ORIGINAL RESEARCH

Fracture Resistance of Anterior Teeth Restored with Post-retained Ceramic Crown vs Ceramic Endocrowns

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Abstract

Aim: To compare the fracture resistance of anterior teeth restored with either glass fiber post (GFP) and conventional lithium disilicate (LDS) crowns or endocrowns made of LDS or hybrid ceramics.

Materials and methods: A total of 21 central incisors with 2-mm ferrule and 1-mm shoulder finish line were applied in this investigation. The teeth were divided into three main groups ($n = 7$) according to the type of restoration used: PC glass fiber post (GFP) and e-max crown, EE (LDS endocrown), and VE (Vita-Enamic endocrown). Mechanical cyclic loading was conducted in a chewing simulator to simulate 6 months of clinical use. Fracture resistance and failure mode were assessed; further examination of fractured specimens was done with scanning electron microscopy.

Results: *Post-hoc* Tukey's test was performed to investigate the pairwise differences in fracture resistance among the three groups, and the results were $p = 0.0452$ between PC and VE groups, which is significant statistically. In contrast, $p = 0.0615$ between PC and EE groups, which is not significantly different. Chi-square test was made to analyze the results of mode of failure among the three groups, and there was a significant difference; p-value = 0.0289.

Conclusion: The LDS endocrowns show fracture resistance similar to that of GFP-supported full coverage LDS crowns, with advantage of more restorable mode of fractures. Vita-Enamic endocrowns, despite having fracture resistance lower than other groups, showed fracture resistance higher than the physiologic load, with restorable fractures more than both LDS endocrowns and GFP LDS crowns.

Clinical significance: For dental practitioners, endocrowns in damaged anterior endodontically treated teeth provide similar fracture resistance to GFP and full crowns, with the advantage of more restorable fractures if occurred.

Keywords: Endocrown, Glass fiber post, Lithium disilicate, Vita-Enamic.

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Introduction

Restoration of extensively damaged endodontically treated teeth remains a challenge. This challenge becomes more complicated when there is a significant loss of the coronal tooth structure.[1] Residual tooth structure is a key determinant in tooth survival.[2] There is a lack of defined guidance on the most appropriate definitive restoration following the completion of root canal treatment, particularly anterior teeth that have experienced significant loss of its coronal structure.[3] Literature has focused on the optimal way to restore badly decayed posterior teeth, but this study paid attention to what is optimal in restoring badly decayed anterior teeth in esthetics, function, and forces challenging area.

Intraradicular posts in endodontically treated teeth were initially intended to retain the core material.[4] Although they showed clinically satisfactory results concerning improving fracture resistance of endodontically treated maxillary incisors and have been used for decades, the use of post-retained restorations has been questionable because of potential tooth weakening.[5,6] Also, the choice of post material with a low or high modulus of elasticity does not prevent catastrophic failures in endodontically treated teeth without a ferrule, indicating that presence of ferrule is way more important than insertion of posts.[7,8]

Recently, improvements in adhesive dentistry opened the way for new treatment options that are more conservative than traditional ones. The endocrown option consists of making the crown with the core as a single unit anchored in the inner portion of the pulp chamber and the large, flat cavity margins, thus obtaining macromechanical retention, provided by the pulp walls, and micromechanical retention, acquired through adhesive bonding. Endocrown restorations require less interocclusal space and reduce the risk of root fracture. Additionally, they eliminate the need for the multiple technical steps involved in post cementation and core buildup.[9]

Lithium disilicate (LDS) glass ceramics have become essential in esthetic and restorative dentistry due to their combination of esthetics and high strength. These ceramics offer excellent esthetics, a flexural strength of 360 MPa, high modulus of elasticity of 95 GPa,

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Table 1: Materials composition

