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Original Research Article

Fracture Resistance of CAD/CAM Endocrowns: Resin Nano Ceramic vs Translucent Zirconia

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ABSTRACT

Purpose: To examine the fracture resistance and fracture modes of Prettau Highly Translucent Zirconia and Resin Nano Ceramic Lava Ultimate CAD/CAM endocrowns versus post and core supported CAD/CAM crowns in endodontically treated extremely damaged maxillary molars.
Methods: Twenty maxillary first molars of similar size and shape were selected. The teeth were all decoronated and endodontically treated, then they were randomly divided equally into four groups (5 each) as follows; Group I: Five teeth restored by post and core supported Prettau Highly Translucent Zirconia (PZ) crowns. Group II: Five teeth restored by PZ endocrowns. Group III: Five teeth restored by post and core supported Resin Nano Ceramic Lava Ultimate (LU) crowns. Group IV: Five teeth restored by LU endocrowns. All specimens were scanned, designed and milled using ZirkonZahn CAD/CAM 5 Tec machine. After cementation, all specimens were thermocycled, then they were subjected to fracture resistance test and fracture mode analysis. The data were collected, tabulated and statistically analyzed.
Results: Group I exhibited the highest fracture resistance followed by group IV then group III while group II exhibited the lowest fracture resistance. Groups I and II resulted in unfavorable unrestorable failures while Groups III and IV resulted in favorable restorable failures.
Conclusions: Endocrowns can be used as a conservative clinical alternative for restoring severely damaged endodontically treated posterior teeth. Resin composites seem to be the material of choice to build-up endocrown restorations.
Clinical Significance: Restoration of extremely damaged and endodontically treated teeth present a critical and time consuming clinical situation.

Keywords: Translucent Zirconia, Resin Nano Ceramic, Endocrowns, CAD/CAM Technology.

INTRODUCTION

One of the greatest challenges facing prosthodontists is the reconstruction of severely damaged and endodontically treated teeth [1, 2]. Generally, endodontically treated teeth suffer from reduced fracture resistance when compared to vital ones [3]. This is mainly due to loss of tooth structure caused by caries, trauma, or extensive cavity preparation associated with dehydration or physical changes that occur in dentin [4-6]. Therefore, the longevity of an endodontic treatment depends on the selection of an appropriate restoration as well as selection of appropriate restorative material [7].

Restorative approaches used to reconstruct endodontically compromised teeth is controversial [1, 2]. Classically, the tooth is built up using a post and core then covered by a full-crown with a sufficient ferrule [8,9]. Although, a ferrule with 1 mm vertical height increases the fracture resistance of the tooth [10], posts may increase the risk of damage to the remaining tooth structure [11] including risk of accidental root perforation during post space preparation [1].

The introduction of endocrown restorations together with modified adhesive techniques and ceramic materials provided an alternative treatment to avoid possible operational errors during post space preparation. Moreover, adhesive restorations do not need a macroretentive design if there are sufficient tooth surfaces for bonding. Also, creating a ferrule, with the adhesive technique, is considered a drawback due to loss of the natural tooth structure [1,2].

Endocrowns require a minimally invasive preparation following a caries-oriented design concept, thus preserving a maximum amount of tooth structure. This preparation includes a circular butt-joint margin and a central retention cavity inside the pulp chamber, where both the crown and core are constructed as a single unit. The rationale behind endocrown restoration is to make use of the whole available pulp chamber to provide stability and retention of the restoration through adhesive bonding. Computer-aided design/computer-aided manufacturing (CAD/CAM) systems provide the possibility of chair-side designing and milling these single-unit restorations [1,2].

