

FRACTURE RESISTANCE OF ENDODONTICALLY TREATED MAXILLARY PREMOLARS RESTORED WITH ENDOCROWNS WITH DIFFERENT PREPARATION DEPTH. IN VITRO STUDY

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ABSTRACT

Purpose: The aim of the study was to assess the effect of different endocrowns extensions inside the pulp chamber on the fracture resistance and failure mode of maxillary premolar.

Materials and methods: Twenty four single rooted upper premolars were root canal treated, arbitrarily divided into three main groups (n=8) according to extension of endocrowns inside the pulp chamber (GI= 2mm, GII= 3mm and GIII= 4 mm). Endocrowns were made-up from Brilliant Crios (BC) CAD/CAM blocks and cemented with adhesive resin cement. Teeth were subjected to thermo-cycling and then to 45° oblique compressive load until fracture. The fracture resistance and failure modes were determined. Data were analyzed with One Way ANOVA followed by Tukey's post hoc test for multiple comparisons.

Results: The fracture resistances were significantly different between all groups; GII scored the highest mean fracture resistance value (647±72.37 N) followed by GI (475.6±69.92 N), and the lowest was scored by GIII (353.9±61.02 N). Regarding fracture analysis of different preparation depths; Gr I showed highest reparability percentage followed by Gr II and Gr III; there was significant difference between Gr (I) and Gr (II) and between Gr (I) and Gr (III) as P-value < 0.05. While, there was insignificant difference between Gr (II) and Gr (III) as P-value > 0.05 as revealed by Chi Square test.

Conclusion: Different extensions of endocrowns inside the pulp chamber affect the fracture resistance and failure mode of upper premolar.

INTRODUCTION

Restoring endodontically treated teeth with massive destruction of the coronal part is still a clinical challenge, particularly due to the loss of its strength after removing the pulp and surrounding dentine tissues. The retention of the restoration

with those mutilated teeth is poor, so the use of intraradicular post and core to retain the crown is required.⁽¹⁾

Even with all clinical success using intraradicular posts, there is a lot of drawbacks of this system; it requires removal of sound dentine from the root

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canal that makes it weak and fragile, sometimes root fracture because of the incompatible modulus of elasticity with radicular dentin⁽²⁾. Moreover; in cases of curved, dilacerated and decalcified root; the placement of the post will be limited. As well separation of the composite core from the post in cases of fiber posts and root fracture risk in cases of metal post⁽³⁾.

An alternative restoration to endodontically treated teeth is the endocrown restorations. Bindl and Mormann⁽⁴⁾ were described the endocrown as adhesive restorations consisting of the entire core and crown as a single monolithic restoration. (i.e. monobloc). Endocrowns bonded to the pulp chamber and the cavity margins, consequently achieving macromechanical retention supplying by the axial opposing pulpal walls and micro-retention/chemical bonding attained with the usage of adhesive cementation.⁽⁴⁾

Restoring molars with endocrowns offer higher strength and fracture resistance during loading than molars restored with conventional post, core and crowns⁽⁵⁾. A 5-year clinical study reveal 87.1% of posterior teeth restored with endocrowns functioned perfectly without debonding or fracture⁽⁶⁾. Due to the advantages of endocrown on molar teeth, endocrowns should also be recommended for premolar teeth. In a clinical study, Bindl and Mörmann⁽⁷⁾ assessed the exhibition of 208 endocrowns on premolars and molars, and discovered that the premolars offered more failures due to adhesion loss. Debonding of endocrowns on premolars is promoted to be due to the bonding area was smaller than molars, and the greater ratio of the prepared tooth structure to the overall crown might have caused a higher leverage for premolars than for molars.⁽⁸⁾ Moreover, maxillary premolars are subjected to more lateral forces, which may affect fracture resistance.⁽⁹⁾

Another attention is the use of innovative and flexible composite CAD/CAM milling blocks reinforced by nanoceramics as an alternative to ceramic ones that were firstly designated for

endocrown⁽⁹⁾. Brilliant Crios (BC) is a reinforced composite material with an inorganic filler (71% by weight) holding less than 20- μ m silica and less than 1- μ m barium glass⁽¹⁰⁾. Contrasting traditional composites, CAD/CAM composites are polymerized at high pressures and temperatures, which provides them greater mechanical properties that may make them desirable for usage in high occlusal forces Areas.⁽¹¹⁾ From a biomimetic viewpoint, these less brittle composite CAD/CAM blocks exhibit mechanical properties closely to human dentin⁽¹²⁾.

