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International Journal of Dentistry and Oral Science (IJDOS)
ISSN: 2377-8075

A Comparative In Vitro Study to Evaluate Two Designs of Endocrowns in Restoring Endodontically Treated Premolars

Research Article

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Abstract

Our study's objective was to compare resistance to fracture and failure types betweena new design of endocrown and a conventional endocrownwhen subjected to shear force.

Materials and Methods: Twenty human maxillary first premolars without cracks or caries that had been extracted for orthodontic purposes were collected.The crown portion of the specimens was removedup to 2 mm above the cementoenamel junction (CEJ). Afterward, these were endodontically treatedand then randomly divided into two groups and restored using two different methodsas follows:

Group H: (n = 10) – teeth were restored with H-shaped endocrowns;

Group EC: (n = 10) – teeth were restored with conventional endocrowns.

All crowns were made from IPS e.max ceramic. Shear forces were applied to these restorations using a test machine until breakage.

Results: No significant difference was observed in resistance to fracture between the two groups. However, a greater number of favorable fractures were observed in the conventional endocrowns'group, whereas most of those in the H-shaped endocrowns were unfavorable.

Conclusion: Under the conditions of this study, it can be concluded that the new endocrown design shows a higher fracture resistance than conventional endocrowns. but it causes more unfavorable fracture types than the latter.

Keywords: Endocrowns; H-shaped Endocrowns; IPS e.max; Shear Force.

Introduction

The rehabilitation of severely damaged coronal hard tissues and endodontically treated teeth has always been a challenge in restorative dentistry. After endodontic treatments, many changes occur in tooth biomechanics [1, 2].

Restorations of endodontically treated teeth are designed to "protect the remaining tooth structure from fracture, prevent reinfection of the root canal system and replace the missing tooth structure"[3]. Some researchers recommended using posts for support and reinforcement of the remaining tooth structure, a claimbased on the ability of posts to distribute stress ina way favorable to improvethe fracture resistance of restored teeth [4, 5]. Conversely, Cagidiaco et al. [6] and Ferrari et al. [5] reported that there was no improvement in survival rates when fiber posts were usedto restore endodontically treated premolars.Also, there is evidence that the loss of dental hard tissues during the post space preparation reduces the rigidity of the tooth [1].With recent developments in adhesive techniques and ceramic materials, provided there exists ample tooth surfaces for bonding, there is no longer any need for macroretentive designs. With the adhesive technique, creating a ferrule is a drawback because of the loss of natural tooth structure and enamel. So,the gold-standard rule for restoring teeth is preserving a maximum amount of tooth structure with minimally invasive preparations [7]. An alternative restorative approach without the use of endodontic posts, named a Monobloc technique, was introduced by Pissis [8]. In 1999, the endocrown was described for the first time by Bindle and Mörmann as adhe-

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Received: May 12, 2020
Accepted: September 07, 2020
Published: April 01, 2021

Citation: Naif Ghanem, Naser Baherly, Hazem Hassan. A Comparative In Vitro Study to Evaluate Two Designs of Endocrowns in Restoring Endodontically Treated Premolars. *Int J Dentistry Oral Sci.* 2021;08(04):2127-2133. **doi:** http://dx.doi.org/10.19070/2377-8075-21000421

sive endodontic crowns and was characterized as total porcelain crowns fixed to endodontically treated posterior teeth [9]. Different from conventional approaches using intraradicular posts, endocrown restorations are anchored to the internal portion of the pulp chamber and on the cavity margins, thereby resulting in both macro- and micro-mechanical retention provided by the pulpal walls and adhesive cementation, respectively [10]. The question that remains to be answered is the feasibility of endocrwons to restore the endodontically treated premolars.While endocrowns on molars have yielded very acceptable results, premolar involved higher likelihood of failure [11]. Thismay be related to the small surface available for adhesive bonding in premolars, and the cusp height resulted in a higher leverage on the premolars than molarsdid [12]. There is a lack of data on the influence of endocrown design on the biomechanical behavior of restored endodontically treated premolars. This article discusses a new design of endocrowns (H-shaped endocrowns), that may increase the surface area for adhesive retention and improve the transmission of masticatory forces to root. Therefore, the objective of this in vitro study was to evaluate the effect of the restoration design (H-shaped endocrowns) on both resistance to fracture and failure types of restored endodontically treated premolars. The null hypotheses tested were that there were no differences between the H-shaped endocrowns and the conventional ones on fracture resistance and failure types of restored endodontically treated premolars.

