FRACTURE RESISTANCE OF CAD/CAM ONE-PIECE AND TWO-PIECE POST-CORE-CROWN RESTORATIONS USING TWO DIFFERENT MATERIALS (IN VITRO STUDY)

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ABSTRACT

INTRODUCTION: Restoring teeth that lost significant percentage of coronal structure necessitates using post and core before crown coverage. The most common systems are the one-piece post and core and the two-element system. Recently the one-piece restoration, the Richmond crown, could be milled using CAD/CAM to rehabilitate severely damaged teeth. A variety of aesthetic materials have become available for milling.

Aim: To compare between the fracture resistance (FR) of one-piece and two-piece post-core-crown restorations using two different materials; hybrid ceramic (HC) and zirconia (ZR).

MATERIALS AND METHODS: The study was conducted on 20 artificial maxillary canines. The teeth were prepared then randomly divided as follows: Group I, one-piece post-crown restoration (N=10) which were further subdivided into Subgroup IA: hybrid ceramic and Subgroup IB: zirconia. Group II, two-piece post-core and cemented crown (N=10) which were also subdivided into Subgroup IIA: hybrid ceramic, and Subgroup IIB: zirconia. The specimens were subjected to fracture resistance testing using universal testing machine followed by analyzing the failed specimens with the stereomicroscope. Results were statistically analyzed using F test (ANOVA) and Post-hoc test (Tukey), significance was judged at 5%.

RESULTS: The FR values (mean±SD in Newtons) were 386.6 ± 25.78N for subgroup IA, 522.2 ± 70.56N for subgroup IB, 429.6 ± 91.87N for subgroup IIA, and 648.6 ± 93.37N for subgroup IIB with no significant difference in FR between the one-piece and the two-piece restorations using either HC or Zr.

CONCLUSION: The one-piece post-crown restorations showed good performance regarding fracture resistance.

KEYWORDS: Post and core, Zirconia, Hybrid ceramic, Richmond crown.

RUNNING TITLE: Fracture resistance of one-piece and two-piece post-core-crown restorations

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INTODUCTION

Because of the loss of structural integrity caused by decay, fractures, previous fillings, and the endodontic treatment itself, endodontically treated teeth are often more prone to fracture than their vital counterparts. The selection of an adequate restoration for root-filled teeth is governed by the quantity of the remaining tooth structure, and by aesthetic and biomechanical requirements (1).

The use of post is usually indicated prior to complete coverage of the tooth. Custom-made metal posts have been commonly used when slight or no coronal tooth structure is present for retention or bonding of the coronal restoration (2).

Endodontically treated teeth require a ferrule for optimal biomechanical performance. It is done by preparing the remaining coronal tooth structure for near-parallel axial walls that traverse the tooth's circumference. The final full crown is thought to give resistance to internal pressures arising from the post that can lead to catastrophic failure (3).

Customized cast posts have been utilised for decades, but increasing patients' requests for aesthetic restorations has driven dentists to use aesthetic metal-free restorative materials such as carbon fiber, glass fiber, fiber reinforced composite, zirconia and hybrid ceramic posts.

Carbon fiber posts, the first non-metallic posts used in dentistry were introduced in 1990, the use of fiber reinforced posts has helped enhance the stress dispersal along the root because their biomechanical characteristics are similar to those of the tooth, in contrast to metal posts, providing more minor damage to the remaining tooth structure, however their dark color compromised the aesthetic effect so they could not be used in clinical situations where composite core or all-ceramic crowns were planned. In1992, glass fiber reinforced post systems were introduced which replaced carbon fibers with quartz or glass fibers to improve the aesthetic outcomes, they were made of uni-directional fibers entrenched in a resin matrix strengthening the posts without sacrificing their modulus of elasticity (MOE). Zirconia posts were introduced in 1995, it offers the visual benefit of having a hue that is close to that of natural teeth, in addition to its good chemical and physical qualities. Fiber reinforced composite posts (FRC) were introduced in 1997 where they were composed of cross-linked polyethylene, silica, quartz or ceramic fibers dispersed in a resin matrix (4).