Brand name	*Composition*
IPS e.max CAD	SiO_2 57.0–80.0%, Li_2O 11.0–19.0%, K_2O 0.0–13.0%, P_2O_5 0.0–11.0%, ZrO_2 0.0–8.0%, ZnO 0.0–8.0 %, and coloring oxides
Vita-Enamic	Fine-structure ceramic network (86% by wt.) is strengthened by an acrylate polymer network, with both networks fully integrated

and sufficient bond strength to tooth structures. Despite their benefits, the inherent brittleness and rigidity of dental ceramics remain common causes of restoration failure on endodontically treated teeth.[10] On the contrary, hybrid ceramic restorations also offer promising results concerning bond strength and fracture resistance. This type of material includes both feldspathic ceramic network and a polymer network. They have similar or even higher fracture resistance compared with LDS and tend to exhibit less catastrophic failures. Also, they have modulus of elasticity of 30 GPa, which is closer to that of dentin 18.6 GPa.[11] Both LDS and hybrid ceramics exhibit clinically acceptable properties esthetically and mechanically when restoring anterior teeth.[12–14] After success achieved by endocrowns in posterior teeth, this encourages to try the same treatment option on anterior teeth despite the anatomical differences between anterior and posterior teeth.[15]

Fracture resistance of dental restorations is important for the clinical success of dental prosthetics. It is influenced by various factors, such as the angle and magnitude of the applied load. In the oral cavity, teeth experience forces in different directions depending on their position and function. Anterior teeth, which incise food during mastication, primarily encounter oblique forces. The aim of this study was to compare the fracture resistance of anterior teeth when restored by different treatment options and materials.

Materials and Methods

Study Design

This study was conducted as an experimental and comparative *in-vitro* study.

Study Setting

Tooth preparation, lab work, and fracture resistance testing were done at the Faculty of Dentistry at Al-Azhar University in Cairo.

Study Sample

Using G power statistical power analysis program (version 3.1.9.4) for sample size determination, it was found that a total sample size of 21 (seven in each group) will be sufficient to detect a large effect size of 0.98, with an actual power (1 – β error) of 0.8 (80%) and a significance level (α error) of 0.05 (5%) for two-sided hypothesis test. All 21 specimens in this study were categorized into three main groups according to type of restoration ($n = 7$): group PC (GFP and LDS conventional crown), group EE (LDS endocrown), and group VE (Vita-Enamic endocrown) (Table 1).

Study Sample and Sample Grouping

Total of 21 samples were divided evenly into three groups according to the restoration they received ($n = 7$); GFP and LDS full crown group (PE), LDS endocrown (EE), and Vita-Enamic endocrown (EE).

Specimens Allocation

Twenty-one sound human maxillary central incisor teeth freshly extracted for periodontal reasons were collected. Inclusion criteria included fully formed apices, straight roots, absence of caries or fractures in the crown or root, and similar dimensions of 17 ± 1 mm root length, 6 ± 1 mm labiopalatally, and 7 ± 1 mm mesiodistally. Exclusion criteria included teeth with open apices, curved roots, fractures caries, or beyond the above dimensions.

Teeth were cleaned using an ultrasonic scaler to remove deposits, debris, and soft tissue remnants, disinfected in a 5.25% solution of sodium hypochlorite for 10 minutes, polished using a rubber cup to remove stains, and then stored in incubator at 37°C in distilled water to prevent dehydration until usage.

Endodontic Procedures

Endodontic access was established following standardized procedures for all specimens. Working length was taken with file#10 and periapical X-ray. Mechanical preparation of the teeth was performed using motor driven rotary files (Rogin, Rogin Dental, China) starting with the sequence of orifice opener, 20 0.4, 25 0.4, 30 0.4, and 35 0.4. The canal was irrigated with 5.25% sodium hypochlorite and ethylenediaminetetraacetic acid during the mechanical preparation process. The root canals were then dried with absorbent paper pints and obturated with gutta percha points that were coated with a resin-based sealer (Adseal®, Meta BioMed, Republic of Korea). Pulp chamber access was temporarily sealed with temporary filling, and specimens were stored in distilled water for 48 hours to allow for cement setting.

Teeth were fixed in standardized resin blocks with centralizing dental survey or after being periodontally simulated with addition of silicone light body impression material. A distance of 1 mm was left between the acrylic margin and the cementoenamel junction (CEJ) for handling convenience.

Teeth Preparation

Teeth preparation was done by a single experienced clinician with the aid of a dental surveyor. A low-speed straight handpiece with adaptor was fixed on the dental surveyor, and preparation was done under water spray. A periodontal probe was used to standardize all measures. Teeth were decapitated 2.5 mm above the lowest point in the proximal CEJ (Fig. 1).

