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EFFECT OF ENDODOCROWN MATERIALS ON FRACTURE STRENGTH OF ENDODONTICALLY TREATED TEETH; COMPARATIVE IN VITRO STUDY

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ABSTRACT

Objective: To assess the effect of different CAD/CAM endocrown materials on fracture strength of endodontically treated mandibular molars.

Materials and Methods: Thirty mandibular second molars were selected and randomly divided into three groups (n=10 each). Group 1; the control group was left intact, where neither root canal treatment nor preparation were performed, Group 2 and group 3 were endodontically treated, mounted in epoxy resin blocks and prepared to receive endocrowns using CAD CAM. Groups 2 and 3 were individually scanned; endocrowns were designed and milled in Grandio Bloc with high filler loading (HFL) about 86% filler and e.max CAD blocks respectively. Each endocrown was verified for fit, and adhesively cemented using standard bonding protocol to its respective molar. Then all samples were subject to fracture resistance using universal testing machine by compressive mode under occlusally applied load at a crosshead speed of 0.5 mm/min, fracture loads were recorded in Newtons (N). Statistical analysis of variance (One–Way ANOVA) and Kolmogorov Smirnov and Shapiro- Wilk test was performed and significance level was set at 0.05.

Results: there was a significant difference between different groups (f=6.54, p=0.005). The highest value was found in Grandio (2572.67±280.28), followed by the control group (2546.94±103.54), while the lowest value was found in e.max (2186.59±352.92). Post hoc pairwise comparisons showed e.max to have a significantly lower value than other groups (p<0.001).

Conclusion: The use of resin composite blocks for fabrication of endocrowns improved the mechanical performance of endodontically treated molars.

KEYWORDS: Endocrown, Endodontically treated teeth; Fracture strength

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INTRODUCTION

Unlike vital teeth, endodontically treated teeth display compromised biomechanical properties due to changes in tooth architecture[1]. The loss of tooth structure in root canal treated teeth may occur due to various factors; including trauma, caries, nonconservative endodontic access cavity preparation, and removal of vital pulp tissue, making the tooth weaker and more liable to fracture[2]. This direct relationship between the amount of the remaining tooth structure and the fracture resistance of endodontically treated teeth, makes the appropriate restoration of endodontically treated teeth a challenging procedure that affects their prognosis and survival rate[3]. Endodontically treated teeth restored with different coronal restorations fracture differently than intact teeth. Therefore, appropriate restorative materials in the appropriate design should be used[4].

There feldspathic of treatment protocols for managing the restoration of endodontically treated badly decayed molars with nonconservative access cavities that are exposed to greater occlusal forces to protect them against probable fracture, but none of them is considered to be optimal in all cases[5,6]. Post, core, and crown are one of the main options of different restorative protocols for molars that have undergone root canal treatment because of the excellent functional factors involved.[7,8,9,10]. There are cases in which a post and core may be difficult or not possible for a tooth. The use of post, core, and crown is limited in teeth with variable root anatomy, severely curved or short roots, narrow root canals, small intermaxillary spaces, and high cost. An alternative conservative option to the use of post and crown to restore the endodontically treated molars is the endocrown, which provides minimally invasive procedures and maximum tissue protection.[11,12,13]

In 1999, Bindl and Mormonn, defined the endocrown as "ceramic restoration workpieces compromising the entire crown and an integrated, apically protruding retention part[14]. The endocrown is made of ceramic or composite resin. It is a partial crown with a full occlusal coverage, cemented to the root canal treated teeth with resin. Unlike the conventional posts, cores, and crowns, the endocrowns are fixed to the internal part of the pulp chamber and on the cavity margins, to increase the macroscopic and microscopic mechanical retention provided by the pulp cavity and adhesion surface [15].

