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# Efficacy of preparation design on fracture resistance of hybrid-ceramic endo-crown on premolars: An *in vitro* study

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**Abstract**

**Aim:** The present study aims to evaluate the effect of different preparation designs on fracture resistance and failure mode of hybrid nanoceramic endocrown on premolars.

**Methodology:** Fourteen endodontically treated maxillary premolars were prepared to receive a hybrid nanoceramic endocrown restorations and divided into 2 groups according to the preparation designs (butt joint and 2 mm ferrule). The endocrown restorations were cemented to the prepared teeth using dual cure adhesive resin cement. All specimens were subjected to a compressive force 5KN until fracture occurs by using universal testing machine. The maximum compressive force was recorded for all specimens, then failure mode of all samples were examined visually and photographically. All repairable samples were examined for extension of the cracks using scanning electron microscope.

**Results:** Endocrowns with ferrule preparation recorded a highly statistically significant difference with the higher mean value of fracture resistance (1911.57 ± 341.29 N), compared to the endocrowns with butt joint which recorded the lower mean value of fracture resistance (1192.70±196.04 N). Regarding the failure mode; endocrowns with ferrule design showed a high percent of catastrophic failure while butt joint showed more repairable failure.

**Conclusion:** Endocrowns with ferrule design showed a higher fracture resistance value but with a high percent of catastrophic failure mode compared to butt joint design that showed lower fracture resistance value with mostly repairable mode of failure.

**Keywords:** Endocrown, hybrid nanoceramic, endodontically treated premolars, fracture resistance, ferrule, butt joint.

## Introduction

The purpose of endodontic treatment is the maintenance of the longevity and function of the affected teeth. Endodontically treated teeth (ETT) are more liable to fracture. Therefore, it's crucial to reconstruct the teeth within a certain period of time and conserve as much tooth structure as possible [1, 2]. One of the conservative treatment options that were made possible by the advances of adhesive dentistry is the endocrown, which was early defined as ceramic monoblock by Pissi [3]. Later in 1999 Bindl and Mörmann used the term of endocrown [4]. Although the endocrown provides short clinical time, lower cost, better aesthetic and preserves the remaining tooth structure, the success and durability of the endocrown are depend on the correct tooth preparation, the most suitable ceramic options and what kind of bonding material is used [5].

The hybrid nanoceramic cerasmart 270 is a unique dental material that provides highest degree of flexibility, strength and ensures the best marginal integrity after milling and bonding due to the fully homogenous and evenly distributed nano-ceramic network [6]. The new technology of full coverage silane coating (FSC) of cerasmart 270, strengthens the bonding between resin matrix particles, resulting in exceptional wear resistance, color retention for long-lasting and realistic-looking restorations [7].

Restoring premolars that have undergone endodontic treatment is a contentious topic. According to some studies, endocrowns in premolars are more likely to fail than molars because they have a smaller adhesion surface, greater crown height, and more horizontally

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directed forces [8]. Others advised that the endocrown should be taken into consideration as a viable option, as the results showed comparable performance to traditional crown [9]. Studies that paid attention to the impact of different preparation designs on the fracture resistance of premolar endocrown were very limited. Consequently, the objective of this study was to shed light on the efficacy of preparation design on fracture resistance of hybrid nanoceramic endocrown on premolars. The null hypotheses tested were that the different preparation designs would have no effect on fracture resistance or failure modes.

## Materials and Methods

### Teeth Selection and Storage

This work was approved by the Research Ethics Committee of Faculty of Dentistry Cairo University, code number 31219. The study's samples included fourteen freshly extracted human maxillary premolars that were free of decay. A 10% maximum variation from the predetermined mean was allowed when choosing the anatomical crowns. With magnifying loops (Univet, Air-X, Dental loupe, 6x magnification, Italy), the teeth were examined under high light conditions. Prior to the study, all teeth were cleaned properly with an ultrasonic scaler (Baolai Medical, China), then maintained hydrated in distilled water at room temperature [10].