Endodontic access was adjusted following standardized procedures to make a triangular-shaped access cavity preparation with 1 ± 0.2 mm ferrule thickness, then prepared with 1-mm thickness shoulder finish line all around located 0.5 mm above CEJ, which leaves a 2-mm ferrule height. The 21 specimens were divided into three groups ($n = 7$) according to type of restorative treatment that will be used; PC, EE, and VE.

Glass Fiber Post Teeth Preparation

The gutta percha was removed, leaving 5 mm apical seal using Gates Glidden drills (Gates Drills, Mani, Tochigi, Japan) and GFP drill (FibreKleer®, Pentron, USA) size 3 with 1.375 mm diameter (green coded) to the desired length (14 ± 1 mm). The posts were silanated (Porcelain Primer, Bisco, USA) and cemented with self-adhesive resin cement (Breeze®, Pentron, USA). Then posts were cut using high-speed contra-angle under copious coolant, leaving 2 mm above the

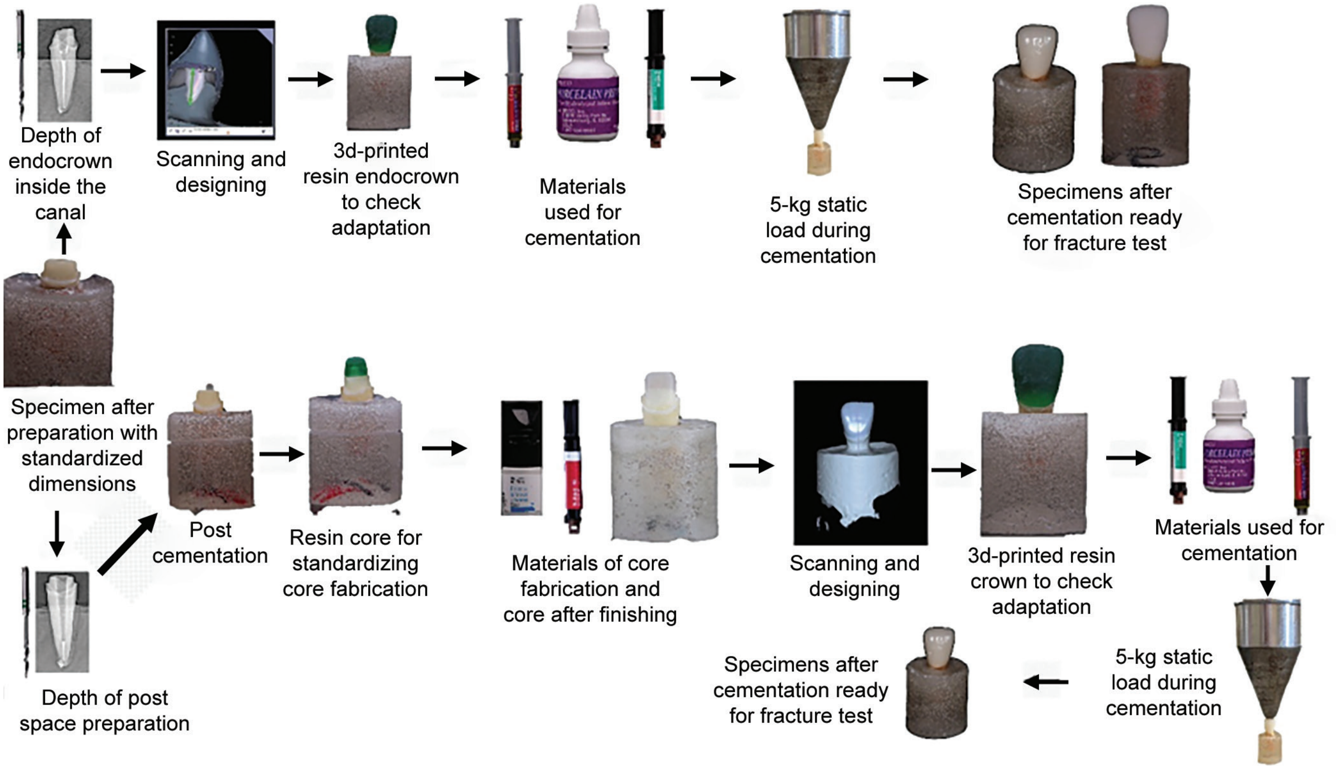


Fig. 1: A schematic flow chart of specimen preparation

ferrule. The specimens were then scanned with Primescan intraoral scanner (Dentsply Sirona, USA), and a resin core with 2 mm height was made with 3D printer (Anycubic photon M3 premium, Anycubic, China). A clear template was made over that resin core to be used as a mold for all specimens in the PC group for standardization. Specimens were etched (Meta Etchant, Meta Biomed, Korea) and bonding agent (Prime&Bond, Dentsply Sirona, USA and Universal adhesive, Bensheim, Germany) was applied. A hole was made in the palatal aspect of the clear template to allow for injecting the build-up material (Build-It^{TM} FR, Pentron, USA) around the GFPs. After injecting, finishing, and polishing; specimens were scanned by intraoral scanner (Primescan, Dentsply Sirona, USA) to acquire the final digital impression and were put into their jars filled with distilled water to prevent their dryness.

Endocrown Teeth Preparation

The gutta percha was removed to a distance 2 ± 1 mm inside the root canal using Gates Glidden drills (Gates Drills, Mani, Tochigi, Japan), and GFP drill (FibreKleer®, Pentron, USA) size 3 (green coded) was used to prepare the endocrown radicular extension. Then the specimens were scanned by intraoral scanner (Primescan, Dentsply Sirona, USA).

CAD/CAM Fabrication of Restorations

The recorded scanning data were transferred as stereolithography files to ExoCAD software (ExoCAD version 3.1 Rijeka). For standardization, upper left central on the ExoCAD software with 10 mm length and 5 mm width was selected for designing and milling all specimens with the same dimensions. For all specimens, cement space was standardized for 50 µm. The block size was C14L for both IPS e.max CAD (Ivoclar Vivadent, Schan, Liechtenstein) and Vita-Enamic (VITA Zahnfabrik). Programill PM7 (Ivoclar Vivadent) was used for milling. After milling, each restoration was checked to fit its corresponding tooth. The e-max specimens underwent crystallization (Programat P15 by Ivoclar Vivadent) and glazing phase (CeraMotion Paste Glaze, Dentaurum GmbH, Germany).