Innovative CAD/CAM technologies have introduced new systems for dental restorations [12]. Unfortunately, zirconia has an opaque milky appearance and causes excessive wear of opposing teeth which limited its clinical use greatly. Recently, to overcome this limitation, highly translucent zirconia blocks (Prettau, ZirkonZahn, Italy) were introduced into the dental market. Using a special coloring method, Prettau Zirconia is able to eliminate the use of veneer ceramics entirely and provide a full-zirconia restoration with clinically acceptable esthetics. Furthermore, according to the manufacturer, Prettau Zirconia is characterized by good density and remarkable smoothness thus does not cause any wear of opposing natural tooth structure. In contrast, veneer ceramics cause wear of natural teeth due to their highly porous structure. It is true that the flexural strength of Prettau Zirconia is 10% less than classic zirconia but this is compensated by using it in increased thickness since there is no need to provide space for veneer porcelain [13].

Resin Nano Ceramic (Lava™ Ultimate CAD/CAM Restorative, 3M ESPE, Germany) is a recent generation of resin composite blocks introduced for CAD/CAM processing after the continuous search for biocompatible materials having the same physical properties as natural dentition [3,12]. This type of composite is a direct result of both nanotechnology[14] and resin technology to provide a combination of strength and esthetics, making those blocks better than feldspathic ceramic or other composite blocks [15].

To date, there is still a controversy about which material or technique can optimally restore endodontically treated teeth. Therefore, the aim of this study was to examine the fracture resistance and fracture modes of Prettau Highly Translucent Zirconia and Resin Nano Ceramic Lava Ultimate CAD/CAM endocrowns versus post and core supported CAD/CAM classical crowns in severely damaged and endodontically treated maxillary molars. There were two null hypotheses: 1) The fracture resistance of restored severely damaged and endodonticaly treated teeth is not affected by type of treatment modality. 2) The material used to restore severely damaged and endodonticaly treated teeth does not affect the fracture resistance of restored teeth and their restorability after fracture.

MATERIALS AND METHODS

Freshly extracted 20 non-carious human maxillary first molars were collected according to the protocol approved by the

Human Research Committee, King Abdulaziz University, KSA. All teeth were examined for absence of root caries, root fillings or root cracks. The teeth were selected to be of similar size and shape regarding root length and crown dimensions. The bucco-lingual and mesio-distal widths at the CEJ were measured in millimeters using a graduated caliper (0-25 mm, 0.01 mm, Germany). The teeth were cleaned and stored in 0.5% Chloramine T solution at 4 ◦C for a maximum of one month until the experiment began. All teeth were decoronated, 2mm above the level of proximal CEJ, using a diamond disc (Diamond discs 910P, Drendel+Zweiling DIAMANT Gmbh, Germany).

Root canal instrumentation of all selected teeth was done using step-back technique with K-files (Mor-Flex K-Type File, Moyco Union Broach, York, PA 17402). Obturation of the canals was done with gutta-percha (Meta Dental Co., Ltd. Korea) and sealer (AH-26, Dentsply Detry GmbH, Konstanz, Germany) using lateral condensation technique.

The endodontically treated teeth were randomly divided equally into four groups (5 specimens each), as follows:

Group I: Five endodontically treated teeth restored by fiber reinforced composite posts (Rely X Fiber Post, 3M ESPE, Germany) and resin composite cores (Filtek Z250, 3M ESPE, Germany) then covered with full coverage Prettau highly translucent zirconia ("PZ", Zirkon-Zahn, Italy) crowns.

Group II: Five endodontically treated teeth restored by PZ endocrowns.

Group III: Five endodontically treated teeth restored by fiber reinforced composite posts and resin composite cores then covered with full coverage Resin Nano Ceramic Lava Ultimate ("LU", 3M ESPE, Germany) crowns.

Group IV: Five endodontically treated teeth restored by LU endocrowns.

The chemical composition and the manufacturers of the materials used in this study are presented in table 1.