### Endodontic Treatment

All teeth were endodontically treated by the same operator using the same sequence for the purpose of standardization. Using a round bur (Carbide Round Burs, Dentsply Maillefer, Switzerland) followed by an Endo-Z bur (Zndo-Z bur, ökoDENT, Germany), all the access cavities were performed using a high-speed handpiece under copious water coolant [11]. Protaper system (Protaper Next, Dentsply Maillefer, Switzerland) was used for root canals treatment using single cone technique, reaching the full working length [12, 13]. The access cavities were sealed with cotton and temporary filling material until teeth mounting completed.

### Teeth Mounting

Using a centralizing device, all teeth were placed vertically in epoxy resin (Kemapoxy 150, CMB Group, Egypt) up to 2 mm apical to the cemento-enamel junction (CEJ), imitating bone level, and held in position till complete polymerization of the resin [14].

### Decapitation of the Teeth

Using a wheel diamond bur (ökoDENT, Germany), the crowns of the collected teeth were trimmed horizontally 3mm coronal to the CEJ from the occlusal surface [15]. Using a random sequence generator, the premolars were randomly divided into 2 main groups (n=7) based on the preparation design. To block the canal orifices and achieve an even pulpal floor, a thin layer of bulk fill flowable composite (SDR, Dentsply Sirona, Germany) material was bonded [16].

### Preparation of the teeth with Butt Joint Design

The pulp chambers were prepared using a specialized milling device (PARASKOP, Milling Unit, Bredent, BF2, USA) (Figure 1) to remove undercuts with 8° coronal divergence using a tapered diamond bur with a rounded end (ökoDENT, Germany) held vertically to the pulpal floor, with a depth of 3 mm from the cavo-surface margin to the floor composite [17]. The dimensions of an oval shaped cavity were 4mm bucco-lingual and 3mm mesio-distal. For standardization, all the walls were 2 mm thickness [14].

### Preparation of the teeth with Ferrule Design

Teeth were prepared using the same milling device, with 2mm circumferential ferrule, 1mm coronal to the CEJ, and 8° coronal convergence (Figure 2) [16, 18, 19]. All axial surfaces had 1mm shoulder margin. The dimensions of an oval shaped cavity were 4mm bucco-lingual and 3mm mesio-distal with 8° coronal divergence, and the depth of the pulp chamber was 3mm [14]. The finished preparations for both designs are shown from side view in (Figure 3) and from occlusal view in (Figure 4).

### Construction of Endocrowns using CAD⁄CAM

All the samples were created with the aid of a CAD/CAM system (InLab MC X5 SW 19.0). In order to create 3D image, the prepared teeth were scanned using InEos X5 (Sirona, Gmbh, Germany) extraoral scanner [20]. The prepared teeth were air dried for 10 seconds, then sprayed with an optical anti-reflection scan powder (IP spray, IP Division, Germany) then placed on the scanning tray. With the aid of Inlab 19.0 software (Inlab software, Version: 19.0.174926, Sirona, GMBH, Germany) the scanned pictures of the prepared teeth were transformed to a virtual model. For margin detection, an automatic and a manual margin finder were selected. The endocrown restorations were designed with 5mm buccal cusp height and 4mm palatal cusp height in butt joint design, and with 5mm buccal cusp height and 4mm palatal cusp height with 2mm wall height in ferrule design and 80µm cement space for standardization [14].

Inlab MC X5 (Dentsply Sirona, GMBH, Germany) was used for the milling procedure, then a diamond wheel was used to manually separate the endocrowns from the block holder. The milled restorations are shown in (Figure 5). All endocrown restorations were checked for seating on their corresponding teeth. The restorations were finished using finishing and polishing kit (GC Polishing kit America Inc. USA) and diapolisher paste (GC Diapolisher paste, America Inc. USA).

### Surface Treatment of Endocrown Restorations

Intaglio surfaces of hybrid nanoceramic cerasmart 270 (GC, Dental, USA) were etched for 60 seconds with 9.5% hydrofluoric acid gel (Bisco, INC, USA), washed for 60 seconds with water, then dried for 30 seconds before applying silane coupling agent (Porcelain Primer, Bisco, INC, USA) and allowed to dry for 1minute [15, 21].