Cementation

The LDS crowns and endocrowns were etched with 9.5% hydrofluoric acid porcelain etching gel for 20 seconds (Meta Etchant), and then rinsed off using air-water spray for 60 seconds, and then cleaned ultrasonically in distilled water bath for 4 minutes and air dried. Silane coupling agent (Porcelain Primer, Bisco, USA) was applied to the etched specimens and dried with air, and then a second coat was applied and left to dry on its own. As for Vita-Enamic, the specimens were treated the exact same way except that they were etched using 5% hydrofluoric acid (Ceramic Etch, Toothmate, Egypt) for 60 seconds.

The prepared teeth were etched using 37% phosphoric acid gel for 15 seconds (Meta Etchant) and then rinsed off using air-water spray for 30 seconds, followed by gentle air drying. A universal adhesive bonding agent (Prime&Bond Elect Universal®, Dentsply Sirona, USA) was applied to the prepared surfaces, rubbed, air-thinned, and light-cured for 20 seconds. Dual-cure resin cement (Breeze®, Pentron, USA) was used to cement the endocrowns. Each endocrown was seated onto its corresponding preparation under a 5-kg continuous load applied vertically using a special loading mechanism, cement was cured for 2 seconds, and excess cement was removed using a sharp explorer, with a final light curing for 20 seconds from each surface. Following cementation, all specimens were stored in distilled water at 37°C for 24 hours.

Table 2: Fracture resistance comparative statistics of anterior teeth restored with PC, EE, and VE

Group	*PC*	*EE*	*VE*
Fracture resistance			
Minimum	202.6	177.8	198.2
Maximum	531.4	314.7	346.3
Mean	355.7	260.8	254.7
Standard deviation	107.4	47.43	45.06

Cyclic Loading

Mechanical aging was performed using a programmable logic-controlled multimodal ROBOTA chewing simulator integrated (Model ACH-09075DC-T, Adtech Technology Co., Ltd., Germany). Each of the four chambers consisted of an upper steel ball as sample antagonist. The specimens were placed in custom-made holding device with a 45° angle. A weight of 5 kg, which is comparable to 49 N of chewing force, was exerted. The test was repeated 75,000 times to clinically simulate 6 months chewing condition. After all specimens underwent chewing simulation, they were put in a testing machine to evaluate their fracture resistance. Pressure on the tip was applied 3 mm below the incisal edge on the palatal surface of the crown at a crosshead speed of 1 mm/minute. The specimens were loaded until fracture, and the maximum breaking loads were recorded in Newtons (N).