Different materials such as feldspathic and glass-ceramic, computer-aided manufacturing (CAD/CAM) ceramics, and composite resins, hybrid composite, and computer-aided design are used for the manufacture of endocrown to improve esthetics and increase the fracture resistance of root-filled teeth.[16,17] E-max CAD is a monolithic lithium disilicate glass-ceramic that is a highly esthetic and biocompatible restoration. It also has high mechanical properties such as high flexural strength and modulus of elasticity.[16] However, its durability and machinability may be compromised as it is brittle, stiff, and hard.[18]

A new generation of biocompatible nanohybrid composite restorative materials (Grandio blocs, VOCO GmbH, Cuxhaven, Germany) has recently been used for indirect restorations. The physical and mechanical properties of these materials are similar to those of natural tooth tissues. The modulus of elasticity of the nanohybrid resin restorative materials is similar to that of dental dentin (18.0 GPa) providing the advantage of better flexural strength and less crack propagation than some of the CAD/CAM ceramic materials.[19,20] A fewer researches has been made on CAD/CAM composite blocks to evaluate their clinical success and performance, therefore this study aimed to assess the effect of using resin composite blocks for fabrication of endocrowns versus ceramic blocks regarding the fracture strength of endodontically treated mandibular molars.

The null hypothesis tested in this study is that there will study is that difference between ceramic reinforced CAD/CAM hybrid resin composite blocks and e.max CAD blocks regarding fracture strength when restoring endodontically treated mandibular molars with endocrowns .

MATERIALS AND METHODS

A two types of CAD/CAM blocks were used in this study as the following: Grandio Bloc with high filler loading (HFL) about 86% filler and e.max CAD blocks. The materials used in this study, their composition and manufacture are presented in ***table 1***.

Teeth selection

In this study, thirty human mandibular second molars that were recently extracted for periodontal reasons, sound, crack-free and free of caries were selected. Selection was based on similar dimensions buccolingually and mesiodistally. The average dimensions of the selected teeth were (7 ± 0.5 mm) buccolingual width, and mesiodistal width (9 mm ± 0.5mm). A digital caliper was used to measure all dimensions at the level of the proximal cementoenamel junction (C.E.J). Molars with other dimensions were excluded. These measurements were used to ensure uniformity of tooth size across

Table (1) Product name, composition and manufacture of tested material

Product	Description	Composition	Manufacturer
Grandio Blocs HFL	Nano-ceramic hybrid CAD / CAM composite block for the fabrication of permanent, aesthetic single-tooth restorations	86% Nanohybrid Filler 14% UDMA+ DMA	VOCO GmbH, Germany, Cuxhaven
e.max CAD blocks	Glass ceramic CAD / CAM block for the fabrication of permanent, aesthetic single-tooth restorations	Lithium disilicate glass ceramic	Ivoclar Vivadent AG,FL-9494 Schaan/ Liechtenstein Germany
Duo-Link universal	Dual cured resin luting cement	Base: 10-20% Ytterbium Fluoride, 10-30%Bisphenol A Diglycidylmethacrylate,10-30% Urethane Dimethacrylate, 1-5%Ytterbium Oxide-Silica, 1-5%Tetrahydrofurfuryl Methacrylate,1-5% Trimethylolpropane Trimethacrylate, >2 3-(Trimethoxysilyl)propyl-2-Methyl-2-Propenoic Acid Catalyst: 10-30%Bisphenol A Diglycidylmethacrylate, Dibenzoyl Peroxide,>1 technically pure	Bisco, Inc. Schaumburg USA
Futura bond DC	Dual curing self etching bond reinforced with nanoparticles	50-100%Acidic adhesive monomer, 5-10% BIS GMA, 5-10% 2hydroxyethyl methacrylate	Voco GmbH, Germany, Cuxhaven
Bis-Silane	Silane coupling agent	Part A: 85% ethanol, 5-10% 3 trimethoxysilyl propyl-2-methyl-2-propenoic acid Part B: 30-50%ethanol, 1-5% (85%phosphoric acid)	Bisco, Inc. Schaumburg USA
Hydrofluoric acid	Glass ceramic etching gel	9.5% Hydrofluoric acid gel	Bisco, Inc. Schaumburg USA

the different groups. An ultrasonic scaler (Satelec, Cedex, France) was used to clean, scale the teeth, while a rotating brush and pumice were used to polish the crowns after removing all gingival remnants. To avoid teeth dehydration and to prevent cracking during preparation all the selected extracted teeth were preserved in distilled water at room temperature from the day of extraction until the time of testing.