With the advancement of the CAD-CAM technology, custom-made zirconia post and core has recently become popular replacing the use of metal post and core especially in the esthetic zone. But if the tooth is overloaded with zirconia posts catastrophic vertical or deep root fractures may result owing to its high MOE. Also, removing them from the root canal may be difficult when endodontic retreatment is required.(5)

Scanning a pattern or impression material and subsequent digital design are required for customizing post and core utilized by CAD-CAM. The restoration is then machined using the pattern or impression data that has been acquired. Digital dentistry advancements have resulted in milled prostheses that are more precisely fitted. In comparison to previous generations, a recent extra-oral scanner, which uses blue-light, decreases scanning time and improves precision and repeatability of the scanning procedure. This method eradicates the requirement for a pattern or a scan post, while also improving the milled post and core's passive fit (6).

With the recent development of scanning procedures, the introduction of five-axis milling machines and the emergence of novel restorative esthetic materials that can be milled using the CAD/CAM technology, the one-piece post-crown technique can be used in restoring severely damaged anterior teeth. Researchers suggest that it is a promising treatment modality that could be used as an alternative to the conventional methods in the esthetic rehabilitation of root-filled teeth. This technique has several advantages, including the fact that it is custom-fit to the root configuration, there is little or no tension at the cervical margin due to absence of core, it provides high strength and sufficient room for ceramic firing with adequate incisal clearance and eliminates the steps needed to fabricate the definitive crown. It is, however, technique sensitive where the post and crown must have the same path of insertion in contrast to the two-piece restorations or else incomplete seating of the restoration would occur, also removal of the crown without the post would be impossible if retreatment is required.(7)

Hybrid ceramic materials such as Lava Ultimate (3mESPE), Cerasmart (GC America), and VITA Enamic (VITA Zahnfabrik) provide a suitable alternative to zirconia in the assembly of all ceramic post and core restorations. Due to the entirely uniform and evenly dispersed nano ceramic fillers in the flexible nano-ceramic matrix structure, they provide optimum physical qualities and impact dispersion. They combine the best characteristics of ceramic in strength and the resiliency of composite. In addition to flexibility, strength and low breaking energy which will decrease the possibility of root fracture, it aids in ensuring the highest level of marginal integrity and strength following bonding (8).

This study was designed to compare between the fracture resistance of CAD/CAM fabricated one-piece post-crown and two-piece post-core and cemented crown restorations using two different materials; hybrid ceramic and zirconia.

MATERIALS AND METHODS

A total of twenty artificial human maxillary canines with anatomic clear root and pulp space (Artmed artificial teeth with anatomical root form, model no. B00YYA8KGS, USA) (Figure 1A) were selected for the study. Split molds were used to embed all of the specimens in an auto polymerizing acrylic resin (ACROSTONE, Dent Product. Egypt) (9). Putty silicon index was taken for the teeth prior to preparation. The crowns of the canines were cut off 2 mm coronal to the cervical line using round end taper diamond stone(komet, Trophagener, Germany) ISO standardized size 12. The remaining coronal tooth structure was prepared with 6° taper creating a 1mm. deep chamfer finish line (8). The silicon index was placed over the prepared tooth to confirm uniform reduction. ISO standardized #1,2,3, and 4 peeso reamer drills (Dentsply Maillefer, USA) were used for preparing the post space. The drills were used in sequence from size#1 to #4 leaving 5mm. in the apical portion of the canal unprepared creating a standard post space of 12 mm. length from the coronal surface(10). Length was adjusted using endodontic ruler. Final shaping was done using fiber post drill size #2 ISO sized 1.5mm. diameter (Dentsply Maillefer, USA) to standardize the post space diameter for all samples [10] **(Figures 1B, 1C).**

The twenty teeth were randomly divided into two main groups (N=10) according to the type of restoration as follows:

Group I: Ten CAD/CAM fabricated **one-piece** post-crown.

Group II: Ten CAD/CAM fabricated **two-piece:** post-core and separate crown.

