. The overall occlusal convergence (taper) was 10°.

Next, a caliper was used to ensure accurate preparation dimensions.[18] The height and thickness of ferrule were measured by a caliper and only teeth with maximally 10% standard deviation of dentin thickness at the ferrule from the mean value were included.

Endocrown fabrication

All restorations were fabricated by a CAD/CAM system (Ceramill System; Amann Girrbach AG, Germany). For this purpose, first the occlusal surface of a sound premolar was scanned by a scanner (Ceramill MAP 400) and the scan image was saved in Ceramill Mind software (Amann Girrbach AG, Germany). The software designed a virtual model of the scan image, and automatic margin finder was used to find the preparation margins. Ceramill Mind software was used to scan the prepared tooth and endocrown restorations were virtually designed according to the primary scan for the purpose of standardization. An 80-µm cement space was also considered for endocrowns.

For the milling process, size C14 A2 shade low-translucent IPS e.max CAD ceramic blocks were used. The blocks were placed in spindle chamber of the milling machine (Ceramill Motion 2 milling machine; Amann Girrbach AG, Germany) and fixed in place with set screw. The milling process was fully automated. After completion of the milling process, the endocrowns were tried-in to ensure their complete seating and adaptation.[11] All restorations were also assessed for rocking. The amount of gap was also measured by a fit-checker. The blocks were then sintered (Programat P310 Furnace; Ivoclar Vivadent, Schaan, Liechtenstein) according to the sintering protocol for IPS e.max blocks, and their fit was ensured by measuring the gap using fit checker.

The internal surface of e.max restorations was etched with 9.5% hydrofluoric acid (Bisco, USA) for 20 s. After rinsing and drying, silane (Bisco, USA) was applied on the internal surface for 40 s. The tooth surface was etched with 35% phosphoric acid (Ultra-etch; Ultradent Products, USA) and rinsed for 15 s. All-Bond Universal (Bisco, USA) was applied on the entire cavity, and cured for 20 s. Duo-Link (Bisco, USA) cement was mixed and applied on the tooth and restoration surfaces; excess cement was removed at the margins.[3] All restorations were subjected to continuous pressure of 1 kg applied perpendicular to the occlusal surface for 5 min.[5] Finally, each restoration was cured from the occlusal, buccal, and palatal surfaces each for 40 s.[3]

Measuring the fracture resistance

The teeth were mounted in custom-made molds with 3 cm height and 2.5 cm diameter containing auto-polymerizing acrylic resin to 2 mm to their CEJ at 45° angle using a surveyor.[1,21] The teeth were then stored in saline at the room temperature for 24 h. The teeth then underwent thermocycling for 10,000 thermal cycles (1 min each) between 5°C and 55°C with a transfer time of 30 s (TC300, Vafaei Industrial, Tehran, Iran).[22] Next, they were transferred to a universal testing machine (Zwick, Germany) and subjected to slowly increasing compressive load at a crosshead speed of 1 mm/min applied by a spherical steel cylinder with 6 mm diameter [Figure 2]. The load gradually increased until fracture. The load causing fracture was recorded in Newtons.[4]

Assessment of mode of failure

The teeth were inspected under a stereomicroscope (SMZ1000, Nikon, Japan). The mode of failure was categorized as repairable (for fractures above the CEJ) or irreparable (for fractures below the CEJ).

Statistical analysis

Measures of central dispersion were reported for FR. Considering the normal distribution of data as confirmed by the Kolmogorov–Smirnov test, the three groups were compared regarding FR using one-way ANOVA. Pairwise comparisons were carried out by the Tukey's *post hoc* test.

RESULTS

None of the teeth broke due to thermocycling; thus, there were no dropouts. Table 1 presents the measures of central dispersion for FR of the groups. The highest and the lowest FR values were noted in shoulder and butt-joint group, respectively. The difference in FR was significant among the three groups ($P < 0.001$). Thus, pairwise comparisons were carried out, which showed that the mean FR of the shoulder group was significantly higher than that of butt-joint ($P = 0.001$) and control ($P = 0.009$) groups. However, the difference in FR between the butt-joint and control groups was not significant ($P = 0.75$).