Materials and Methods

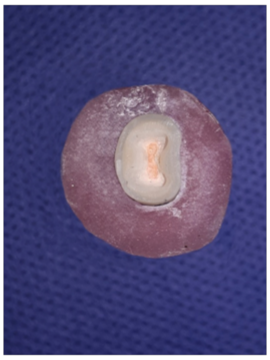
From the data of a previous study [13], a power analysis was performed to determine the number of specimens that would be required in each test group to assess if there wereany statistical differences between the groups. Based on this analysis, 20 maxillary first premolars without cracks or caries that had been extracted for orthodontic purposes were collected. All external debris was manually cleaned from the teeth with dental scaler, before storing these at 18C saline. The teeth were selectedof similar sizes and shapes by measuring the root length and buccolingual-mesiodistal widths at the cementoenamel junction by visual inspection and digital caliper measurements, allowing a maximum deviation of 10% from the mean width (buccolingual: 8.46 ±0.4 mm; mesiodistal: 4.96 ±0.4 mm). All teeth had one radiographically visible root, and were extracted in the course of a comprehensive orthodontic treatment plan at the Department of Orthodontics at Tishreen Universityin Latakia, Syria. The dental crowns were sectionedabove the cementoenamel junction up to 2mm. Later, complete endodontic treatment using nickel titanium files of Twisted File system (Twisted File, SybronEndo, USA)was peformed. After each file, the canal was rinsed with sodium hypochlorite (5.25% w/v), and was dried with paper points and obturated with gutta-percha (Pearl Endopia, Pearl Dent, South Korea) by a lateral condensation technique and an eugenol-free sealer (Adseal, META BIOMED, South Korea). Subsequently, teeth were randomly assigned to two groups (n = 10): Group H (H- endocrowns) and Group EC (conventional endocrowns).Before starting the preparation procedure, the teeth were individually fixed with acrylic resin(BMS 017, BMS Dental, Italy)in polyvinyl chloride (PVC) rings parallel to the acrylic resin. The remaining crown structures of the teeth were kept free from the acrylic, and the root was covered by up to 2 mm below the CEJ, which is approximately the level ofthe alveolar bone in a healthy tooth. The rings were removed following the mounting procedure.

Group H: H-Shaped Endocrowns

The teeth were prepared to receive H-shaped endocrowns. The principle behind using such a design is that such an endocrwonwould fit in an H-shaped cavity in the pulp chamber in comparison with the preparation of an ordinary endocrown cavity,where the two parallel flanges of the H aim to engage the dentin buccally and palatally and are individually adapted to leave a minimal residual lateral dentin thickness of at least 1 mm. Preparations were performed with a cylindrical bur (FG 199X016, DiAMANT, Germany) with water coolant, and the burwas replaced every five preparations. The depth of the cavity was 3 mm and the outline of the preparation was rounded to prevent stress concentration on sharp corners with a cylindrical diamond bur (850VF314018, DiAMANT, Germany) (Figure 1).

Impressions were made with a one-step technique involving Putty and Light condensation silicone (Zetaplus, Oranwash L, Zhermack, Italy). They were then casted with Gypsum IV (Marmorock, Siladent) to get dyes for fabricating the IPS e.max CAD H-shaped endocrowns (e.max CAD LT A2/C14, IvoclarVivadent, Liechtenstein). All the H-shaped endocrowns gypsum dyes were scanned with a 3D scanner (Freedom HD, ARUM, South Korea). After this stage, the H-shape endocrowns were designed using exocad software (Exocad, DentalDB, version 2016. 10, Modern UI, Germany) and milled with a milling device (Arum5x-400, ARUM, South Korea). Using this software, the luting space was set at 40 µm, and the endocrown heights were standardized to 6.5 mm in the fissure and 8.5 mm, and 8 mm in the buccal and palatal cusps regions, respectively (distances measured from the CEJ).After the milling stage, the lithium disilicateH-shape endocrowns were additionally crystallized using a Programat P300 furnace (Programat ® P300, Ivoclar Vivadent, Liechtenstein) for 2 minutes at 820°C

Figure 1. The shape of tooth pulp chamber after preparation in group H.



plus 7 minutes at 840°C.