Each group was further subdivided into two subgroups (n = 5) according to the material used, hybrid ceramic (Cerasmart, GC America, USA) or zirconia (GC initial, GC America, USA) as follows:

- Subgroup IA: Five CAD/CAM fabricated one-piece hybrid ceramic restorations.
- Subgroup IB: Five CAD/CAM fabricated one-piece zirconia restorations.
- Subgroup IA: Five CAD/CAM fabricated two-piece hybrid ceramic restorations.
- Subgroup IIB: Five CAD/CAM fabricated two-piece zirconia restorations.

Polyvinylsiloxane impression material (Elite HD+, Zhermack, Italy) was used to make impression of the post space and the remaining coronal tooth structure. Equal quantaties of base and catalyst of polyvinyl siloxane putty impression material were hand mixed and loaded in the metallic cylinder. Light body impression material was injected into the post space preparation simultaneously using automix gun until it filled the post space completely. A plastic post was placed into the post space filled with the light body impression material to support it upon removing the cylinder after polymerization of the impression. Light body was injected over the coronal tooth structure and the finish line carefully to avoid entrapment of air bubbles. The metallic cylinder loaded with putty impression material was placed over the tooth and the plastic post placed into the post space to take one-step impression. According to the manufacturer's instructions, the cylinder was removed after polymerization of the impression material which took about 2-3 minutes. Impression was inspected visually for any defects or air bubbles. The finish line was checked carefully using magnifying glass to ensure uniform, continuous and free of any imperfections. The plastic post coated with the polymerized light body impression material was inspected to ensure it was in its correct place and wholly covered with the impression material[11]. **(Figure 1D)**. Scan spray (Dentify Engen, Germany) was applied on the impression prior to its scanning using extra-oral scanner (inEos X5, DENTSPLY SIRONA, USA) to create virtual 3D dies onto which the restorations were designed using the inlab CAD 16.1 software and then milled using in-Lab MC X5 milling machine (DENTSPLY SIRONA, USA) **(Figure 2)**.

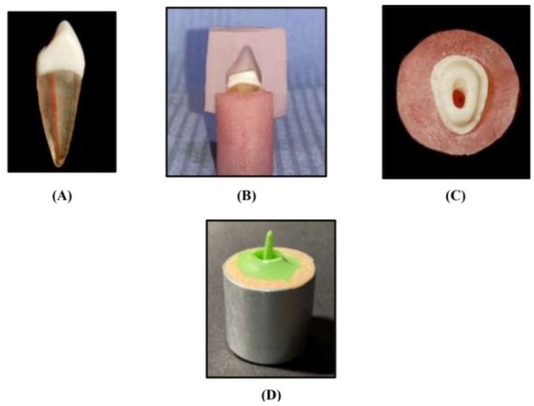

Figure (1): Schematic illustration of tooth preparation and impression making: (A): Artificial maxillary canine, (B): Index used to check unifrom tooth reduction, (C): Incisal view of the prepared specimen, and (D): PVS impression of the post space and remaining coronal tooth structure.

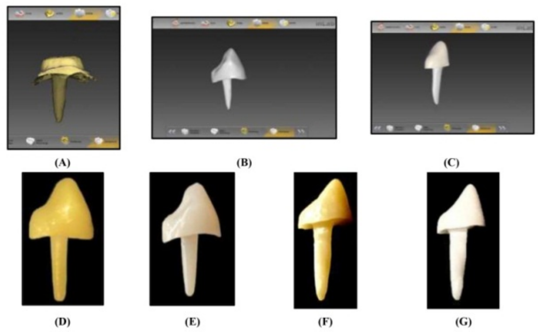

Figure (2): Designing and milling the restorations: (A): Proximal view of the virtual 3D die after scanning the impression showing post space and coronal tooth structure, (B):One-piece restoration design, (C): Post and core restoration design, (D): Milled one-piece hybrid ceramic, (E): Milled one-piece zirconia restoration, (F): Milled hybrid ceramic post and core, and (G): Milled zirconia post and core restorations.