Data were recorded using computer software after each sample was placed individually on a computer-controlled materials testing machine (Instron Industrial Products, Norwood, MA, USA) with a load cell of 5 kN. Fractures were classified as the following: restorable fractures (above CEJ) and nonrestorative fractures (below CEJ in the mid or apical portions of root).[16]

Data were checked for distribution using Kolmogorov–Smirnov and Shapiro–Wilk tests. A one-way analysis of variance test was conducted to compare the fracture resistance values across the three groups. To further investigate the pairwise differences in fracture resistance, the researchers performed a *post-hoc* Tukey's test. Additionally, a Chi-square test was used to compare the mode of failure distribution among the three restoration groups.

Results

The highest mean value for fracture resistance was recorded for PC group (355.7 ± 107.4 N), followed by EE group (260.8 ± 47.43 N), with the lowest value recorded in VE group (254.7 ± 45.06 N) (Table 2). The difference between PC and EE groups was statistically insignificant ($p = 0.0615$). In contrast, the difference between PC and VE groups was statistically significant ($p = 0.0452$) (Fig. 2 and Table 2).

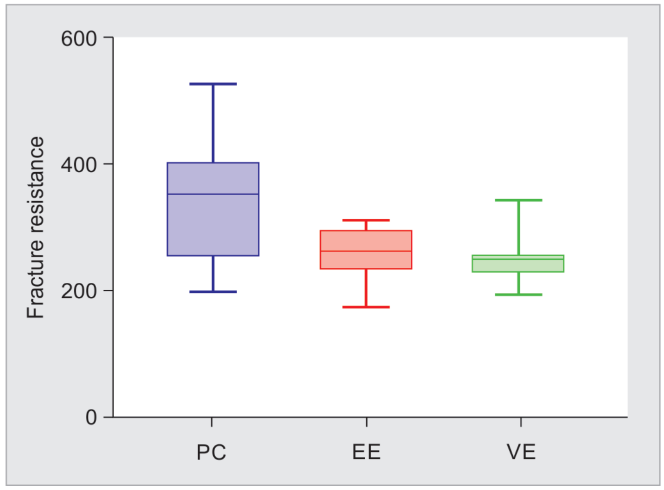


Fig. 2: Box and whisker chart revealing fracture resistance comparative statistics of anterior teeth restored with glass fiber PC, post and e-max crown; EE, e-max endocrown; VE, hybrid endocrown