Group EC: Conventional Endocrowns

In this group, the teeth were prepared with a round inlay cavity of 3 mm depth using a cylindrical bur (FG 199X016, DiAMANT, Germany), and the internal line angles were later rounded with a cylindrical diamond bur (850VF 314018, DiAMANT, Germany). The cavity was limited to at least 1-mm residual marginal dentin thickness (figure 2).

Impressions were made with a one-step technique with Putty and Light condensation silicone (Zetaplus, Oranwash L, Zhermack, Italy). They were then casted with Gypsum IV to get the dyes necessary for manufacturing the IPS e.max Press endocrowns using the lost wax technique. The waxedendocrowns were invested (IPS Press VEST,IvoclarVivadent, Liechtenstein) in rings (IPS Investment Ring Base, Ivoclar Vivadent Liechtenstein,) and were prepared forpressing. The rings were placed into a furnace (Programat EP 3010, Ivoclar Vivadent, Liechtenstein), then the ingots positioned in their place (E.max Press Ingots LT A2, IvoclarVivadent, Liechtenstein). Finally, the pressing procedures were completed according to the manufacturer's instructions. After cooling for about 60 minutes, the investment was removed, and the endocrowns were cleaned with 50µm aluminum oxide at 4-bar pressure and adjusted to their individual dyes. Finally, the endocrowns were glazed (IPS E.max Ceram Glaze Powder, Ivoclar Vivadent; IPS E.max Ceram Glaze and Stain Liquid, IvoclarVivadent) in accordance with the manufacturer's manual. The endocrowns in this group were standardized to a height of 6.5 mm in the fissure and 8.5 mm, and 8 mm in the buccal and palatal cusps regions, consecutively (distances measured from the CEJ).

Luting Phase

Before insertion, the endocrowns' surfaces to be bonded were etched with hydrofluoric acid (Ultradent Porcelain Etch, 9%; Ultradent Products, South Jordan, UT, USA) for 90 seconds, and then rinsed for 30 seconds with running water and dried for 30 seconds with oil-free air. A silane-coupling agent (Silane, UltradentProuducts, South Jordan, UT, USA) was applied and allowed to dry for 1 minute. The abutments were etched with 37% phosphoric acid-etching gel(Eco-Etch, IvoclarVivadent, Liechtenstein) (enamel for 30 seconds and dentine for 15seconds), then rinsed for 30 seconds, and dried with oil-free air for another 20 seconds. The adhesive system (Tetric N-Bond Universal, IvoclarVivadent, Liechtenstein) was applied to the prepared surfaces of the abutments according to the manufacturer's instructions, before having them polymerized for 10 seconds. All endocrowns were adhesively luted with luting composite resin cement(Variolink N, IvoclarVivadent, Liechtenstein. (The Variolink N base and catalyst were mixed at a 1:1 ratio and coated onto the endocrowns' surfaces to be bonded. Endocrowns were then seated with light finger pressure, and excess luting material was removed. The light-polymerizing unit (Bluephase, IvoclarVivadent, Liechtenstein) was held on the buccal, mesial, lingual, distal and occlusal surfaces for 1 minute. The curing power was 1200 mW/cm^2. All specimens were then placed in a custom-made carrier with an inclination of 30 degrees and loaded in a universal testing machine (Ibertest, IBMU Series, Spain) with a 4-mm steel sphere and a crosshead speed of 0.5 mm/min until the first major load dropoccurred (figure 3).

Fracture resistance was recorded in newton, and failure modes of all samples were assessed from visual and periapical radiographs after fracture. "Unfavorable failures" were defined as non-repairable, catastrophic failures below the CEJ and included vertical root fractures;"favorable failures," on the other hand, were defined as repairable failures above the CEJ and included adhesive failures. The values obtained and the fracture modes were noted and submitted into IBM SPSS software (version 19, IBM, Boston, MA, USA).