In groups I and III, post spaces were prepared in the palatal canal of all selected teeth to a depth of 10 mm ±1mm. All post spaces were prepared to the same depth to eliminate variables caused by differences of post length. The gutta percha was removed from inside the canal using gates glidden drill #3 (Dentsply-Maillefer Instruments SA, Ballaigues, Switzerland) to the previously decided depth. The post space preparation was completed using Rely X fiber post special drill (3M ESPE, Germany) and was prepared to receive Rely X fiber post size #2 (diameter 1.6 mm). Before cementation, the canals were irrigated with NaOCl, rinsed with water and then air-dried. The posts were cemented with self-adhesive Rely X UniCem resin cement (3M ESPE, Germany) which was mixed and applied according to manufacturer’s instructions. The cement capsule was mixed in a high frequency mixing unit (deGotzen, Italy) for 15 seconds, then the cement was introduced inside the canals and the posts were seated. Excess cement was removed then light polymerization was performed for 40 seconds from the coronal direction over the post using light curing unit (Mini LED, 1250 mW/cm^2, Satelec, Acteon).

Core build-ups were done using Filtek Z250 resin composite (A3). The cores were built in increments of 2mm which were light-cured for 20 seconds. The final height of the composite cores was adjusted to be 4 mm, so that the coronal parts of all the samples were standardized at the same height (Fig.1).

All the samples of groups I and III were prepared for full coverage all-ceramic crowns [16, 17]. The finish line was designed to be chamfer finish line with 1mm depth placed 1.5 mm apical from core/dentin junction to provide ferrule effect. The preparation of all samples was performed using a diamond stone (Diamond instruments 856P, Drendel Zweiling Diamant GMBH, Germany) at high speed with water spray, the diamond stone was specially designed with a central non-cutting shaft so that the thickness of the finish line can be standardized for all the samples.

In groups II and IV, all samples were prepared to receive endocrowns. The preparation was designed with circular butt margin 2 mm above cement-enamel junction (CEJ) and a central cavity with a standardized depth and wall thickness [1,7] as shown in figure 2.

All samples of this study were prepared by the same operator. For group I and II, both the classical crowns and the endocrowns were milled from Prettau Highly Translucent Zirconia ceramic blocks while for group III and IV, Resin Nano-Ceramic Lava Ultimate blocks were used for classical crowns and endocrowns construction. All samples were scanned, designed and milled using ZirkonZahn CAD/CAM 5 Tec machine (ZirkonZahn, Italy).

All crowns and endocrowns were cemented using self-adhesive Rely X Unicem resin cement. The fitting surfaces of the crowns and endocrowns were blasted with aluminum oxide ≤ 40μ, then the blasted surfaces were cleaned with alcohol and dried with water- and oil-free air [15,18]. Rely X Unicem capsule was mixed in a high frequency mixing unit for 15 seconds, then the cement was applied to the fitting surface of the restoration. All crowns and endocrowns were seated with light finger pressure [1,19], and excess cement was removed. Light curing was activated on buccal, lingual, mesial, distal and occlusal surfaces for 20 seconds for each surface.

All specimens were subjected to 2000 thermal cycles between 5°C and 55°C (Willytec thermocycler, Germany) with a dwell time of 30 seconds in each bath. Then, the teeth were vertically mounted in epoxy resin blocks such that the crowns remained free of the acrylic, and the roots were covered to a height of 2 mm below the CEJ (which is approximately the level of alveolar bone in a healthy tooth) [1]. Before testing, all specimens were stored in distilled water for 24 hours at 37±1°C in an incubator (Foc Incubator, Japan).

The fracture resistance was determined by mechanically loading the specimens to failure in a universal testing machine (Model LRX-plus; Lloyd Instruments Ltd., Fareham, UK). A compressive load was applied along the long axis of the specimens with a hardened steel sphere (Fig. 3) at a crosshead speed of 1 mm/min. Fracture resistance was recorded in newtons (N). The fractured specimens were observed with naked eyes to establish the failure modes, which were classified as favorable or unfavorable failures. “Favorable failures” were defined as restorable failures occurring above the level of bone simulation. On the other hand, “unfavorable failures” were defined as un-restorable which are catastrophic failures occurring below the level of bone simulation, including vertical root fracture or extensive damage [20].