Failure Mode

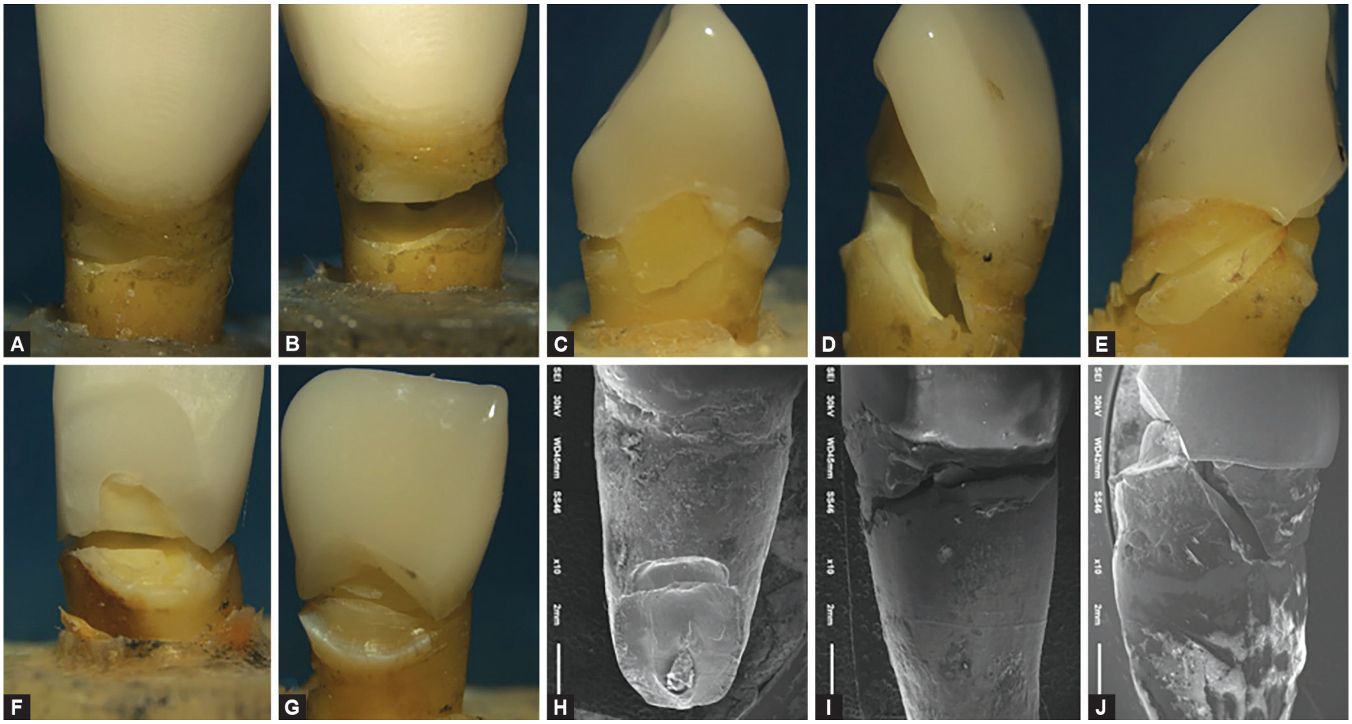
The VE group showed the highest number of restorable failures (six out of seven), and only one sample was unrestorable. The PC group exhibited the highest number of nonrestorable fractures (six out of seven samples), and only one was restorable (debonding). The EE group exhibited a more favorable mode of failure; four were restorable failures and three were nonrestorable failures (Fig. 3).

Discussion

Restoring endodontically treated teeth (ETT) has always posed a challenge for dentists, as incorrect restorative decisions can lead to tooth loss since these teeth often suffer significant structural loss.[17] However, advancements in adhesive dentistry and improvements in restorative materials characteristics and their manufacturing processes have enabled restorations to help restore the integrity of treated teeth by conserving more tooth structure compared with traditional methods.[18]

The choice of material for endocrowns significantly impacts biomechanical stress distribution and the longevity of endodontically treated teeth. The LDS is considered one of the best restorative options due to its excellent optical properties, high fracture strength, and adhesive capabilities, which helps in preserving more tooth structure which is deeply needed in ETT. Also, its translucency can mimic the natural tooth color, making them ideal for anterior restorations.[19] Hybrid ceramics can be considered as an alternative restorative material as it has similar characteristics when compared with LDS. Resin-based ceramics may have similar fracture resistance compared with LDS and tend to exhibit less catastrophic failures since they have modulus of elasticity of 30 GPa, which is closer to dentin which is 18.6 GPa than that of LDS which is 95 GPa.[11]

Based on the results of the current study, there was no significant difference between teeth restored with GFPs and conventional LDS full-coverage crowns and teeth restored with LDS endocrown restorations. This may be explained by the fact that anterior teeth restored with post and cores distribute occlusal forces along the length of the root, reducing stress concentrations at the crown–root interface efficiently and the modulus of elasticity of GFPs closely matches that of dentin, allowing them to absorb and dissipate forces more effectively.[20,21] On the contrary, anterior teeth restored with LDS endocrowns have greater thickness occlusally which is not present in conventional crowns, and they have less interference surfaces (single block), which reduces internal stresses among interfaces and thus reduces failures.[22,23] Also, they behave like short posts. Several studies found that post length or extension in the root canal insignificantly affects fracture resistance of the restored teeth.[16,22,24] This agrees with other studies that found that there were no significant differences in fracture resistance between anterior teeth restored with GFP and e-max crowns and e-max endocrowns.[22,23,25–28] However, this disagrees with a study



Figs 3A to J: (A and B) Stereomicroscopic pictures showing nonrestorable fractures of VE specimen; (C) EE specimen; (D and E) PC specimen and restorable fracture; (F) VE specimen; (G) EE specimen, and screenshots from electron microscopy showing nonrestorable fractures of (H) PC specimen; (I) VE specimen; (J) EE specimen

by Silva-Sousa et al.[3] who stated that fracture resistance of teeth restored with GFP is significantly higher than that restored with endocrowns.[29] This may be due to using canines not central incisors, periodontal ligament simulation being not performed, and the thermomechanical cycling was simulating 1 year.