Figure 2. The shape of tooth pulp chamber after preparation in group EC.

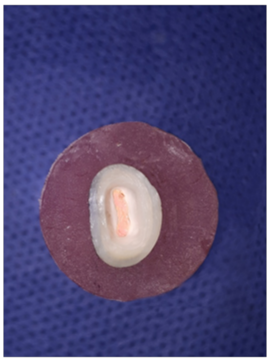
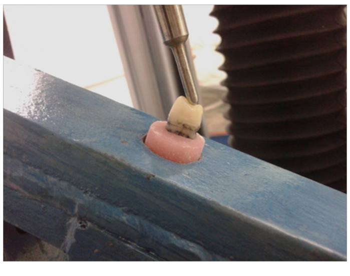


Figure 3. Position of the specimen in the setup for static loading (pressure forces was applied at an angle of 30 degrees on the inner inclines of support cusps.



Results

Statistical Analysis

Approximate normality of data distribution was tested using Kolmogorov-Smirnov and Shapiro-Wilk tests. Student's t-test was usedto study the differences between the groups' means. After the fracture load test, failure types were classified and their relative frequencies were calculated and evaluated using chi-square analysis. In all tests, P values smaller than 0.05 were considered statistically significant.

Fracture Resistance

The fracture resistance results for the two experimental groups are shown in (Table 1). Kolmogorov-Smirnov and Shapiro-Wilk tests indicated that the fracture resistance data were normally distributed (figure4).

Only one value was irregular in relation to the normal distribution in Group H, so this value was discarded and a parametric test was used.

Student's t-test showed no significant differences between the means of the two experimental groups-P=0.160 >0.05.(Table 2).

Failure Modes

Frequencies of different failure modes in the two groups areshown in (Table 3) (figure5).

The chi-square test demonstrated significant difference in the frequencies of favorable and unfavorable failure modes between the two groups.

Table 1. Fracture resistance (in newtons) of the two groups.

Test Group	Mean	Std. Deviation	Max	Min	Median
H	647.8	208.3	1062	400	576
EC	513.9	99.27	647	361	528

Table 2. Result of t-test on the fracture resistance of the two groups (N).

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Fracture resistane	1.156	0.297	1.468	17	0.16	87.878	59.866	-38.429-	214.185

Figure 4. Box plot of the fracture resistance of the two groups.

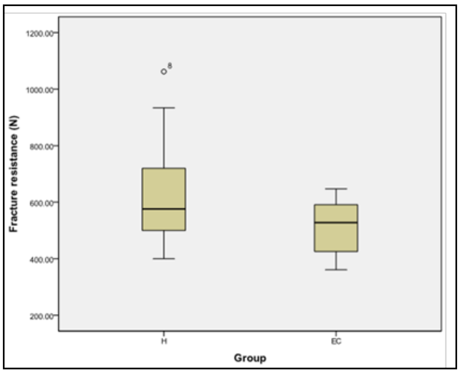


Figure 5. Some failure modes: A: Displacement of the endocrown without fracture, B: Fracture of the endocrown, C and D: Fracture of the endocrown and tooth under CEJ.

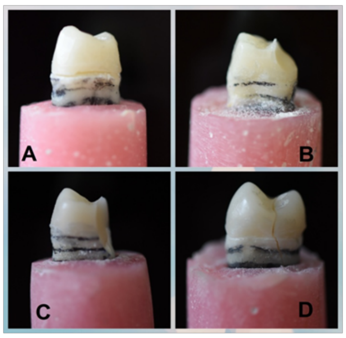


Table 3. Frequencies of different fracture modes in the two groups.

	Group H N=10	Group EC N=10
Favorable Fractures		
Fracture of the endocrown and tooth above CEJ	0	4
Fracture of the endocrown	0	1
Displacement of the endocrown without fracture	0	2
Unfavorable Fractures		
Fracture of the endocrown and tooth under CEJ	9	3
Fracture of the tooth under CEJ	1	0

Discussion

The sample consisted of 20 ex-vivo single-rooted first premolars that have been randomly allocated to two groups and restored as follows:

Group H: This group was restored by IPS e.max CAD endowcrowns, designed so that its deep portion, i.e. the portion inserted into the pulp chamber, is H-shaped.