Statistical Analysis

Statistical Package for Social Sciences (SPSS) vs. 17 were used to perform data management and analysis. Comparisons between the different groups were done using the Kruskal-Wallis test followed by the post hoc Bonferroni [21]. All p-values are two-sided. P-values < 0.05 were considered significant.

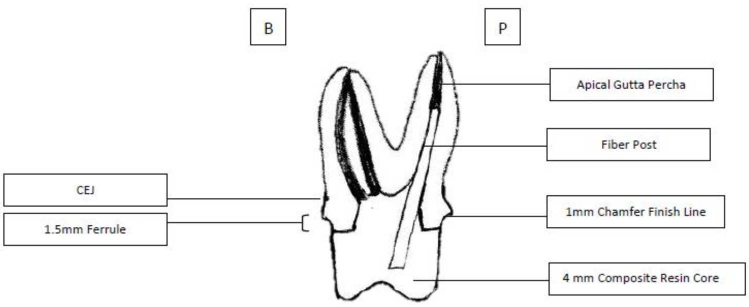

Fig (1): Schematic drawing of the standardized tooth preparation for post and core supported crowns.
P= Palatal Root, B= Buccal Roots.

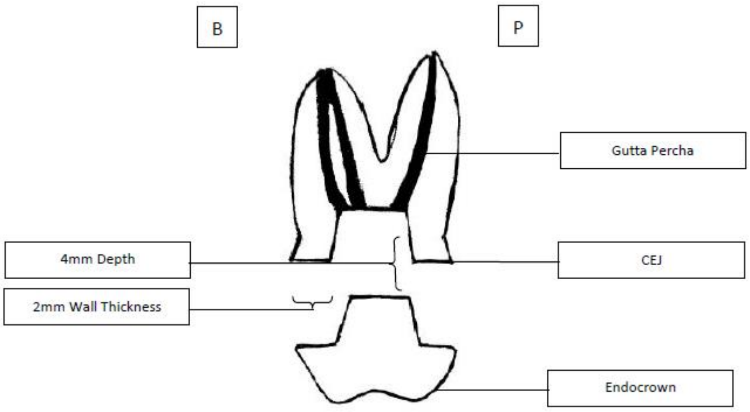

Fig (2): Schematic drawing of the standardized tooth preparation for endocrowns. *P= Palatal Root, B= Buccal Roots.*

Fig (3): Schematic diagram showing the relationship between the loading element and the tested crown. The loading element is presented by red color, the tested crown is presented by the yellow color while the abutment tooth is presented by the white color.

Table (1): Chemical composition and manufacturers of the materials used in this study.

Material	Composition	Manufacturer
Prettau Highly Translucent Zirconia "PZ"	Zirconium oxide (70-97%), Aluminium oxide (<1%), Yttrium oxide (<6%), Hafnium oxide (<5%).	Zirkon-Zahn, Italy
Resin Nano Ceramic Lava Ultimate "LU"	Total nanoceramic material content is 80% by weight: silica nanomers (20 nm), zirconia nanomers (4 - 11 nm), zirconia-silica nanocluster particles (0.6-10 µm). Highly cross-linked methacrylate-based resin matrix Silane coupling agent	3M ESPE, Germany
Rely X Fiber Post	Unidirectional glass fibers (60-70 wt %), epoxy resin matrix containing zirconia fillers (30-40 wt %).	3M ESPE, Germany
Filtek Z250 Resin Composite (A3)	Bis-GMA (Bisphenol A diglycidyl ether dimethacrylate), UDMA (urethane dimethacrylate), Bis-EMA(Bisphenol A polyethylene glycol diether dimethacrylate), 60 vol% Silica/Zirconia (0.01-3.5 µm) with average size 0.6 µm.	3M ESPE, Germany
Rely X Unicem Resin Cement	Powder: Alkaline (basic) fillers, silanated fillers, initiator components, pigments. Liquid: Methacrylate monomers containing phosphoric acid groups, methacrylate monomers, initiator components, stabilizers	3M ESPE, Germany

RESULT

Fracture Resistance:

The mean, standard deviation (S.D.), and minimum and maximum fracture resistance of the four tested groups are shown in table 2 and figure 4. Group I exhibited the highest fracture resistance (2727 N ± 77) followed by group IV (2223 N ± 101) then group III (1788 N± 67) while group II exhibited the lowest fracture resistance (1586 N ± 52).