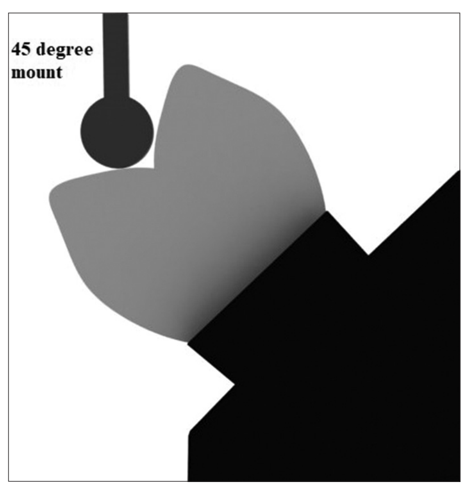

Figure 2: Schematic diagram of 45° mounting and loading of the samples

Table 1: Measures of central dispersion for fracture resistance of the groups

Group	*n*	Mean±SD (*n*)	95% CI for mean		Minimum	Maximum
			Upper bound	Lower bound		
Butt-joint without ferrule	10	1282.9±251.71	1462.96	1102.83	759.98	1595.39
Shoulder with ferrule	10	1768±386.1	2045.17	1492.77	1256	2537.53
Control (sound)	10	1371.9±110.79	1451.15	1292.64	1230.67	1598.78
P			<0.001			

SD: Standard deviation, CI: Confidence interval

Table 2 shows the frequency of repairable and irreparable fractures. The mode of failure was not significantly different among the three groups ($P > 0.05$).

Table 2: Frequency of repairable and irreparable fractures

Group	Failure type	
	Repairable, *n* (%)	Irreparable, *n* (%)
Butt-joint without ferrule	6 (60)	4 (40)
Shoulder with ferrule	8 (80)	2 (20)
Control (sound)	8 (80)	2 (20)

DISCUSSION

This study assessed the effect of preparation design on FR of endodontically treated maxillary premolars restored with LDS endocrowns fabricated by the CAD/CAM technology. The null hypothesis was that the FR of the two groups with different preparation designs (butt-joint and shoulder) would not be significantly different. The results revealed that the shoulder group had the highest FR (1768.98 ± 386.1 N). The difference in FR was statistically significant among the three groups ($P < 0.05$). Pairwise comparisons revealed that the shoulder group had significantly higher FR than the butt-joint ($P = 0.001$) and control ($P = 0.009$) groups. However, the difference in FR between the butt-joint and control groups was not significant ($P = 0.75$). Thus, the null hypothesis of the study was rejected.

The average FR of sound teeth in the present study was 1371.9 N which was similar to that of previous studies.[1,21] The mode of failure was not significantly different among the three groups. Thus, according to the results, endocrowns without ferrule could almost but not completely reinstate the FR of a sound tooth while the FR of endocrowns with ferrule was significantly higher than that of sound teeth and butt-joint group.

The results of this study showed that endocrowns with axial reduction and 1 mm shoulder finish line have a significantly higher FR than butt-joint endocrowns. Taha *et al*.[2] evaluated mandibular first molars restored with Enamic ceramic endocrowns and reported results similar to this study. From the biomechanical point of view, restoration somewhat adapts to the stress generated at the bonding interface. These forces spread at the cervical butt-joint (compressive forces) or axial walls (shear forces). The butt-joint surface is parallel to the occlusal plane; it provides a stable surface which is resistant against compressive forces. However, addition of a short axial wall with shoulder finish line can have several biomechanical effects including resistance to shear stress and balanced load distribution at the pulpal floor and margins. Moreover, compared with butt-joint design, axial reduction may decrease the thickness of resin cement, which in turn will decrease the polymerization shrinkage, thermal alterations, and stresses applied to ceramic.[2]