Zirconia restorations were sintered up to 1000ºC for 2 hours, then for 4 hours at 1450ºC and finally left to cool for 1 hour at 1000ºC. The length of the post was checked using digital Vernier caliper. Zirconia restorations were sandblasted using a chairside airborne particle-abrasive device (Bio-art Microjato, England) adjusted at 3 bar pressure for 15 seconds with 50µm Aluminum oxide (Al_2O_3) particles [12]. The posts were checked for complete seating using OKKLU-EXACT fit checker spray(Dent-e-con e.K Gartenstraße, Germany) prior to their cementation.

The hybrid ceramic restorations were etched with HF acid (iTena, France) 9% for 30 seconds, water rinsed and air dried. Silane coupling agent (iTena, France) was be applied using micro-brush on both the post and the internal surface of the core for the post and core restorations, and on the fitting surface of the crown for the one-piece restoration then air dried according to the manufacturer's instructions. Ceramic Primer (Z prime. Bisco Inc., USA) was applied on the zirconia post, internal surface of the core and the fitting surface of the crown by micro-brush then air dried for three seconds.

Dual cure resin cement (G cem, GC America, USA) was used to lute the restorations to their respective teeth using static load device under 1kg.load. The restorations were left under the static load for 5 minutes resulting in a standardized homogeneous cement film thickness, exposed to brief light curing for 5 seconds to easily remove the excess cement then exposed to extended light curing for 40 seconds to ensure complete polymerization of the resin cement [13].

The specimens with luted post and core restorations were scanned using the inEos X5 extra-oral scanner to fabricate the crowns so that the hybrid ceramic post and core restorations were restored with hybrid ceramic crowns and zirconia post and core restorations were restored with zirconia crowns. The same luting protocol mentioned previously was done to lute the crowns to their respective specimens.

The specimens were exposed to 500 thermal cycles between 5℃ and 55℃ with a dwell time of 1 minute and transfer time of 30 seconds using the thermocycling machine (Custom made in dental biomaterials dept., faculty of dentistry Alexandria University, Alexandria, Egypt). After thermocycling, all specimens were exposed to cyclic loading of 50000 load cycles with a load of 50N at a frequency of 2Hz using load cycling machine.[9]

Universal testing machine (Tinius Olsen TMC, USA) was used to apply static compressive load to each sample at 45°to the long axis of the tooth **(Figure 3)** with a cross head speed of 1mm/min until failure occurred (8). Failure loads were recorded for each specimen in Newtons. Failure was defined as the point when fracture occurred in post, core, crown or root [14]. After failure, specimens and fracture patterns were examined using the stereomicroscope (Olympus, Japan).

The mode of failure of the specimens was evaluated and classified [15] as follows: **Type 1:** Partial fracture or chipping of the crown without involvement of the post or the core portions. **Type 2:** Complete fracture of the crown without involvement of the post or the core portions. **Type 3:** Fracture of remaining coronal tooth structure with the involvement of the post portion but without involvement of the root. **Type 4:** Fracture of the crown, post and core portions but without involvement of root (complex fracture). **Type 5:** Fracture extending to the root surface.

RESULTS

Significance of the obtained results was judged at the 5% level. F-test (ANOVA) was used for normally distributed quantitative variables, to compare between more than two subgroups. Post Hoc test (Tukey) test was used for pairwise comparisons.

There was no significant difference in fracture resistance between the one-piece (Group I) and two-piece (Group II) restorations using either hybrid ceramic or zirconia (P>0.05). However, zirconia subgroups showed significantly higher fracture resistance values than those of the hybrid ceramic (P<0.05). The highest mean fracture load of all subgroups was for subgroup IIB (two-piece zirconia) 648.6 ± 93.37N. Subgroup IB (one-piece zirconia) was the second and had mean fracture load of 522.2 ± 70.56N, followed by subgroup IIA (two-piece hybrid ceramic) with mean fracture load of 429.6 ± 91.87N then subgroup IA(one-piece hybrid ceramic) which showed the lowest mean value at 386.6 ± 25.78N. These data are represented in **(Table 1)** and **(Figure 4).**

Table (1): Comparison between the different studied subgroups according to fracture load