Group EC: This group was restored by conventional IPS e.max Press endocrowns.

The sample size was calculated based on a previous study [13] and by using G*Power (v3.1) as 2-tailed t-test. A power of study of 85% and an alpha value of 0.05 were used.

Orthodontically extracted human teeth were used in this study, which may account for the marked differences in fracture resistance between the teeth in our sample. We should take into consideration the distinct characteristics of theanatomy and bondable superficial structure of every tooth in the sample, as these factors may increase the aforementioned differences. Nevertheless, using human teeth as abutments simulates clinical conditions more accurately, taking into account the morphological characteristics of teeth. Moreover, bondable enamel and dentin surfaces, pulp chamber circumference, and the crown-to-root ratio are more precise in human than artificial teeth. It should be mentioned that all the teeth in the sample were chosen to besimilar in shape and size before applying any tests to reduce possible variation and errors.

Upper premolars were chosen as abutments in this study because they are the most fractured among human teeth, Salis et al., for instance, found that 49% of fractures among upper teeth were in premolars and more than 50% were in support cusps [14]. Also, there is little consensus among researchers and in- and ex-vivo studies on the use of endocrowns in restoring premolars, as some ex-vivo studies found they were better than conventional crowns for restoring premolars in terms of fracture resistance the study of Chia et al.[7] illustrates this point. However, other studies didn't identify such a difference between endocrowns and conventional crowns, such as Forberger et al. [15], Lin et al. [16] and PedrolloLise [17]. While studies have showed that endocrowns - being sound alternative in restoring endodontically treated and compromised posterior teeth - could be applied to all human teeth, their performance in premolars under mastication forces was less satisfactory than theirs in molars. This may be attributed to the smaller size of premolars' pulp chambers and the smaller bonding surface [12]. In light of the above, we chose to conduct the present study placing retentional shape endocrowns into premolar pulp chambers (H-shaped) not only to increase the bonding surface between the tooth and the restoration, but also to reduce the interface displacement between the dentin and porcelain through interlock between the H shape and the pulp chamber's dentin. The aim was to determine whether such a shape could increase endocrown fracture resistance in premolar. So, the new endocrowndesign compared with that of conventional endocrowns. All restorations were fabricated with IPS e.max: Group (H) with IPS e.max CAD porcelain; Group (EC),IPS e.max Press.

IPS e.max CAD porcelain and CAD\CAM technique were chosen to fabricate Group H's restoration to eliminate the effect of wax and laboratory procedures, such asinvesting, casting, finishing and polishing. The reasoning behind was that the Hshape preparation in the pulp chamber was quite small and needed very precise waxing to achieve the required applicability. However, as concerns Group (EC), the restorations were fabricated by lost-wax technique and IPS e.max Press porcelain.

Valentine et al.conducted a clinical study to compare endocrowns fabricated by two methods: one by CAD\CAM technique (Cerec) and the second was by lost-waxtechniqueusing IPS e.max Press porcelain. It was found that there was no difference between the two methods regarding restoration success in the oral cavity [18].

IPS e.max CAD blocks' fracture resistance was 2.25Mpa/m^2, while IPS e.max Press ingots' fracture resistance was 2.5-3.0 Mpa/m2; thus, the difference between the two materials we used to fabricate the restorations in our study could be discarded because both are largely similar regarding composition and physical properties [19, 20].

Premolars were fixed into acrylic bases because its elasticity coefficient is close to that of the alveolar bone, and the bases were designed to be fixed in the specific base of Ibertest (IBMU4 series) general mechanical tests' deviceused to evaluate the restorations' fracture resistance.Constant pressure forces were applied at an angle of 30 degrees on the inner inclinesof support cusps (the palatal cusp) until failure. This method of applying forces was adopted because it was used in many previous studies [13, 21], and given that applying forces at an angle of 45 degrees is not favorable in the mastication function.We did not use simulated periodontal ligament, such asartificial silicone periodontiumbut simply fixed the teeth directly into acrylic bases. Utilizing only acrylic bases may be justified in light of the findings of previous studies that there existed no difference between samples designed with or without periodontal ligament simulator [22, 23]. Moreover, Chia et.al found that samples designed with artificial silicone periodontium around abutment's roots show bigger thicknesses proportional to the thickness of periodontal ligament around human teeth. In addition, uneven thicknesses of a periodontal ligament simulator may cause uncontrolled movement in the ex-vivo abutments leading to more errors [7].