The maximum functional force applied to premolars is reportedly 401 N.[23] That being the case, all teeth in the present study were capable of resisting functional loads after 10,000 cycles. In this research, the difference in FR of butt-joint endocrowns and the control group was not significant. Hence, endocrowns even without ferrule can reinstate the FR almost to the level of sound teeth. The clinical survival rate of premolars with endocrowns is reportedly 68% and 75% after 55 months and 10 years, respectively. However, the survival rate of premolars with conventional crowns is 94% and 95% after 55 months and 10 years, respectively.[24] A systematic review[24] reported that in half of the reviewed studies[4,5,25] (3 out of 6), the FR of premolars with endocrowns was similar to that of post and crown restorations; in two studies,[20,26] the FR of endocrowns was higher than post and crown, and in one study,[27] the FR of endocrowns was lower than post and crown restorations. Search of the literature by the authors yielded no study comparing the FR of premolars restored with endocrowns and sound teeth as the control group. According to the systematic review,[24] clinical studies on endocrowns[28,29] reported higher failure rate of premolar endocrowns than molar endocrowns. Furthermore, the survival rate of premolars with endocrowns was significantly lower than molars with endocrowns and premolars with prosthetic crowns. All failures in clinical studies on premolars were due to adhesion loss and were therefore repairable. Such discouraging clinical results regarding premolars restored with endocrowns are in contrast with *in vitro* findings. Under *in vitro* conditions, survival rate, FR, and stress distribution of premolars restored with endocrowns were comparable to those of post and crown restorations, which may be due to the fact that most clinical studies fabricated endocrowns from feldspathic ceramic; while, more recent materials are currently available in the market.

Regarding finish line configuration, two studies[2,10] showed that creating a 1-mm ferrule increased the FR of endocrowns and decreased the number of irreparable fractures.[24] Although the majority of studies used endocrowns without ferrule, it should be noted that ferrule confers greater resistance to teeth restored with endocrowns and also conventional crowns. However, attempts to create a ferrule should not lead to loss of residual enamel at the margin close to CEJ. In the absence of ferrule, a concave bevel at the circumferential enamel can be created to increase the bonding surface area in the enamel and improve the biomechanical behavior of endocrowns. Placing the margins supra-gingivally is imperative to be able to isolate the prepared tooth and apply the bonding protocol by placing a rubber dam.[24] Einhorn *et al*.[10] evaluated the effect of ferrule design on FR of mandibular molars and found results similar to the present findings, showing that FR was significantly higher in groups with ferrule.

In the present study, the frequency of irreparable failure in endocrowns without ferrule (40%) was slightly, but not significantly, higher than that in endocrowns with ferrule (20%) and sound control teeth (20%). Similarly, two studies[2,10] showed that addition of 1 mm ferrule decreased the frequency of irreparable fractures in endocrowns.[24] Also, Einhorn *et al*.[10] reported lower frequency of catastrophic failure in endocrowns with 1 mm ferrule. Four finite element analyses on premolars[6,14,30,31] showed that teeth restored with endocrowns had lower stress level in dentin and cementum than other conventional restorations (metal casting post and core, fiber post, and metal post). Nevertheless, another study showed that maximum stress in endocrowns was three times higher than that in restorations with fiber post.[24]

This study had some limitations. Only one type of resin cement was used; different resin cements can bring about different results with respect to FR. *In vitro* design was another limitation, which limits the generalization of results to the clinical setting. Furthermore, FR of endocrowns fabricated from different materials should be evaluated and compared. Marginal gap is another important factor in success of endocrown restorations which should be evaluated. Furthermore, different aging protocols can be employed in future studies. Finally, clinical studies are required on long-term clinical success of premolars restored with endocrowns.

CONCLUSIONS

Preparation design had a significant effect on FR of endodontically treated maxillary premolars restored with LDS CAD/CAM endocrowns, such that the addition of a short axial wall in shoulder group significantly increased the FR of endocrowns.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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