### Surface Treatment of the Teeth

All bond universal (Bisco, INC, USA) was then applied after the teeth surfaces had been etched with 37% phosphoric acid (Meta BIOMED, Korea) for 30 seconds, washed for 20 seconds, and air dried for another 5 seconds. Excess solvent from the bond was then dried for 3 seconds with moisture free air before being light cured for 20 seconds [15].

### Cementation

On the teeth's prepared surfaces, the dual cure resin cement (BisCem, Bisco, INC, USA) was applied [15]. Each endocrown was cemented to its corresponding tooth (Figure 6) using finger pressure, and any residual cement was cleaned off with a microbrush, then placed on a specially designed cementation device with 3kg constant load to prevent the restoration's rebounding during cementation. To insure complete polymerization of the resin cement, the endocrowns were light cured for 20 seconds on each surface [14].

**Fracture Resistance Test**
Fracture test was done by using a universal testing machine; each sample was loaded with 5 KN using a metallic rod with spherical tip (3.4 mm diameter) travelling at cross head speed of 1mm/min. The load was applied occlusally. The fracture load was measured in Newton.

**Failure Mode**
After fracture resistance test, all specimen's failure modes were visually and photographically evaluated using a digital camera, stereomicroscope (Leica Stereomicroscope, S8 APO, Germany), and digital microscope at magnification x35 [22]. For all repairable samples, the crack extensions were confirmed using a scanning electron microscope (Model Quanta 250 FEG, Field Emission Gun, Company, Netherlands) [23]. The failure was considered repairable if the fracture was at or coronal to CEJ and irreparable if the tooth fracture was apical to CEJ [24]. Data were analyzed using the statistical software SPSS. Statistical analysis of the results was performed by applying Independent T-test for fracture resistance results, and Kruskal-Wallis test for failure mode results.

**Results**
The Independent T-test revealed a highly significant difference between the two groups at the 0.001 level ($P < 0.001$ & 99% confidence). The cerasmart 270 endocrown with ferrule design had the higher mean of fracture resistance (1911.57 ±341.29 N), whereas the cerasmart 270 endocrown with butt joint design had the lower mean value (1192.70 ±196.04N) (Table 1, Figure 7).
The hybrid nanoceramic 270 endocrown behaved differently upon fracture. The failure modes were classified into 4 different categories: I: Debonding of the restoration without fracture. II: Fracture in restoration only. III: Fracture of restoration /tooth complex at or coronal to CEJ. IV: Fracture of restoration/tooth complex apical to CEJ [24]. According to the results of Kruskal-Wallis test, there was a significant difference between the two groups at the 0.05 level ($P < 0.05$).
In the group of cerasmart 270 endocrown with ferrule design, failure mode showed that under vertical compression load, the majority of failures were irreparable failure with 71.4% (n=5) of the samples have fracture apical to CEJ type IV failure mode, and 28.6% (n= 2) of samples have repairable failure type III.
In the group of cerasmart 270 endocrown with butt joint design, the majority of failures were repairable with 85.72% (n=6) of samples have fracture coronal to CEJ (5 samples of type II and 1 sample of type III) and 14.28% (n=1) of sample showed irreparable fracture apical to CEJ (Table 2).