Table (2): Fracture resistance of the four tested groups expressed in Newtons.

Groups	N	Characteristics	Mean	S.D.	Minimum	Maximum
I	5	Prettau Zirconia "PZ" crown + post and core	2727 a	77	2634	2805
II	5	Prettau Zirconia " PZ" endocrown	1586 d	52	1546	1667
III	5	Lava Ultimate "LU" crown + post and core	1788 c	67	1733	1894
IV	5	Lava Ultimate "LU" endocrown	2223 b	101	2130	2390

Group means having different letters are significantly different from each other. Overall p-value < 0.001.

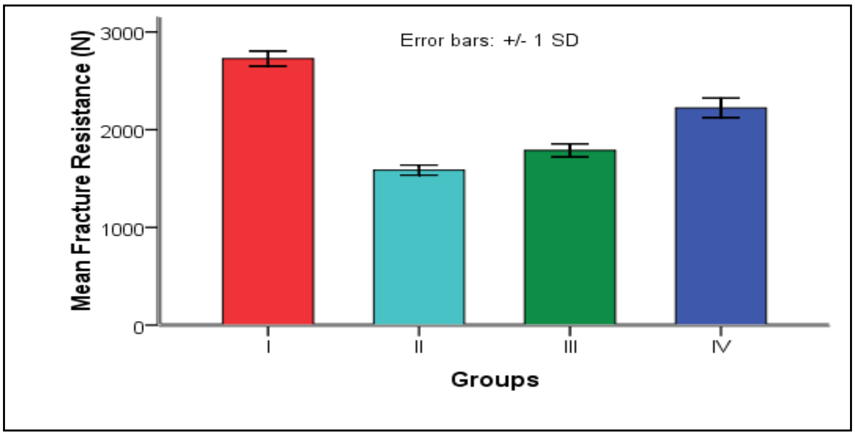

Fig (4): Fracture Resistance of the four tested groups expressed in Newtons.

Fracture mode analysis

Figures 5-8 show representative fractured specimens from each of the four tested groups. Group I (post and core supported PZ crown) and group II (PZ endocrown) resulted in unfavorable failures while Group III (post and core supported LU crown) and group IV (LU endocrown) resulted in favorable failures.

Fig (5): Fracture mode of a representative sample of group 1 (post and core supported Prettau Zirconia crown) showing root involvement (unrestorable, unfavorable failure).

Fig (6): Fracture mode of a representative sample of group II (Prettau Zirconia endocrown) showing root involvement (unrestorable, unfavorable failure).

Fig (7): Fracture mode of a representative sample of group III (post and core supported Resin Nano Ceramic Lava Ultimate crown) leaving the tooth intact (restorable, favorable failure).

Fig (8): Fracture mode of a representative sample of group IV (Resin Nano Ceramic Lava Ultimate endocrown) leaving the tooth intact (restorable, favorable failure).

DISCUSSION

The idea of using and rapid shaping ceramic blocks of high optimized qualities to restore damaged teeth has challenged great advances in CAD/CAM technology using the CEREC method. [7] During the past decades, the CAD/CAM grinding system was modified to provide a more flexible shaping technique to help custom shaping and precise milling of ceramic restorations. Moreover, the fitting surfaces of the restorations became more fitting and the outer surfaces had better morphology. Also, endocrown restorations can be done and cemented in a single visit.

Unfortunately, there were some clinical obstacles as limited depth of the optical impression to record the pulp chamber and in some cases part of the root canal [1]. This obstacle may result in a blurred image which may affect the accuracy of the final restoration. Mormann and Bindl [22], demonstrated great improvements in the CEREC 3D intra-oral scanning camera of the CEREC 3D unit, where the depth scale is extended to about 20 mm, thus, overcoming this limitation.