	Group I (N=10)		Group II (N=10)			
Load	Subgroup IA (One-piece hybrid ceramic) (n = 5)	Subgroup IB (One-piece zirconia) (n = 5)	Subgroup IIA (Two-piec hybrid ceramic) (n = 5)	Subgroup IIB (Two-piece zirconia) (n = 5)	F	P
Min. – Max.	358.0 – 422.0	430.0 – 593.0	306.0 – 543.0	548.0 – 750.0		
Mean ± SD.	386.6 ± 25.78	522.2 ± 70.56	429.6 ± 91.87	648.6 ± 93.37	11.798^*	<0.001
Median (IQR)	380.0 (370.0 – 403.0)	546.0 (467.0 – 575.0)	462.0 (372.0 – 465.0)	615.0 (585.0 – 745.0)		
Sig. bet. subgrps.	$p_1=0.050^*$, $p_2=0.805$, $p_3=0.075$, $p_4=0.002^*$					

IQR: Inter quartile range SD: Standard deviation

*: Statistically significant at $P \leq 0.05$

F: F for ANOVA test, Pairwise comparison bet. each 2 subgroups was done using Post Hoc Test (Tukey)

p: p value for comparing between the studied subgroups

p_1: p value for comparing between **subgroup IA** and **subgroup IB**

p_2: p value for comparing between **subgroup IA** and **subgroup IIA**

p_3: p value for comparing between **subgroup IB** and **subgroup IIB**

p_4: p value for comparing between **subgroup IIA** and **subgroup IIB**

The modes of failure of the tested subgroups are shown in **(Figure 5)**.

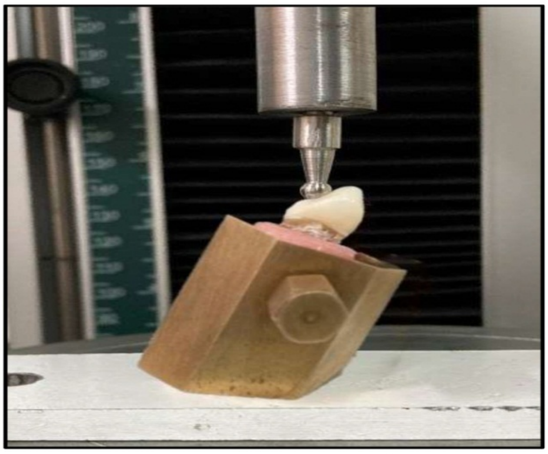

Figure (3): Compressive static load applied 45° palatal to the specimen.

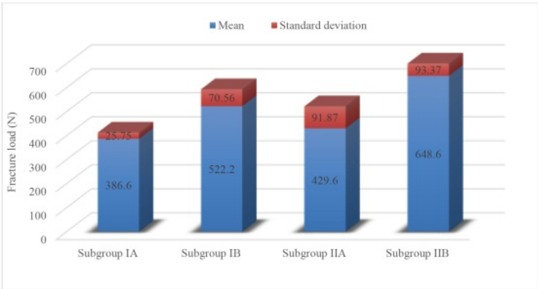

Figure (4): Graph showing mean and standard deviation of fracture loads in Newtons of the tested subgroups.

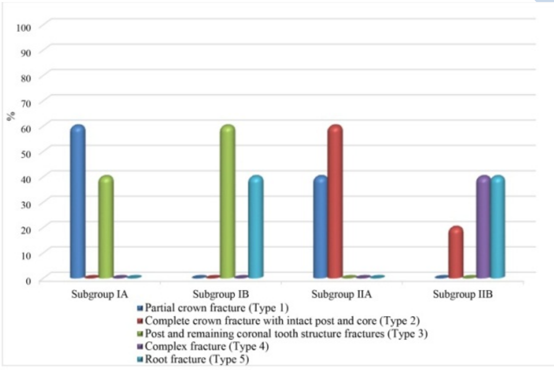

Figure (5): Graph showing percentages and modes of failure of all tested groups.

DISCUSSION

Post and core restoration is widely utilised in contemporary dentistry to restore badly damaged endodontically treated teeth. The performance of the post and core is determined by a variety of elements, the most significant of which are the material and design of the post and core [16].