Teeth were randomly divided into three groups (n=10 each). Gp 1 (control) was left intact. Gp 2 and 3 (n=10 each) were endodontically treated, prepared to receive endocrowns using CAD CAM. Groups 2 and 3 were individually scanned, endocrowns were designed and milled in Grandio blocs (Nano ceramic hybrid blocks,-CAD/CAM Materials, VOCO GmbH, Germany)CAD E.Max, and Lithium disilicate glass ceramic blocks UP CAD (Shenzhen Upcera Dental Technology Co., Ltd., China) respectively.

Sample preparation

For each molar in groups 2 and 3, an endodontic access cavity was prepared using a No. 2 round carbide bur (Mani, Utsunomiya, Japan), followed by an ENDO-Z bur (Dentsply, Switzerland) mounted in a high-speed water-coolant handpiece. The working length was determined by passively inserting the K-File #10 into each root canal until the tip of the file could be seen at the root apex. The working length was 1/2 mm before apical foramen. All root canals were instrumented to the full working length using Ni-Ti rotary system (ProTaper Next, Densply Germany) up to file X3 as a master apical file. NaOCl 2.5% and EDTA 17% were used for irrigation with a 27-gauge needle. Glyde (Glyde File Prep Root Canal Conditioner@Densply Maillefer) was used as a lubricant throughout the preparation. All root canals were dried with paper points and obturated with the Protaper Next gutta percha point X3 was coated with sealer (Tubli-Seal EWT, SybronEndo) using the single cone technique. Excess gutta-percha was removed to canals orifices with a heated cutter (System B Heat Source, Kerr Dental) and the coronal part was vertically compacted with a plugger. Internal and interproximal cavities were then prepared following a minimally invasive approach with minimal tooth preparation simulating the extent of caries usually present in the interproximal region as shown in figure 1. In order to ensure a three-dimensional filling of the root canals, radiographs were taken. The teeth were sealed with a thin layer of flowable composite (Filtek Z350, 3M ESPE Dental Products, St. Paul, USA) and light-cured for 20 seconds following etching the floor of pulp chamber with 37% phosphoric acid then stored at 37°C and 100% humidity.

To mimic the clinical situation of the periodontal ligament as closely as possible and to facilitate handling of the teeth during instrumentation, the roots of the teeth of all groups were fixed in epoxy resin blocks placed in a specially designed cylindrical acrylic mold[21]. To simulate the anatomical relationship with the alveolar ridge, the cementoenamel junction of each tooth was positioned 1.5 mm above the resin margin.[22,23].

Endocrown Preparation

A standardized OD cavity was prepared in mandibular molar teeth using the #4261 inlay preparation kit (Komet Inlay preparation Kit, Brasseler, GmbH, Germany) in a high-speed handpiece with water spray, in a following sequence starting with #845KR, then #8845 KR and ending with #845 KREF. The preparation has standardized dimensions with an overall intracoronal occlusal divergence of 8 degrees toward the occlusal surface and flat occlusal preparation to achieve a pulp chamber rectangular in shape and 5 mm from the cavosurface margin, with rounded internal line angles[24]. A circumferential axial preparation 90-degree with butt joint margin or cervical sidewalk preparation at a level of 2.5 mm below the prepared occlusal surface were made. The buccolingual dimensions of the proximal extension were 5.0 mm. All preparations were free of undercuts and the angle between the gingival floor and axial walls was 90°. During cavity preparation, the cavity dimensions were checked with a digital caliber.

Prior to digital scanning, prepared teeth were air-dried for 10 seconds and sprayed with anti-reflective optical scanning powder. Subsequently, all specimens in groups 2 and 3 were scanned in different directions using "dof freedom full HD" scanner to create a virtual 3D model, as shown in Fig 2.