However, there is a lack of information about different extensions of endocrowns inside the pulp chamber in an attempt to increase the retentive surface area using a novel CAD/CAM material to restore extensively decayed premolars. So the aim of the current study was to compare the fracture resistance of single rooted upper premolar teeth restored with BC endocrowns with three different pulp chamber extensions (2mm, 3mm and 4mm depth). The null hypothesis of this study was that the chamber depth would not affect the fracture resistance, nor failure type of upper premolar endocrowns.

MATERIALS AND METHODS

Sample Size Calculation

Sample size calculated depending on a previous study⁽¹³⁾ as reference. According to this study, the response within each subject group was normally distributed with standard deviation (21.6). If the true difference in the experimental and control means is (34.8), minimally the study needed (7) subjects in each group to be able to reject the null hypothesis that the population means of the experimental and control groups are equal with probability (power) (0.8). The Type I error probability associated with this test of this null hypothesis is (0.05).

Teeth selection

Twenty four decay free extracted single-rooted upper premolar were collected for the study. A magnifying lens was used to inspect the teeth.

After measuring the mesio-distal and bucco-lingual dimensions using a metal caliper crowns were selected to be with comparable dimensions.

Teeth mounting

Natural teeth were fixed in orthodontic acrylic resin blocks using a ready-made round plastic shape sample holder in a vertical direction using a dental surveyor, teeth were embedded in the resin blocks as the cemento-enamel junction (CEJ) is 2 mm above the resin.

Endodontic treatment

Access cavities were prepared with a round bur using a high speed hand piece under water coolant. The working length was measured using a K-file size 15 and a radiograph. Rotary system (Protaper, Dentsply, Maillefer, Ballaigues, Switzerland) was used for manipulating root canal till files size F3 Irrigation was completed using sodium hypochlorite 4.2% in between files. Paper points (Dentsply-Maillefer, Ballaigues, Switzerland) were used for drying root canals. The prepared canal was built-in by using a master cone of a size F3 with a tug-back stroke to attain the full working length. The gutta-percha point was coated with Resin sealer (ADSEAL, MetaBiomed, Korea). Excess gutta percha was detached with hot instrument and vertically condensed with a heated plugger. The access cavities were closed with temporary filling material (Cavit, 3M ESPE, Seefeld, Germany). All teeth were decoronated till 2mm above the proximal CEJ using Computerized Numerical Control milling machine (C.N.C Premium4820, imes-icore, Germany). The CNC milling machine was accustomed to prepare the teeth with 90 butt margin design. The prepared teeth were haphazardly divided into three groups (n=8) and received pulp chamber restorations to achieve symmetrical pulp chamber floors at depths of 2, 3, and 4 mm from the butt margin using a three-step etch-and-rinse adhesive (Optibond FL, Kerr Corporation, Orange,

CA, USA) and a dual cured flowable composite (Charmcore, Dentkist, Korea), then light cured by (Elipar S10, 3M ESPE, Seefeld, Germany). The preparation depth was standardized with periodontal probe and rubber stopper positioned taking the butt margin as reference point:

- Group I (Gr 2mm): 8 samples were prepared with 2 mm chamber extension.
- Group II (Gr 3mm): 8 samples were prepared with 3 mm chamber extension.
- Group III (Gr4mm): 8 samples were prepared with 4 mm chamber extension.

The CNC milling machine was attuned to prepare the premolars; all the internal walls were prepared to eliminate undercuts with an 8° coronal divergence using a tapered diamond-coated stainless-steel bur with a rounded end (Hager and Meisinger GmbH, Berlin, Germany) held perpendicular to the pulpal floor. An oval shape preparation was resulted with (4.5mm buccolingual and 2.5 mm mesio-distal) dimensions⁽¹³⁾. All internal line angles were smoothed and rounded.