The current study simulated extensively damaged and endodontically treated maxillary molars. These teeth were classically treated by crowns with sufficient ferrule and supported by a post-and-core [8,9]. A ferrule with 1 mm vertical height doubled the resistance to fracture when compared to teeth restored without a ferrule[10]. In contrast, Gegauff, reported that crown lengthening to create a ferrule decreased the static failure load due to reduced cross section of the preparation together with an altered crown-to-root ratio [23]. Moreover, to create a sufficient ferrule, sound tooth structure is lost mainly enamel which may compromise bonding strengths as enamel provide stronger bonding than dentin [1]. Furthermore, endodontic posts create unnatural restored structures as the root canal is filled with a material that has a specific stiffness different than the pulp tissue. Therefore, recreating the original stress distribution within the natural tooth is not applicable. However, it was reported that glass fiber posts were able to provide the best stress distribution within restored teeth as their physical properties are very close to dentin and thus have demonstrated excellent clinical performance. Moreover, their use in conjunction with advanced adhesive systems provided good bonding to root canal walls, thus allowing an accurate post fit and conservative root preparations [3, 24, 25].

On the other hand, endocrowns beside decreasing the need for macroretentive features and thus preserving maximum possible tooth structure, they save time and reduce expenses required for post and core procedure [1,7]. Lin et al,[7] stated that CEREC endocrowns provide a clinically acceptable and an efficient alternative to post and core restoration. Furthermore, Bindl et al [26] and Salameh et al [27], reported that the overall failure rate of endocrowns was similar to classical crowns.

The restorative material itself plays an important role in the success of any restoration. It is still controversial whether the modulus of elasticity of the restorative material should be high or low. Rigid restorations, if properly bonded, will distribute the load uniformly and strengthen the remaining tooth structure, however, if the tooth is overloaded, a vertical or deep root fracture may occur. On the other hand, a flexible restoration may bend when overloaded, resulting in loss or failure of the restoration, but would leave the root intact for retreatment [2].

Since thermal cycling is an important factor in regard of the clinical performance of restorations, the specimens of the four tested groups of the present study were subjected to thermal cycling. Thermal cycling creates stresses at the interfaces between dentin, cement, and resin composite or zirconia; however, it has been shown that additional mechanical loading does not decrease the fracture resistance of resin composite crowns [28,29].

The results of this study show that PZ classical crowns (group I) provided significantly the highest fracture resistance. Higher elastic modulus crown materials significantly affected the mechanical behavior of the restored teeth [30]. Due to the high stiffness of zirconia crowns, limited strain occur in the coronal portion of the specimen with increased stress while there is lack of stress in the core portion [3] which may be the cause for the high fracture loads. However, the fracture resistance of PZ endocrowns (group II) was significantly lower than PZ crowns covering the post and core restored molars. This may be attributed to the sudden jump in mechanical properties at the junction between dentin and zirconia which resulted in high stress concentration at the interface especially at the cervical region, the weak point of a restorative system, due to great difference in their moduli of elasticity. This was in agreement with several studies [1,2,3,12]. Moreover, the stress concentration at the interface was further aggravated by the weak bond strength between zirconia and resin cements that could eventually lead to undesirable consequences [2].

However, the insertion of fiber posts increases the stiffness of the root and thus decreases the mismatch between the zirconia and the dentin and consequently decreases the stress concentration allowing for better distribution of stresses [31]. Furthermore, using low stiffness glass fiber posts may act as a shock absorber and possibly reduce stresses which might have resulted in higher fracture loads. This was in agreement with Govare N and Contrepois M [3] Ausiello P et al.[24] and Salameh Z et al. [27].