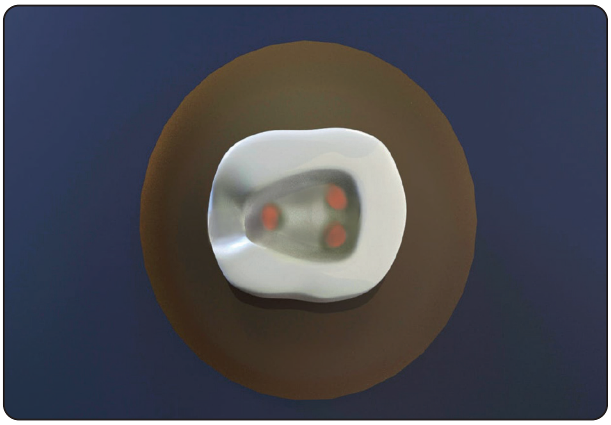

Fig. (1) diagram representing the obturated molars minimal tooth preparation simulating the extent of caries, OD cavity

Using "Exocad Dental B 2.4 Plovdiv" software, 20 endocrowns were designed from scanned models, with all parameters such as insertion axis, margin placement, occlusal thickness, and cement gap set by default.

The selected appropriate size of IPS E. Max/ CAD and composite blocks for the fabrication of the endocrown were milled using the "imes-icore coritec 250" 5-axis milling machine, following the manufacturer's instructions. The milled composite endocrowns were adjusted and finished according to the manufacturer's instructions using the recommended finishing tools. For finishing and glazing the IPS e.max CAD restorations, IPS e.max CAD paste was applied to the outer surface of the endocrowns and a crystallization firing was conducted in a ceramic furnace according to the manufacturer's instructions. The endocrown restorations were placed on the crystallization tray in the firing chamber and the firing process was started using a stored firing program. At the end of the program, the crystallization tray was removed and the endocrown restorations were allowed to cool to room temperature in a dry place. All the finished endocrowns (Lithium disilicate glass ceramic and composite) were fit checked and verified for complete seating and adaptability, each on their respective prepared molar.

Restoration cementation procedures:

Surface treatment for Grandio group:

The prepared teeth were cleaned with a fluoride-free cleaning paste and brushed, rinsed, and dried with water and oil-free air. The fitting surfaces of all restorations were then silanized according to manufacturer instructions using Bis-Silane (Bisco) for 60 seconds and air dried for 5 seconds then bonding agent Futura bond DC was applied according to the manufacturer instructions using micro brush on the restoration fitting surface and the cavity walls and margin then light cured for 10 seconds using LED curing unit (Dr's light AT, Good doctors co.ltd. Korea) with light intensities (1400 mW/cm2).

Surface treatment for E. max group:

Before cementations the endocrowns were etched on their internal surfaces with 9.5% hydrofluoric acid gel for 20 seconds following the manufacturer's instructions, and thoroughly rinsed with water for 20 seconds then dried with oil-free air. Then, their internal surfaces with 30% phosphoric acid gel for 15 seconds following the manufacturer's instructions, and thoroughly rinsed with water for 20 seconds then dried with oil-free air[25]. Finally, the fitting surfaces of all restorations were then silanized according to manufacturer instructions using Bis-Silane (Bisco) for 60 seconds and air dried for 5 seconds.

Cementation procedures:

Dual-link universal resin cement (Bisco) was then used for cementation of the restoration. The endocrowns were placed on the corresponding models by static finger pressure, then loaded axially with a static load of 5 kg. initial light curing for 3 sec from all aspects and after removal of excess cement, light cured for 40 sec from all aspects[26,27,28] figure 3.

Loading Test

For measuring fracture resistance, all the specimens were loaded into a computer-controlled material testing machine ((Model 3345; Instron Industrial Products, Norwood, MA, USA) with a load cell of 5 kN and data were recorded using computer software (Instron® Bluehill Lite Software).). The specimens were compression-loaded occlusally at a crosshead speed of 0.5 mm/min. The load at failure manifested by an audible crack and was confirmed by a sharp drop at the load-deflection curve recorded using computer software (Bluehill Lite Software Instron® Instruments) figure 4. The maximum load required to produce fracture was determined in Newtons (N)

Failure mode analysis

Fractured teeth were examined with USB digital microscope at 25X magnification and photographed using image analysis software (View Ti Capture 1.3.0.1). In the Grandio group, a mixed type of failure was detected; cohesive failure either within restoration and adhesive failure along cement line. in E. Max group, A mixed type of failure was detected; cohesive failure either within the tooth and restoration and adhesive failure along cement line, figure (5).