Construction of Brilliant Crios CAD/CAM endocrowns

First the preparations were scanned using Bluecam and the CEREC 3D software (version 4.3) for designing the endocrowns. Standardized endocrowns were milled with the CEREC MCX5 milling (Sirona, Bensheim, Germany) (MD distance between proximal contact areas: 6.56 mm; distance between buccal and lingual faces: 8.88 mm; height from the margin to the top of the buccal cusp: 7.42 mm; height from the margin to the top of the lingual cusp: 7 mm); this will assured standardization of the point of load application during testing; with 50µm spacer. Then the restorations were milled from Brilliant Crios Blocks (Brilliant Crios, Coltene, Switzerland). All endocrowns were checked over there corresponding teeth for seating.

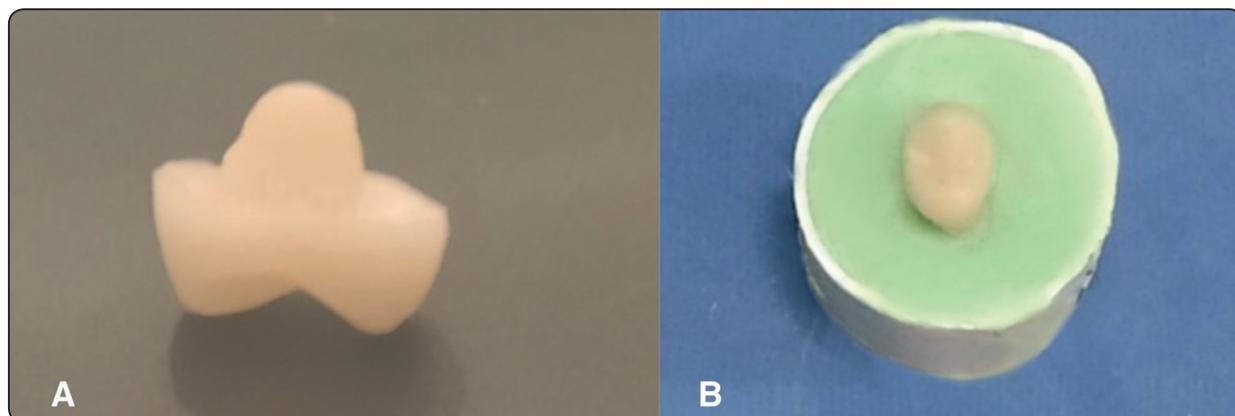


Fig. (1) a) Fitting surface view of endocrown after milling. b) : Occlusal view of endocrown after cementation.

Bonding procedures

Prior to cementation, endocrown fitting surfaces were treated according to the manufacturers' instructions. BC Endocrowns were sandblasted with 25–50 μm Al_2O_3 powder (0.15 MPa/1.5 bar pressure). A silane coupling agent (3M ESPE Dental Products, St. Paul, MN, USA) was applied to the fitting surfaces and air-dried for 60 s, subsequently, adhesive agent was applied for 20 s and air-dried. The prepared teeth were cleaned with fluoride free pumice for 15 seconds, rinsed thoroughly with water for 15 seconds. The enamel of all preparations were etched for 30 s with 37.5% phosphoric acid (Ultra-Etch, Ultradent Products), rinsed, and dried. Self-adhesive resin cement (RelyX Unicem 2 Automix, 3M ESPE, Seefeld, Germany) was applied to the fitting surface of the endocrowns. Then each endocrown was bonded to its corresponding tooth with finger pressure, excess cement was removed immediately with a microbrush. A static load of 3 Kg was applied on the occlusal surface of the cemented endocrowns using a specially designed loading device, the endocrowns left under the static load for 5 minutes, then light cured with a LED curing unit (Elipar S10, 3M ESPE, Seefeld, Germany), at each surface for 20 seconds according to manufacturer's instructions. All samples were thermo-

cycled for 5000 cycles between 5° and 55° with the dwell time of 30s dwell time in a thermal cycling machine (C-501F, Will laboratory supplies LTD, Suzhou, China). Then, the samples were stored in a saline for 24 hours before testing.

Fracture resistance determination

Each sample was fixed in a universal testing machine (Model LRX-plus; Lloyd Instruments Ltd., Fareham, UK), Then a load was applied at a cross-head speed of 1.0 mm/min and at an angle of 45° to the long axis of the tooth using with a stainless-steel sphere (3.4 mm in diameter) contacting the palatal plane of the buccal cusps until fracture (Fig. 2). The fracture resistance of each specimen was recorded in Newton. All data were statically investigated.