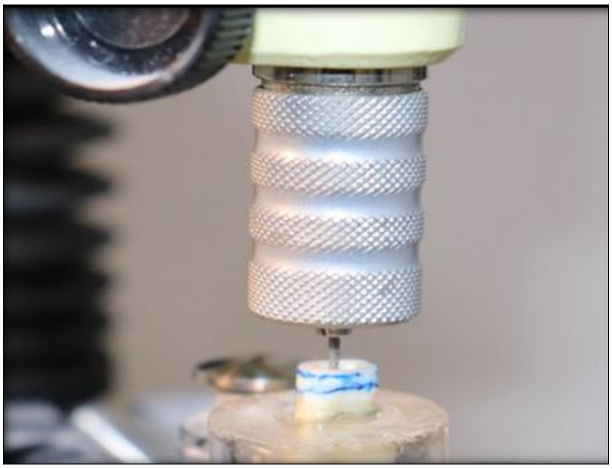

**Fig 1:** Preparing the teeth with 90° butt joint

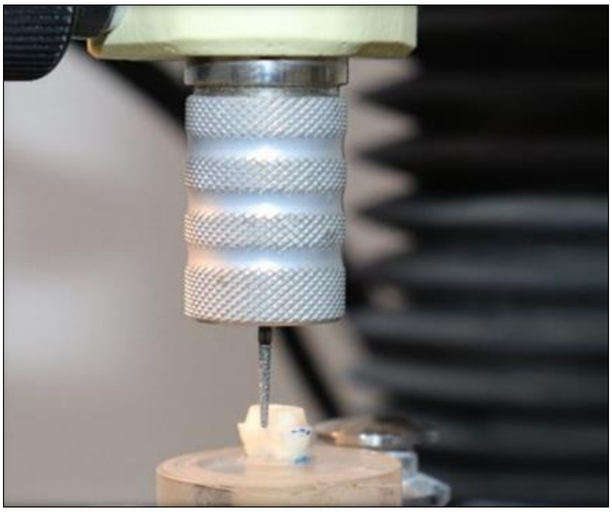

**Fig 2:** Preparing the teeth with 2mm ferrule axial reduction

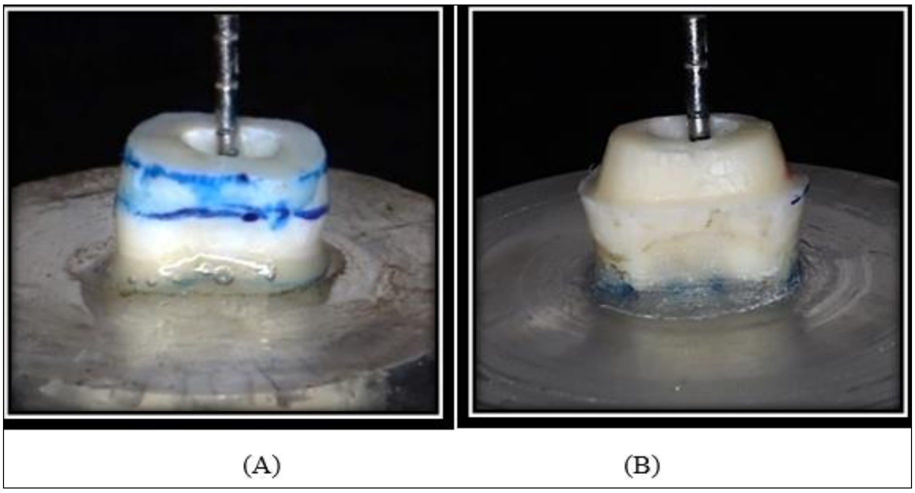


**Fig 3:** Side view of prepared teeth (A: 90° butt Joint, B: 2 mm ferrule axial wall)

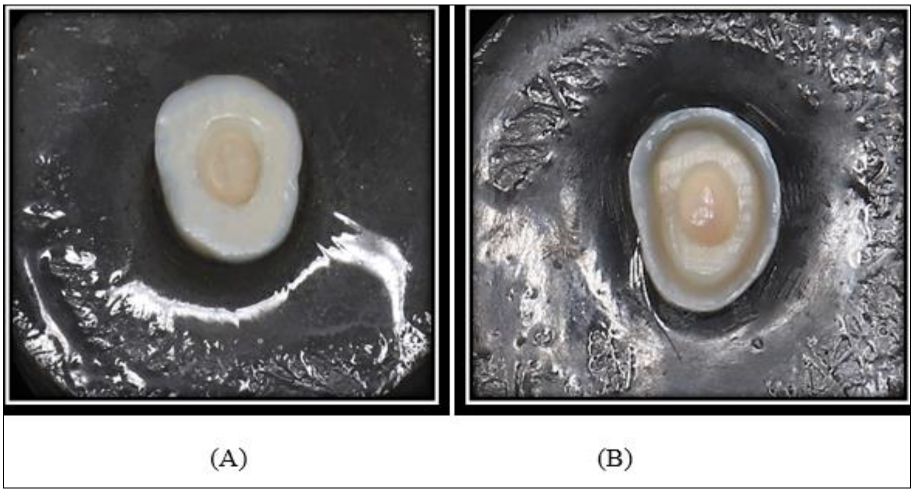


**Fig 4:** Occlusal view of prepared teeth (A: 90° Butt Joint, B: 2mm Ferrule and shoulder finish line)

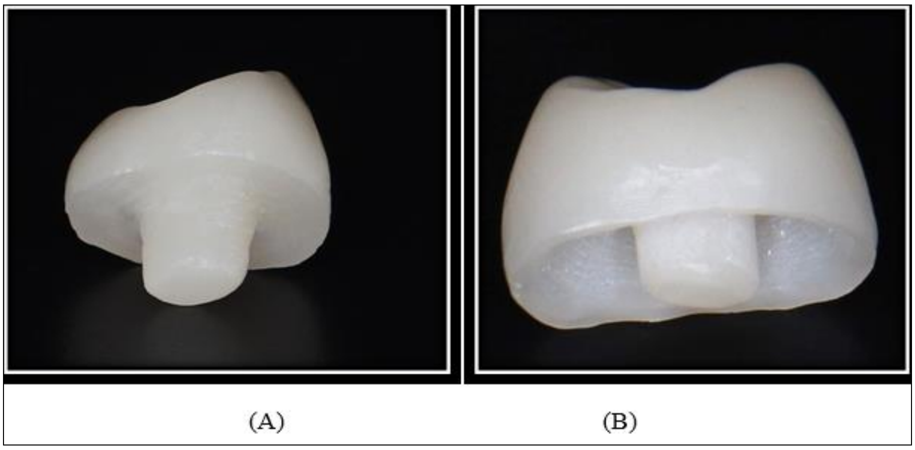