Sample size calculation

A pilot study was conducted using three specimens from each group. The mean values were 2539.8, 2388.6 and 2116.3 Newtons, respectively and the common standard deviation was assumed to be 250 Newton. The effect size f was (0.701). Using alpha (α) level of (5%) and Beta (β) level of (20%) i.e., power = (80%); the minimum estimated sample size was a total of 24 samples. Sample size was increased to 10 samples per group to compensate for any loss of samples during the study procedure. Sample size calculation was performed using G*Power Version 3.1.9.2.

Statistical Analysis

Numerical data were presented as mean and standard deviation (SD) values. Shapiro-Wilk's

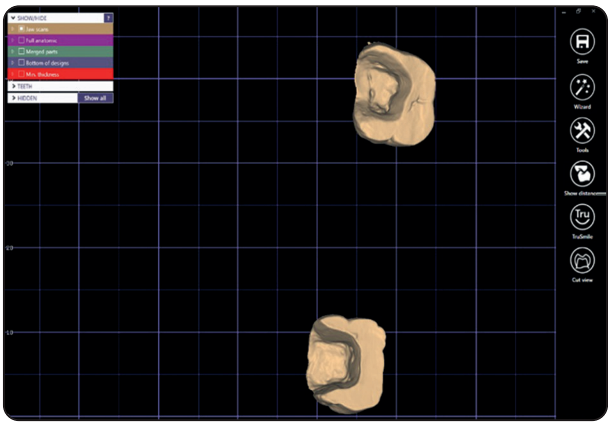

Fig. (2) Showing a virtual 3d model of scanned groups 2,3

Fig (3) Diagram showing endocrown placed on the corresponding models.

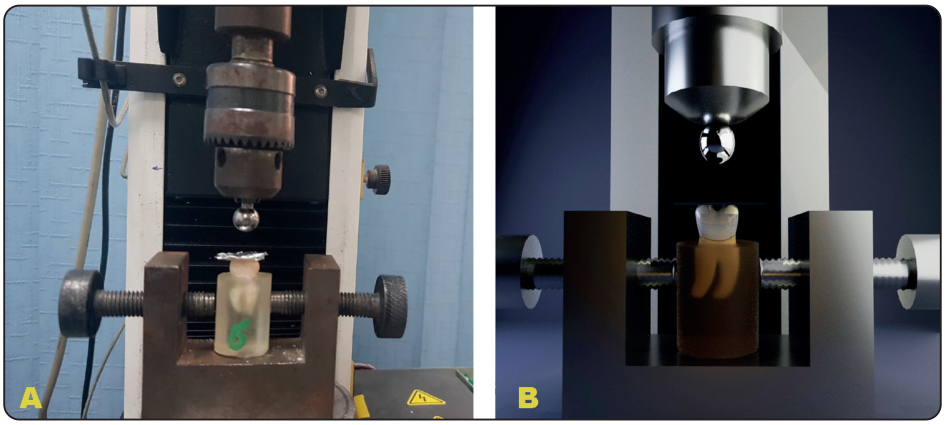

Fig. (4 a,b), Showing specimens were loaded into a computer-controlled material testing machine