Fracture mode

Following the fracture resistance test, fracture mode all samples were inspected visually and by Digital microscope (U500x Digital microscope, Guangdong, China). Each sample was snapped using USB Digital microscope with a built in camera connected with a compatible personal computer using a fixed magnification of X30. The samples were examined to decide different fracture modes.⁽¹⁴⁾



Fig. (2) Fracture resistance test with a Universal testing machine.

- Favorable Failures: repairable fractures of the teeth above cemento-enamel junction (CEJ) and fractures in the restorations. (Figure 5; a, b, c)
- Unfavorable Failures: non-repairable fractures below the CEJ including vertical root fracture. (Figure: 5d)

Statistical analysis

Collected data were obtained through laboratory tests of Endo- Crown fracture resistance and fracture analysis. Data were statistically analyzed by Microsoft Excel[®] 2016, Statistical Package for Social Science (SPSS)[®] Ver. 24. and Minitab[®] statistical software Ver. 16. Fracture resistance data were revealed as mean and standard deviation while fracture analysis data were revealed as counts for further statistically analysis. Using One Way Analysis of Variance (One Way ANOVA) followed by Tukey`s post hoc test for multiple comparisons, Chi Square test was done for comparison of different failure modes.

RESULTS

Influence of Preparation Depth on Fracture Strength values

Regarding fracture resistance of different preparation depths (mm); mean ± standard deviation of group (I), group (II) and group (III) were (475.6±69.92 N/mm²), (647±72.37 N/mm²) and (353.9±61.02 N/mm²) respectively, Gr II recorded the highest mean value followed by Gr I, while Gr III recorded the lowest value.

Using One Way Analysis of Variance (One Way ANOVA) followed by Tukey`s post hoc test for multiple comparisons revealed that; there was significant difference between all groups as P-value < 0.05, as listed in table (1) and showed in figure (3).

TABLE (1): Descriptive and Comparative Study of Fracture Resistance (N/mm²) of Endo-crown Restorations according to Different Preparation Depths (mm):

	N	M	SD	P-value
Group (I)	8	475.60 ^a	69.92	0.000000115462*
Group (II)	8	647.00 ^b	72.37	
Group (III)	8	353.90 ^c	61.02	

N; Number, M; Mean, SD; Standard Deviation, P; Probability Level Means with different superscript letter in the same column were significant different using Tukey`s post hoc test

**Significant Different*

Effect of Preparation Depth of Endocrowns on Failure Type

Regarding fracture analysis of different preparation depths, Gr I showed highest repair ability percentage followed be Gr II and Gr III as listed in table (2) and showed in figure (4).

For multiple comparisons of fracture analysis of chamber extension depths regarding repairable and non-repairable specimens using Chi Square test, there was significant difference between group (I) and group (II) from one side and group (I) and group (III) from other side as P-value < 0.05 listed in table

(2). Group (I) showed lower significant percentage than group (II) and group (III). On the other hand, there was insignificant difference between group (II) and group (III) as P-value > 0.05 listed in table (3). Examples of fracture specimens are presented in (Figure 5)

TABLE (2): Descriptive and Comparative Study of Fracture Analysis of Endo-crown Restorations according to different chamber extension Depths

	Non- Repairable	Repairable
Group (I)	2 ^a (25%)	6 ^a (75%)
Group (II)	6 ^b (75%)	2 ^b (25%)
Group (III)	6 ^b (75%)	2 ^b (25%)

Means with different superscript letter in the same column were significant different.

TABLE (3): Multiple Comparative Study of Fracture Analysis of Endo-crown Restorations according to different chamber extension Depths

Preparation Depth (I)	Preparation Depth (J)	P-value
Group (I)	Group (II)	0.025*
	Group (III)	0.025*
Group (II)	Group (III)	1.000

P; Probability Level

Means with same superscript letter in the same column were insignificant different using Chi Square test.