CAD/CAM fabricated zirconia post and core has been used to restore endodontically treated anterior teeth [17]. However, the high MOE of partially stabilized zirconia (209 GPa) [18] leads to stress transfer to the dentin causing root fracture [19]. Hybrid ceramic material was selected as post and core restoration which contains 70% filler particles by weight. The MOE of this material is about 13GPa which is very close to that of dentin (18GPa) [20]. According to Awada and Nathanson [21], hybrid materials are less brittle and more flexible than traditional ceramics, implying that there would be less catastrophic failure as well as less chipping and crack formation during milling. They are also more compatible with milling machines and have a high marginal quality [22].

In the present study artificial teeth with MOE close to that of natural dentin (16GPa)[23] have been selected as they have identical root length and shape which facilitates standardization of tooth preparation and fabrication of the restoration in contrast to natural teeth which vary in length, degree of mineralization, presence of root curvatures or canal calcifications as stated by Rosentritt et al [9]. Also, Beck et al evaluated the fracture resistance of copy-milled zirconia ceramic posts using transparent plastic cylinders with conical post space for the aim of standardization [24].

Zirconia restorations were sandblasted using 50µm Aluminum oxide particles (Al_2O_3), then ceramic primer (Z-prime) containing MDP (10-methacryloxydecyldihydrogen phosphate) monomer was applied onto them prior to their luting to their respective teeth. G-Cem dual cure resin cement was used to lute the milled restorations to their respective teeth because it is generally accepted that dual cured composites are effective especially in areas of difficult light access such as the middle and apical root canal thirds [25]. Resin cements have become popular in recent years because they improve retention, minimize leakage, and promote short-term root strengthening through bonding the restoration to the dentin creating a monobloc effect [26]. Hydrofluoric acid etching followed by the application of silane coupling agent regarding hybrid ceramics, and airborne-particle abrasion combined with the application of phosphate monomers regarding zirconia significantly enhances the bond strength with the resin cement [12].

In this study, the teeth were exposed to thermal cycling using 500 thermal cycles and dynamic loading of 50000 load cycles with a load of 50N simulating approximately 2 years of clinical service to examine the specimens' behavior under clinically approached circumstances [27].

The results of this study showed that there was no significant difference in fracture resistance between the one-piece and the two-piece restorations using either hybrid ceramic or zirconia. However, teeth restored with zirconia showed higher fracture resistance values when compared to those restored with hybrid ceramic. The high MOE and the rigid nature of zirconia led to higher mean values than the hybrid ceramic material.

The mean failure load in subgroup IIA was 429.6±91.87N, this result agreed with Falcão Spina et al [15] who evaluated the fracture resistance of custom-made post and core restorations milled from different materials. They found that the mean fracture resistance values of hybrid ceramic posts were 414.5±83.9N.

The results also were consistent with Türker et al [28] who compared the fracture resistance of different post systems; cast metal, glass fiber composite and milled zirconia posts. They found that the zirconia posts showed mean fracture resistance values of 638.28 ± 155.87N. Additionally, Dayalan M et al [29] evaluated the fracture strength of zirconium oxide posts fabricated using CAD-CAM technology, they found that the zirconia posts showed mean fracture values of 627.79± 92.6N which agreed with our study.

On the other hand, the present study disagreed with Beck et al [24] where they compared the fracture resistance of fiber-reinforced composite (FRC) resin posts with the fracture resistance of copy-milled zirconia ceramic post and core. They found that copy-milled custom-made zirconia post and core showed low mean fracture resistance of 139.30±42.70N. This may be because the posts and cores were neither luted to their respective teeth nor restored with crowns during aging and testing procedures.

Also, this study disagreed with Alkhatri et al [30] where they compared the fracture resistance and failure modes of root filled teeth restored with hybrid ceramic and zirconia post and core assemblies fabricated using CAD/CAM. They found that there was no significant difference between the tested groups and the mean failure values were lower than our results (328.06 ± 54.37N and 271.06 ± 69.57N for the zirconia and hybrid ceramic post and cores respectively). The low failure values could be attributed to the fact that all the teeth in their study were restored with all metal crowns made from Co–Cr alloy prior to testing the specimens nevertheless the type of the post and core material.