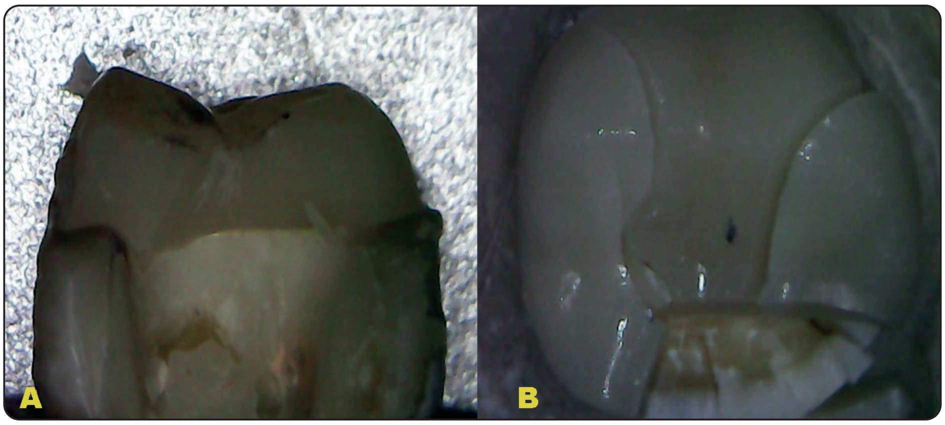

Fig. (5 a,b): Mixed failure mode was detected

test was used to test for normality. Homogeneity of variances was tested using Levene's test. Data were parametric and showed variance homogeneity so they were analyzed using one-way ANOVA followed by Tukey's post hoc test. The significance level was set at $p<0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.1.3 for Windows*.

RESULTS

Results of intergroup comparisons presented in table (2) showed that there was a significant difference between different groups ($f=6.54$, $p=0.005$). The highest value was found in Grandio (2572.67±280.28), followed by the control group (2546.94±103.54), while the lowest value was found in Emax (2186.59±352.92). Post hoc pairwise comparisons showed Emax to have a significantly lower value than other groups ($p<0.001$). Maximum load values for different groups are presented in figure(6).

TABLE (2): Intergroup comparisons of maximum load (N)

Maximum load (N) (Mean±SD)			*f-value*	*p-value*
Control	*Grandio*	*Emax*		
2546.94± 103.54^{A}	2572.67± 280.28^{A}	2186.59± 352.92^{B}	**6.54**	**0.005***

Means with different superscript letters within the same row are significantly different; *significant (p<0.05)

* R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

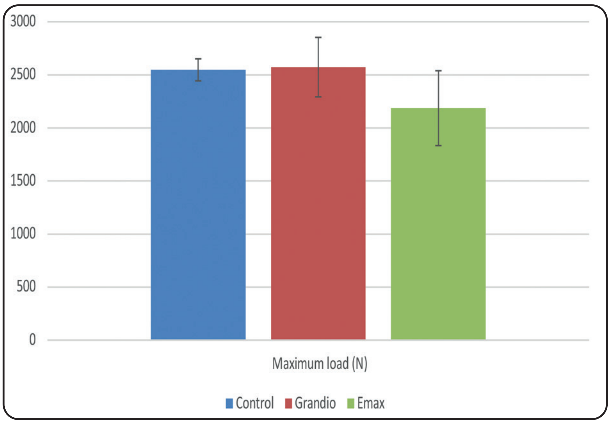

Fig. (6) Bar chart showing mean and standard deviation values for maximum load (N) in different groups

DISCUSSION

One of the debatable issues in restorative dentistry is restoration of root canal treated teeth. Various treatment protocol options, materials and designs are available. As adhesive dentistry advances, conservative treatment modalities such as endocrowns have become a reliable alternative treatment for conservative restoration of endodontically treated molars[15]

The endocrown is a partial crown made of ceramic or composite that is attached to the post-endodontic teeth with resin cement. This restoration covers the entire occlusal area and uses the pulp chamber to increase the bonding surface.[16,18] In the preliminary stage when the cavity is removed and pulp tissue is removed, evaluation of teeth adhesion properties of the remaining healthy coronal structures of root canal treatment teeth is done. This evaluation includes the residual tooth structure that must be healthy, without fissure, and of 1 mm minimal thickness. A part of the resin will serve as the basis for the definitive restoration, so it is necessary to detect thin cavity walls before reconstructing the pre-endodontic build up with composite resin.

It was noticed that CAD/CAM composite blocks had different microstructure as well as variable filler weight percentages and hence differences in the tested mechanical properties. However, it seems that the filler percentages have a more considerable role in these properties than do the microstructural constituents.[29] Thus in the current study CAD/CAM resin composite and E.Max blocks were used for endocrowns fabrication to restore OD cavity in endodontically treated molars and then subjected to fracture resistance test to determine their mechanical performance under load.