The differences in modulus of elasticity of ceramic, cement and dentin may cause a risk of root fracture [1,2]. This was supported by the fracture mode analysis of this study that shows root fracture in both groups restored by Prettau zirconia (Fig. 5 and 6). The vertical force applied to the tooth may easily cause a root fracture which implies that a significant amount of force was transmitted to the root. Clinically, tooth fractures occur quickly and accidentally which would lead to more severe fractures. Root fracture present a very critical case for clinical repair where extraction may be a better treatment option [1,2,7].

Regarding Lava Ultimate material, the endocrown restorations (group IV) showed significantly higher fracture resistance than the classical crowns covering the post and core restored teeth (group III). This may be attributed to the fact that the endocrown makes the restored tooth similar to a monoblock as it eliminates the effect of multiple interfaces within the restorative system. Several researches were in agreement with the results of this study [1,2,7]. Moreover, Zarone et al stated that usually interface imperfections are randomly distributed and influence stress distribution in localized areas [3]. Belli et al stated that the higher the number of adhesive interfaces within finite element analysis models, the higher the stresses [32].

Furthermore, using an endocrown, with its monoblock effect, constructed from a material having a similar elastic modulus to dentin allows the whole restorative system to undergo similar deformation as the sound tooth and thus distribute stresses along the whole restored tooth [3]. Therefore, the design and the constructing material help endocrowns to restore structural integrity and strength of extremely damaged and endodontically treated teeth [1,12]. Moreover, the presence of a ferrule might have caused the reduction of fracture resistance of the classic crown in comparison to endocrowns [1].

A point of concern is the influence of adhesion at the interface between different materials on the distribution of stresses [2]. It can be speculated that the bonding between the resin cement and Lava Ultimate restorations is much better than that to zirconia ones. This is related to the similarity in the chemical nature of the matrices of both the resin cement and the lava Ultimate which might have resulted in better stress distribution along the interfaces.

The data accumulated from this study helped us determine that endocrowns were capable of supporting compressive loads superior to posterior masticatory forces. The maximum forces encountered in the molar region is 847 N for men and 597 N for women [33].

To summarize, endocrowns, comprising both the crown and core as a single unit, was suggested to provide a monoblock effect. This is a restorative concept based on the biomimetic feature which allows the restoration to form a structurally and mechanically homogenous complex with dentin[1,2]. When the monoblock system is subjected to occlusal loads, the whole system will deform uniformly and the generated stresses will be distributed along the whole system decreasing the stresses transferred to the vulnerable tooth structure. Thus, two important factors should be available to provide a monoblock effect, first; the elastic modulus of the restoration should be as close as possible to the tooth structure, second; proper bonding is essential between the restorative material and the dentin. Consequently, the restorative material used to construct the endocrown is the main factor for providing the monoblock effect. According to the results of this study, Lava Ultimate endocrowns provided a monoblock effect, due to its low elastic modulus and good bonding with dentin, which was clear from the results of the fracture mode analysis (Fig 7 and 8) that show fracture of the lava ultimate restorations leaving the root intact for retreatment (favorable mode of failure). On the other hand, Prettau zirconia did not allow a monoblock effect due to the high elastic modulus compared to dentin and the less efficient dentin bonding which resulted in stress concentration and root fracture (unfavorable failure- Fig 5 and 6). Therefore, development of materials with mechanical properties as similar as possible to natural teeth may decrease the possibility of unfavorable root fractures [1,2].

The first null hypothesis of this study was rejected as the treatment modality used, whether post and core supported classical crowns or endocrowns, significantly affected the fracture resistance of restored severely damaged and endodontically treated teeth.. Also, the second hypotheses was rejected as resin composite material increased the fracture resistance when used for endocrowns construction while zirconia increased the fracture resistance of the restoration system when used for classical crown construction over post and core. Moreover, the failure in the 2 resin composite groups was restorable opposite to both zirconia groups which was unrestorable.

CONCLUSION

Endocrowns can be used as a conservative clinical alternative for restoring severely damaged endodontically treated posterior teeth. Resin composites seem to be the material of choice to build-up such restorations. Long term clinical studies should be performed to confirm the clinical success of endocrown restorations.

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