*Significant Different

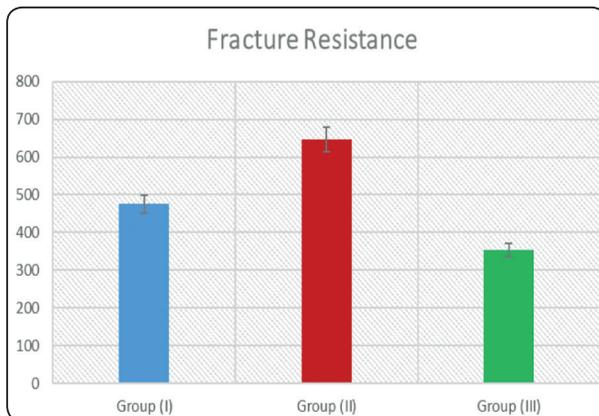


Fig. (3): Bar Chart revealing Descriptive and Comparative Study of Fracture Resistance of Endo-crown Restorations according to Different Preparation Depths

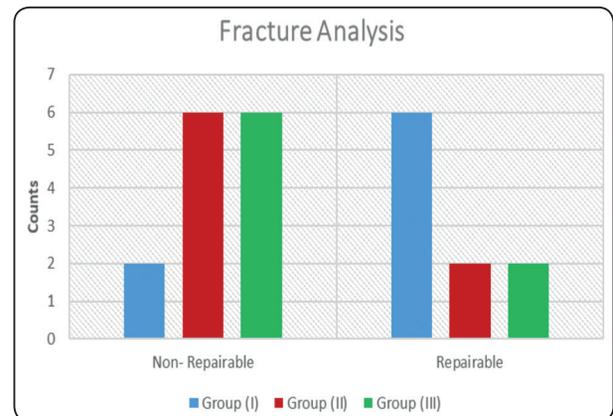


Fig. (4): Bar Chart revealing Descriptive and Comparative Study of Fracture Analysis of Endo-crown Restorations according to Different Preparation Depths