Evaluating Fracture Resistance

Ibertest IBMU4 series device was used to evaluate the samples' fracture resistance by applying pressure forces at an angle of 30 degrees on the inner inclinesof support cusps (the palatal cusp) until failure. Results showed that the forces needed to reach failure in the H-shaped endocrownswere higher than the physiological forces that occur in oral cavity, as natural mastication forces in premolars is between 222-445 N(24). In our study, H-shapedendocrowns' fracture resistance under inclined pressures was 647.8 ± 208.3 N, and it was higher than that of the conventional endocrowns Group under inclined pressure (513.9 ± 99.72 N). This superiority of H-shaped endocrowns may be attributed to its retentional shape into the pulp chamber, given that a part of the dentin was locked between the parallel arms of the Hshape, and this provided Group H endocrownswith a higher fracture resistance.

Our study differed from Schmidlin et al.'s [13], which found statistically significant differences in fracture resistance between H-shaped endocrowns and conventional endocrowns. This difference may have been due to Schmidlin's use of two types of porcelain (IPS Empress CAD and IPS e.max CAD), and this is why the H-shaped endocrowns' group (fabricated with IPS e.max CAD) had higher fracture resistance than that of the conventional endocrowns (fabricated with IPS Empress CAD),This is contrast to our study, where the choice was to usea uniform porcelain material (IPS e.max) with the only difference relating to the method of manufacture.

Discussing Failure Types

Regarding tooth fixability,failure types shown in our study were divided into two major types: favorable and unfavorable. These were regarded unfavorable: restoration and tooth fracture under the cemento-enamel junction, and tooth fracture under the cement-enamel junction. On the other hand, favorable failure types were: restoration and tooth fracture above the cemento-enamel junction, restoration fracture, and restoration separation from tooth. Failure types' repetitions were recorded for the two groups, and Chi-square test was applied to obtain statistically significant differences in failure types between Groups H and EC. Favorable failure types' ratios was 0% for Group H and 60% for Group EC.

The very low favorable failure types' ratio in Group H could be interpreted as follows: when inclined force is applied on the inner inclination of support cusp (palatal cusp), the deep portion of the endocrown tends to move buccaly under the effect of the force's momentum. Therefore, this movement will be transferred to the dentin locked between the two parallel arms of the H shape, but leaves the root close to the deep portion of the endocrown when force is applied; and most of it will be transferred to the root directly. In addition, this effective mechanical bond in Group H between tooth and restoration will result in less deviation between dentin and porcelain, and this is a problem most conventional endocrowns have, which makes the tooth and the restoration a single unit that break together under force effect [13]. This is what was clear in Group H as all failure types were restoration and tooth fractures under the cemento-enamel junction.

As for the high ratio of favorable failure types in Group EC, it may be attributed to the fact that retention in conventional endocrownsfundamentally depends on bonding cement. In this case, the whole interface between dentin and porcelain is located close to the momentum center of rotation of inclined forces exerted on the restoration [17]. Also, we should consider that the 3 mm extension of the restoration into the pulp chamber is always located above the alveolar bone level (represented by the acrylic base), which is why we had 4 cases in this group of the restoration and tooth breaking above the cement-enamel junction in addition to 2 other cases were separated from the teeth. All these failure types are considered favorable regarding tooth fixability.

Conclusion

Under the conditions of this study, it can be concluded that the new endocrown design demonstrates a higher fracture resistance than that of conventional endocrowns. However,it causes more unfavorable fracture types than the those resulting from conventional endocrowns. Thus, wecould consider the new design ofendocrown an alternative to the conventional one. Utilizing different materials and More clinical researches are needed to improve the efficiency of the new design, however.

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