**Fig 5:** Endocrown restorations after milling process viewed from the fitting surface (A: Butt joint, B: Ferrule)

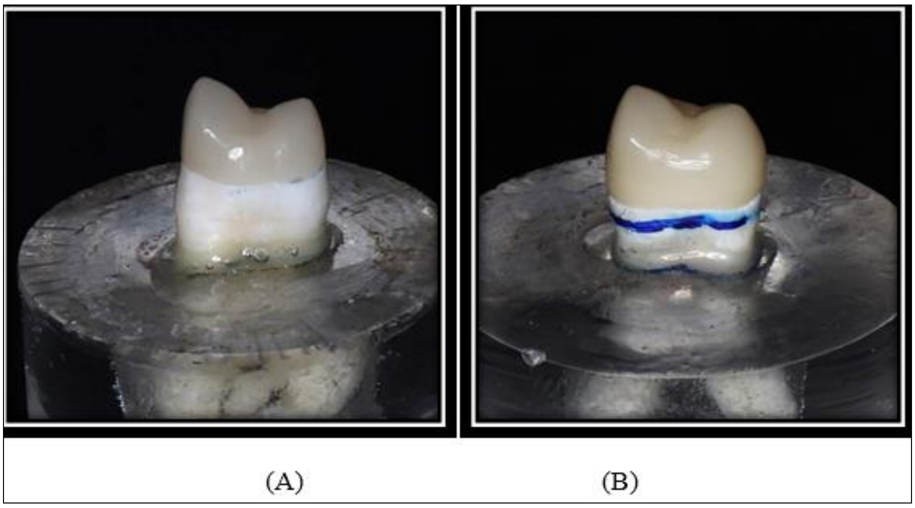


**Fig 6:** Side view of the endocrown restoration after cementation (A: Butt joint, B: Ferrule)

**Table 1:** Descriptive data for the two groups:

| Control | N | Mean | Std. Deviation | 95% Confidence Interval for Mean | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| Butt-joint | 7 | 1192.70 | ±196.04 | 1011.40 | 1374.00 |
| Ferrule | 7 | 1911.57 | ±341.29 | 1595.93 | 2227.21 |
| P-value** | 0.000HS | | | | |