In this study, the one-piece zirconia restorations (subgroup IB) showed significantly higher fracture mean values when compared to the one-piece hybrid ceramic restorations (subgroup IA) where the mean failure loads in subgroups IA and IB were 386.6 ± 25.78N and 522.2 ± 70.56N respectively. This could be due to the high rigidity of zirconia compared to the less rigid, more flexible nature of the hybrid ceramic material [21].

Regarding the mode of failure, subgroup IA showed post fracture accompanied with crown dislodgement in 40% of the specimens while 60% of the specimens showed partial crown fracture only with intact post. However, in subgroup IB all the specimens showed post fracture accompanied with root fracture in 40% of the specimens and crown dislodgement only with intact root in 60% of the specimens.

Half of the specimens of the one-piece restoration showed post fracture with crown dislodgement mode of failure. This could be explained due to the concentration of force on the post-crown junction with the absence of the core portion that led to this type of failure in contrast to the two-piece restorations which did not show this mode of failure in any of the specimens [7].

Root fracture in case of zirconia could be explained due to the divergence of the MOE between the root dentin and the zirconia post. Another possibility is that the load on the root-restoration system, which comprised various stiffness components, was distributed differently. The more rigid portion can withstand forces without deformation, but stress transfer to the less rigid part causes it to shatter [31]. The distribution of the occlusal forces along the root length is affected by the rigidity of the post, which should be close or equal to the rigidity of the root itself [32].

This form of zirconia post failure was confirmed in a research by Bittner et al [5], who investigated milled zirconia post and core failures and discovered that most of catastrophic failures in all groups occurred in the cervical half of the root. Additionally, Palepwad and Kulkarni [33] compared the fracture resistance of zirconia and cast metal posts with different lengths and found that the majority of teeth restored with zirconia posts showed root fracture mainly in the cervical third when compared to the other specimens.

The post design in the current study was tapered post for both materials; hybrid ceramic and zirconia. The tapered post shows greater stress concentration at the coronal third of the root, whereas at the apex the stresses recorded are lower. The lower concentration of the stress at the apex of tapered posts was due to the conservation of the tooth structure as stated by Fernandes and Dessai [34]. This agreed with our results where there were cervical root fractures in the specimens restored with zirconia posts.

Although hybrid ceramic showed more favorable pattern of failure than zirconia where no root fracture was evident in subgroup IA, remake of the restorations in both subgroups would be difficult as retrieval of the fractured post in the canal would be problematic, however the mean failure loads of the one-piece restorations of both materials (386.6N for the hybrid ceramic and 522.2N for zirconia) exceeded the reported maximal occluding force in the anterior region of the oral cavity (120-240N) [35] therefore, none of the systems could be considered at risk for failure as a result of normal occlusal forces.

Subgroup IIA showed the most favorable failure modes of all the tested subgroups as no post fracture was evident in any of the specimens so remake of the fractured crowns was possible, this could be due to the low MOE of the hybrid ceramic material and the presence of flexible nano-ceramic fillers in their components (about 71% by weight) which prevented the transfer of the stresses to the post [10].

However, subgroup IIB showed only one specimen with a favorable mode of failure where remake could be done in which only the crown fractured and the post and core remained intact. The rest of the specimens showed either complex fracture (40% of the specimens) where there was total coronal destruction with post fracture, or root fracture (40% of the specimens). This could be due to the rigid nature of zirconia material and its high MOE; however, the mean failure loads were very high (648.6 ± 93.37N) when compared with the maximum bite force in the anterior region of the human dentition (120-240N) [35].

CONCLUSIONS

Within the limitations of this study, it could be concluded that:

1- The one-piece restoration is a promising treatment modality that can be used in the esthetic restoration of severely damaged endodontically treated anterior teeth as an alternative to the conventional two-piece post-core and crown restorations.
2- Hybrid ceramic material can be used as an esthetic alternative to zirconia to fabricate post and core restorations as it showed more favorable mode of failure than zirconia post and core restorations.

CONFLICT OF INTEREST

The authors declared that they have no conflicts of interest.

FUNDING STATEMENT

The authors received no specific funding for this work.

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