Also, based on this study results, PC group has fracture resistance values significantly higher than VE group. This may be explained by the lower flexural strength of Vita-Enamic (150–160 MPa) when compared with that of Empress E-max CAD (360 MPa), and hybrid materials contain more than one interface with different values of modulus of elasticity, which decreases its fracture resistance compared with monolithic materials. This disagrees with a study that found that there is no significant difference between anterior teeth restored with GFP and hybrid endocrown.[23] This may be due to using different type of hybrid material Lava Ultimate, which has higher flexural strength (200 MPa) compared with that of Vita-Enamic (150–160 MPa). For the same reason besides thermomechanical cycling simulating 1-year clinical service and not performing PDL simulations, the result of this study differs from another study that found no significant difference in fracture resistance between anterior teeth restored with GFP and LDS crown, and hybrid endocrown used MZ100 as a hybrid material for endocrowns with 174 MPa flexural strength.[22] Also, this disagrees with a study which stated that fracture resistance of anterior teeth restored with hybrid endocrowns is significantly higher than those restored with GFP and crowns and LDS endocrowns.[26] This can be due to different methodology.

Concerning failure mode, there is no significant difference in fracture resistance between endocrowns restored with LDS and hybrid ceramics. This agrees with results of other studies.[22,23,28] This could be explained by the fact that LDS endocrowns have higher fracture resistance (360 MPa), but it has a higher modulus of elasticity (95 GPa), and Vita-Enamic endocrowns have modulus of elasticity of 30 MPa which is closer to that of dentin, but it has more interfaces when compared with LDS.

It should be noticed that there are higher values of fracture resistance for the PC group compared with the VE and EE groups. This can be explained by the fact that anterior teeth restored with post and cores show significantly lower modified Von Mises stresses compared with endocrowns, and the flexural strength is more in LDS compared with hybrid ceramics.[3,30–32]

Based on the results of this current study, statistical analysis of the number of specimens with catastrophic tooth fracture in each of the three groups revealed a statistically significant difference. In the GFP group (PC), the majority of the failures (six out of seven specimens) were classified as nonrestorable failures, which indicate fractures below the CEJ in the mid-root (two) or apical portion of the root (four). Only one specimen in this group exhibited a restorable failure, which was debonding. This can be explained by the fact that specimens in the PC group had more interfaces (GFP, dual-cured self-adhesive resin cement, and dual-cured core build-up material), each with different modulus of elasticity besides the potential weakening resulting from post space drilling.[6]

In contrast, Endocrown specimens tended to be more restorable, as stress often concentrates at the interfaces, leading to more coronal restorable failures. This is because endocrowns have fewer interfaces with different modulus of elasticity. Zarone et al. found that stress in maxillary central incisors restored with an endocrown primarily accumulates at the interface.[33]

For the EE group, the failure modes were better, with four specimens exhibiting restorable failures (above the CEJ) and three specimens with nonrestorable failures. Hybrid ceramics group (VE) predominantly showed restorable failures, with six out of seven specimens failing above the CEJ. Only one specimen in this group exhibited a nonrestorable failure. This is explained by the fact that hybrid ceramics have modulus of elasticity closer to dentin than that of LDS. This actually agrees with a study by Güngör who found 100% repairable fractures.[24] Another study that used different hybrid ceramics (Lava Ultimate) concluded that among the 28 samples with ferrule and no ferrule, only two samples were with irreparable fractures.[16,33]

The limitations of this study include using only 75,000 loading cycles, which resembles 6 months under function; more load cycles may affect the results, and mechanical loading only is not fully representative to the oral environment.

Conclusion

Within the limitations of this study, the following conclusions can be drawn:

- All specimens exceeded the maximum single tooth bite force on the central incisors, indicating that GFP LDS crowns, LDS endocrowns, and Vita-Enamic endocrowns are valid options in restoring damaged anterior endodontically treated teeth.
- Endocrowns showed better outcome when it comes to fracture mode, indicating that they are better options than GFP.

Ethics Approval and Consent to Participate

The study received approval from the ethical committee of the Faculty of Dentistry, Al-Azhar University, before commencement (EC. Ref No: 712/197). This study was started in 2022 and ended in 2024.

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