-** P-value for comparison between groups (independent t test), and it is conceded to be statistically significant if the P value ≤ 0.05. HS =highly significant (p-value ≤ 0.001)

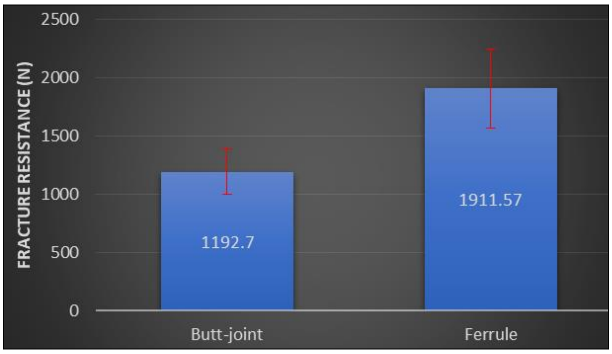


**Fig 7:** Bar chart representing fracture resistance mean value for the butt joint and ferrule groups

**Table 2:** Comparison of the Failure Mode between the two groups:

| Groups | Repairable | | Irreparable | |
|---|---|---|---|---|
| | % | Count | % | Count |
| Butt-joint | 85.72% | 6 | 14.28% | 1 |
| Ferrule | 28.6% | 2 | 71.4% | 5 |

## Discussion

Historically, metal or fiberglass post, core, and crown restorations have been used to repair premolar teeth that have significantly lost coronal tooth structure. Concerns with this technique include the possibility of root weakening or even perforation as a result of the sound tissue being removed from the root canal to facilitate room for the post [25].

Furthermore, in recent years, there has been debate concerning the usefulness of a post in the root canal for the overall retention of the restorations [26]. Bonded ceramic restorations are now preferred to traditional crowns since they don't require macro-mechanically destructive preparations as a result of enhanced dentin adhesive and new ceramic materials that have been developed [10]. Moreover, by conserving sound dental tissue and root canal, endocrown preserves the tooth [27].

Cerasmart is a hybrid nanoceramic material with unique properties such as lower brittleness, greater flexibility, stress absorption properties and the ability to adjust the surface easily, for all these benefits, cerasmart was chosen [28].

Previous studies have found that premolar teeth showed challenges in endocrowns when compared to molar endocrowns in terms of occlusal force action and bond strength, which may be related to the reduced surface area of the pulp chamber [8]. Skupien *et al*. stated that higher survival rate was not related to the presence of a ferrule in case of anterior and molar teeth, while it is obvious that the existence of a ferrule has a direct impact on premolar survival [29].

The first null hypothesis was rejected, results showed that the hybrid nanoceramic (cerasmart 270) endocrowns with ferrule had higher mean fracture resistance values (1911.57±341.29 N) than the hybrid nanoceramic (cerasmart 270) endocrowns with butt joint design (1192.70±196.04 N) and the mean difference was highly statistically significant. It can be attributed to increasing the retention micro-mechanically and macro-mechanically. Also, it has been reported that ferrule with 2mm vertical height doubles the resistance to fracture than teeth restored without ferrule and provides a greater amount of dentin for redistribution of force [30].

Another possibility could be related to stress distribution. The stress concentration was higher in the teeth without ferrule. With a ferrule, stress was distributed evenly along the coronal and radicular parts, with no stress concentration. Finite element analysis confirmed a beneficial ferrule effect on stress distribution which affected the mechanical behavior of the teeth and the failure mode of the restorations [31]. By increasing the adhesive surface area between abutment teeth and endocrowns, force transmission to the dental abutment was improved [32, 33].