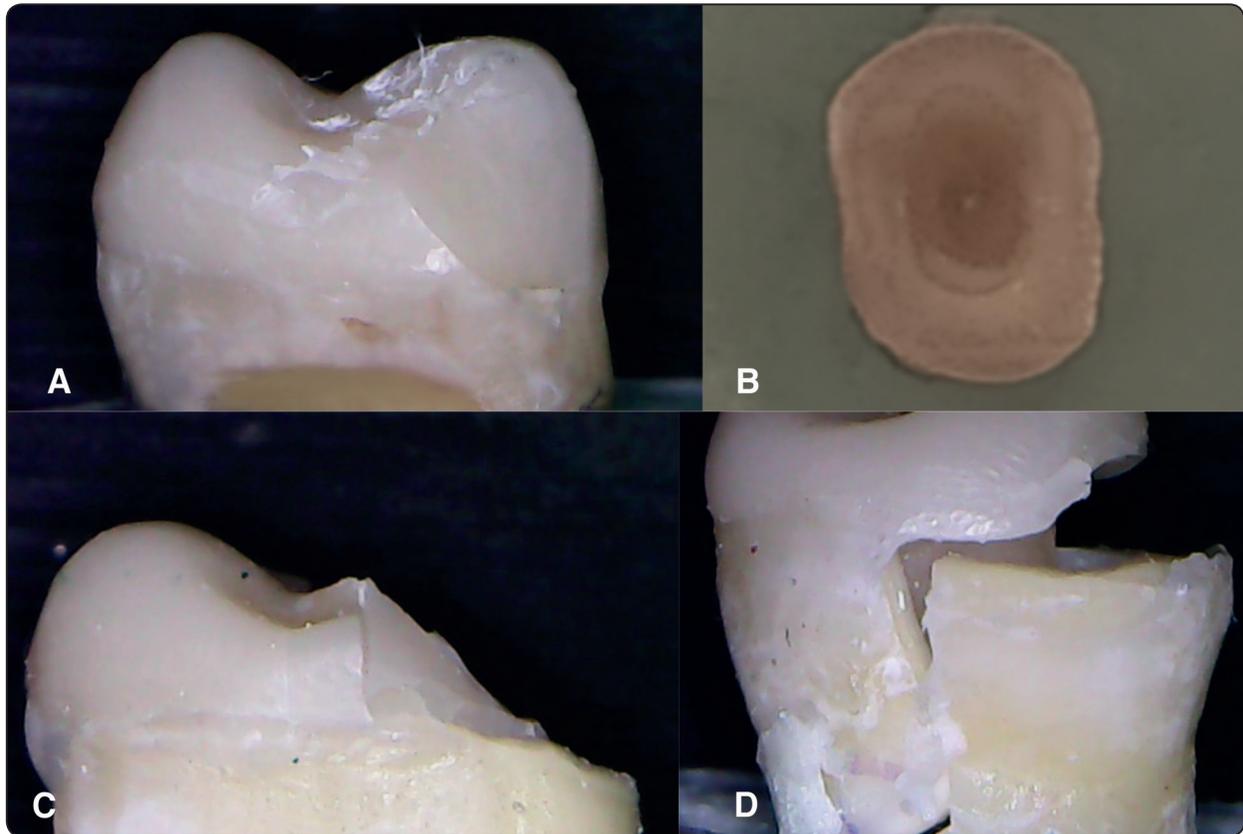


Fig. (5) : Represent mode of failures of endocrowns: a : Repairable failure : failure within the endocrown material. b: Repairable failure: adhesive failure; debonding of endocrowns and dentin. c : Repairable failure: failure within dentin above the CEJ . d: Irripairable failure: tooth fracture under the CEJ with vertical root fracture.

DISCUSSION

The null hypothesis of this study was rejected because a statistical significant effect was found regarding effect of preparation depth on both fracture resistance and failure type of upper premolars endocrowns.

Natural extracted teeth were used in this study because of their modulus of elasticity, bonding characteristics and strength that mimic clinical situation⁽¹⁵⁾. Attention was paid to the selection of teeth with comparable sizes, in which the teeth were selected to be of approximate similarity in size and shape with 10% maximum deviation from the determined mean to eliminate any extreme variation for the maxillary premolars.

Endocrown on maxillary premolars teeth were selected in this study because in previous study⁽¹⁶⁾ showed a non-satisfactory performance compared to molar teeth, according to bond strength and occlusal forces. This is due to smaller pulp chamber and the use of materials with low bonding strength on teeth.

Brilliant Crios (BC) was used in this study because it is an innovative submicron hybrid reinforced composite material with comparable modulus of elasticity of the tooth structure (10.3 GPa); it may improve the flexural strength by the stress absorption ability and improve the bonding to the tooth structure.⁽¹⁰⁾ This is not evaluated in any previous study.

All teeth were decoronated at right angles to the long axis and above the proximal CEJ by 2 mm

to mimic the compromised condition of severely mutilated endodontically treated premolars.⁽¹⁷⁾

The depth of the pulp-chamber extension required by endocrown restorations has not been exactly defined. Bindl and Mörmann⁽⁹⁾ stated that while cavity depth could not be standardized precisely, it should sort between 1 and 4 mm. It has been supposed that the occlusal stresses that occur during function are transferred to the pulp chamber walls. The deeper the pulp cavity and resulting intracoronary extension, the greater the surface area that can be utilized for adhesive retention and transmission of masticatory forces.¹³ The present study explored the possibility of endocrowns on premolar teeth, especially with different pulp chamber depth.

The samples in the study were exposed to lateral occlusal loading to simulate the clinical condition; the forces in the posterior region are perpendicular, but are more angular in the premolar region.⁽¹⁸⁾ Moreover, in group function occlusion, maxillary premolars are exposed to repeated oblique occlusal forces that are translated into high lateral forces. This situation is the worst scenario for maxillary premolars as the risk of tooth fracture and restoration debonding is much higher.⁽¹⁶⁻¹⁹⁾

The specimens were exposed to 5000 thermocycling to clinically simulate the 6 months chewing condition, according to previous studies.⁽¹⁸⁾