In this study ceramic reinforced CAD/CAM hybrid resin composite blocks were used. The aim of any dental restorative material is to have similar characteristics to that of the tooth structure particularly when there is extensive loss in tooth structure involving one or both marginal ridges as in case of onlays, overlays in vital teeth or endocrown in endodontically treated teeth. Hence, resin ceramic combination in a network structure exhibits the positive characteristics of ceramics and resin. This material has low rigidity, hardness, and stiffness but high flexibility and fracture toughness. Resin with dispersed ceramic fillers has good fracture and wear resistance and high compressive strength. CAD/CAM composite materials have comparable hardness and elastic moduli to tooth structure. Also, it combines ceramic good strength with composite lower hardness.[30]

The experimental use of natural teeth presents problems due to anatomic variations and the heterogeneous nature of tooth matter. The selection of intact natural mandibular molar seemed to represent the acceptable possible option to simulate clinical situations. The average dimensions of the selected teeth were (7 ± 0.5 mm) buccolingual width, and mesiodistal width (9 mm ± 0.5mm). A digital caliper was used to measure all dimensions at the level of the proximal cementoenamel junction (C.E.J) in order to standardize the molar size to obtain reliable data.[31] A paralleling device (surveyor) was used to mount each tooth inside the acrylic block to be exactly parallel to its long axis to assure that the mechanical load will be applied on the desired angulation to provide the most accurate results.

For OD cavity design, an inlay preparation kit was used in order to obtain standardized OD cavities in molar teeth. All of the burs are diamonds, have rounded tips that develop a smooth transition between the floor and wall surfaces of the preparation; eliminating the sharp edges so decreases the chances of postoperative tooth fracture. The burs' built-in taper of 6° to 10° delivers an ideal insertion path for the restoration once it is completed. All of the burs in the kit have different width, allowing the practitioner to select the minimal dimension of buccolingual preparation required for a successful restoration. Furthermore, the burs create a 90° angle at the cavosurface margin for easier cementation and an enhanced functional distribution of forces on the occlusal surface.[32]

The fracture resistance test in this study was performed by universal testing machine at a cross head speed of 0.5mm/min according to the ISO standard recommendation for the rate of loading as this cross-head speed is more sensitive in measuring the fracture resistance of restored teeth. The compressive load was applied by mean of steel cylinder with a rounded end of 5.7 mm diameter adjusted parallel to the long axis of tooth. The rounded end was contacting the occlusal inclined planes of both buccal and lingual cusps beyond the margin's restorations. [33, 31]

The result of the present study shows that both tested materials were able to restore the tooth fracture resistance close to the control non restored tooth and this was in agreement with Reymus et al[34]. Resin composite has a lower elastic modulus so more load is absorbed within the composite restorations and it transmits less of the applied load to the underlying tooth structure. More flexible and less rigid materials may be desirable for the restoration of posterior teeth given the inherent ability of teeth to flex under occlusal loading.

In other words Rosentritt et al[35] stated that there was a trend to a correlation between in vitro performance and fracture results and the individual material properties: as expected materials with lower modulus of elasticity and flexural strength provided lower fracture resistance. Previous studies have shown that resin-based materials and composites have higher shock absorbing capacity than ceramics

The null hypothesis of this study can be confirmed as the result show a significant difference in fracture resistance of Grandio Bloc with its high filler loading and E.Max CAD blocks. Matzinger et al 2019[29], stated that can probably be attributed to a balanced mixture of small (.20 nm) and medium fillers (.1 ƒÊm) in the resin composite which improve both physical and mechanical properties of this material.

The explanation for the mixed type of fracture mode" adhesive and cohesive within the restoration" in the current study is that the adhesively bonded restoration using low modulus restorative materials may not only restores the missing tissues, but also reinforces the remaining structure of the prepared tooth, as it limits the stress intensity transmitted to the remaining tooth structures. Thus, composite resin endocrowns used in the present study may redistribute stresses and may present elastic biomechanics similar to those of the sound tooth.[36]

CONCLUSION

Under limitations of current study, the following conclusion can be driven: the proper balance between filler and polymer matrix was able to improve the mechanical performance of resin composite blocks. The use of CAD/CAM resin composite could be considered a good choice for endocrowns fabrication to restore endodontically treated molars.

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