The high mean fracture resistance values of endocrowns with axial extension are going well with Abdel-Aziz and Abo-Elmagd, who concluded that the fracture resistance of endodontically treated mandibular premolars is increased by the presence of the ferrule in both endocrown and post, core and crown than that without ferrule [24]. The results of this study were in harmony with other studies, Taha *et al*. and Elsaid *et al*., who found higher fracture loads for endocrowns with ferrule and shoulder finish line as compared to endocrowns with butt joint [34, 35]. The results of Adel *et al*. were also in harmony to our results, who reported that endocrown with 1mm ferrule exhibited higher fracture resistance than butt joint endocrown in upper premolars [19]. This outcome was also consistent with Hassan *et al*. who reported that endocrown with 1.5mm ferrule showed higher fracture resistance than endocrowns without ferrule [36]. Another research implies our findings by Ahmed *et al*. who reported that the design with circumferential ferrule preparation increased fracture values for the two different treating modalities (post, core, crown and endocrown) with two different ceramic materials (zirconia and lithium disilicate) [37].

On the other hand, some studies were in disagreement to our results, Chang *et al*. and Biacchi *et al*., reported that since enamel is preferred to dentin for bonding, producing a ferrule may result in loss of sound enamel and hence impaired bonding strength. The difference in the results may be due to the difference in methodology and the material used, Chang *et al*. used Pro-CAD which is leucite reinforced ceramic blocks rather than hybrid nanoceramic cerasmart 270 in this study, and Biacchi *et al*. compared between endocrowns and post & core supported crowns in molars [38, 39].

Furthermore, Al-khafaji and Jasim stated that endocrown with butt joint preparation in maxillary first premolar had higher fracture resistance than ferrule design. This disagreement may be related to the type of restoration used in their study. They used lithium disilicate but in this study we used hybrid nanoceramic material which has different mechanical properties [40]. Our study's findings were also in conflict with Naji *et al*. who stated that fracture resistance of maxillary first molar restored with endocrowns with butt joint design using hybrid nanoceramic cerasmart 270 had higher fracture resistance than endocrown with 2mm ferrule design. The disagreement could be attributed to the difference in the type of the tested teeth, as the performance of molars under load differs than that of premolars [15]. Moreover, because the crown height proportion relative to the tooth width is higher in premolars as compared to molars, this anatomical variation increases the lever effect in premolars. Adding ferrule decreased the lever effect and enhanced the fracture resistance [41].

The second null hypothesis was also rejected. Endocrown with butt joint design showed a high percent of repairable failures. This pattern of failure was further supported by Al-shibri and Elguindy, who compared endocrown with butt joint preparation using two materials; hybrid nanoceramic cerasmart and lithium disilicate. The results showed that endocrown made from hybrid nanoceramic had 70% repairable fractures to only 30% of irreparable fractures apical to the CEJ [14].

On the other hand, the results of our study showed a high proportion of catastrophic failure for ferrule design compared to butt joint design. This mode of failure was in agreement with Einhorn *et al*. who reported in their study that 2mm ferrule endocrown preparations showed a catastrophic failure. The endocrown with 1 mm ferrule showed fewest catastrophic failures compared to 2mm ferrule. As a result, regardless of ferrule height, endocrowns had a high percentage of irreparable failures [32].
One of the limitations of this study, being an *in vitro* study which cannot simulate all oral environments. Furthermore, unlike in dynamic occlusion which the force is applied laterally, the fracture test in this study was performed using compressive mode of load applied occlusally.
Endocrowns restoring extensive tooth structure loss of endodontically treated premolar teeth is a viable treatment option from the static mechanical point of view. Both butt joint and ferrule design can withstand high occlusal loads. It is of great importance to analyze the mode of failure as this may be a key deciding factor when selecting the proper line of treatment in different situations.

## Conclusion
Within the limitations of this *in vitro* study, it was concluded that:
1. All fracture resistance loads obtained in the two designs were far beyond the maximum masticatory forces.
2. Endocrowns with ferrule design showed a higher fracture resistance in comparison to endocrowns with butt joint preparation design.
3. Endocrowns with ferrule design showed a high percent of catastrophic failure mode but at loads larger than the normal masticatory forces.
4. Endocrowns with butt joint design showed mostly repairable mode of failure at loads larger than the normal masticatory forces.

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## Conflict of Interest
The authors have no proprietary, financial, or other personal interest in any of the products, services, or companies mentioned in this article.

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