Comparing between the groups, Gr 3mm scored the highest mean fracture resistance value followed by Gr 2mm and the lowest was scored by Gr 4mm. G3mm scored higher fracture strength than G2mm because it has deeper pulp chamber depth; there are more surface area for bonding, retention and stress distribution. These results are in agreement with a study of Lise et al.⁽²⁰⁾ who investigate the biomechanical behavior of premolar endocrowns with two different intracoronary depths; they found that 2.5 mm depth was more susceptible to failure than 5 mm depth under lateral occlusal loading. In addition, Dartora et al.⁽²¹⁾ found that larger extension

of endocrowns inside the pulp chamber provided superior mechanical performance, improved stress distribution in endocrowns and superior fracture resistance. On the other side; the results of the present study was contradicted with the result of Ghajghouj and Faruk⁽²²⁾ who found no significant difference of fracture resistance of endocrowns with 2 and 3mm chamber extension. This contradiction could be attributed to the force axis used was at a 90° angle instead of the 45° for the fracture loading test in the current study. Additionally, the results of the present study was also contradicted with the result of Hayes et al⁽²³⁾ who found that the 2 and 4mm chamber extension groups demonstrated the highest fracture resistance, with the 3-mm group similar to the 2-mm group. This contradiction could be attributed to the dissimilarity of the natural teeth used; as mandibular molar teeth were used instead of the upper premolars in the current study.

The unexpected result for Gr 4mm which scored the lowest fracture strength agrees with Hayes et al⁽²³⁾ who found that endocrowns with a pulp chamber of 2 mm in depth showed a higher fracture resistance than teeth with 4mm chamber depth. This could be due to scanning process, software design, and milling effects have an influence on the fitting accuracy of CAD/CAM restoration. Even with the major improvements in CAD/CAM technology systems, there might be some clinical problems.⁽²⁴⁻²⁶⁾ Even though the manufacturer information states that the CEREC Bluecam has a capture depth to 15mm (CEREC AC Operating Manual, Sirona), previous studies found that increasing the preparation depth negatively affected the accuracy of the captured image.⁽²⁴⁻²⁶⁾

Moving to repairing possibility of endocrowns restorations, Gr2mm demonstrated highest reparability percentage (75%) followed by Gr3mm and Gr4mm which scored (25%). The 2- mm pulp chamber extension group shown mostly restoration debonding accompanied with repairable tooth fracture. While seventy –five percent of the 3-mm and 4-mm chamber extensions groups demonstrated

catastrophic (irreparable) fracture. This could be attributed to the pulp chamber depth of the preparations; in Gr 2mm repairing possibility is the highest because the projection of the crown in pulp chamber is very small (2mm) so debonding between the restoration and the tooth will occur without fracturing the root. This explanation was in agreement with Hayes et al⁽²³⁾ who found that endocrowns with a pulp chamber of 3 and 4 mm in depth showed a higher catastrophic failure than teeth with 2mm chamber depth, and the authors recommended that extension cavities not exceed 2 mm because deeper cavities tended to result in more irreparable fractures. Correspondingly Lise et al⁽²⁰⁾ found that a shallow preparation with 2.5 mm intraradicular extension in premolars endocrowns decreased the risk of accidental root fracture than the 5mm extension ; authors attributed this to the minimal removal of sound tooth tissue in 2.5 group that would weaken the tooth-root complex. Authors stated that deeper restoration designs ('5-mm deep endocrown') and the friction against the intraradicular walls provided extra macro-mechanical retention⁽²⁷⁾, while the retention following the '2.5-mm deep endocrown' design relied mainly on pure adhesion. In this situation, the whole interface is located very close to the rotation center of the moment of force created by the oblique load, considering that the extension of 2.5 mm was located above the simulated bone level represented by the embedding resin and didn't fractured the root , which considered an advantage as de-bonded restorations could be re-cemented. Moreover the result of the current study is in consistent with Zhu et al.⁽²⁸⁾ who explored by finite element analysis the effect of remaining tooth structure and restorative material type on stress distribution in maxillary endodontically treated premolars. Authors compared between three different extensions of restoration (1.0 mm, 2.0 mm, and 3.0 mm). They reported that the decreased extension of (1mm) endocrown restoration resulted in decrease in the von Mises stress in coronal dentin and the risk of tooth fracture.

CONCLUSIONS

Within the limitation of this study, the following conclusions were drawn:

- 1) Brilliant Crois endocrowns with 2 and 3 mm pulp chamber extensions provide greater fracture resistance than those with 4 mm as a treatment modality of endodontically treated maxillary premolars.
- 2) Brilliant Crois endocrowns with 3- and 4-mm chamber extension demonstrated mostly catastrophic tooth fracture, whereas the 2-mm chamber extension displayed mostly repairable after failure.

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