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Fracture Strength of Hybrid Ceramic Endocrown Restoration with Different Preparation Depths and Designs

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***Abstract**: Objectives: An in-vitro study evaluating the effect of different preparation marginal designs and depths fracture resistance of Vita Enamic endocrown restorations. Materials and Methods: Forty endodontically treated upper premolars were prepared to be restored with Vita Enamic endocrown resorations. They were divided into two main groups (n=20) according to the preparation marginal design into butt-joint group (B) and (1mm) shoulder finish line group (S).The two main group were subdivided into two subgroups (n=10) according to the extension depth of pulp cavity into (B2&B4) indicating butt-joint prepared teeth with 2mm and 4mm pulp cavity extension depth respectively and (S2&S4) indicating shoulder finish line prepared teeth with 2mm and 4mm pulp cavity extension depth respectively. All endocrowns corresponding to preparation were cemented by self adhesive resin cement (RelyXUnicem). All specimens were thermal aged with 2500 cycles in water bath between 5 ºC and 55 ºC. The fracture resistance test was done by using universal testing machine and all possible failure modes were detected. Results: The highest mean values of fracture load (562.68±23.07 N) was for Group (S4). Statistically, there was significant difference between two different marginal design and no significant difference between the preparation depths within the same marginal design. The fracture mode analysis showed no significant difference among tested groups. Conclusions: The fracture resistance of teeth restored with endocrown restoration can increased by axial wall reduction of shoulder finish line marginal design.*

***Keywords:** Endodontically treated teeth, CAD/CAM, Polymer infiltrated ceramics, Endocrowns and Fracture resistance.*

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I. Introduction

Protection of root canal affected teeth from expected loss is the main aim of endodontic treatment.[1,2]These endodontically treated teeth (ETT)havedecreased stiffness as well as fracture resistance that seem to be related structural integrity loss by trauma, caries or extensive cavity preparation instead of dehydration or physical changes in dentin.[1]So restoration of endodontically treated teeth is considered a clinical challenge.The conventional treatment approach for endodontically treated teeth with coronal substance loss is crown restoration built on core part supported by post fixed to root canal.[3,4] With improvement of adhesive dentistry, an alternative treatment approach to post and core system of sever crown damaged teeth is endocrown restoration.[3]

Endocrown restoration is defined as a type of adhesive restoration consists of entire core and crown as a single unit ,having macroretention from available surface of pulp chamber axial wall and microretention from adhesive resin cement.[5]Endocrown restorations have many advantages such as being conservative technique, eliminating technical steps during fabrication, less time consuming and reduced treatment cost. Teeth with short, obliterated, dilacerated or fragile roots, extensive loss of coronal tissue and limited interocclusal space are indicated for endocrown restorations.[6,7,8,9]

Endocrown restorations preparation differs from that of conventional complete crown as being adhesive restoration doesn't require subgingival margin placement with subsequent gingival inflammation.[1,10]General guidelines of endocrown restorations are 90°butt margin, 2-3mm cuspal reduction ,smooth internal transition and internal taper 6-10 degree.[11,12,13]Utilization of available space inside pulp chamber improve the retention and stability of restoration but the precise dimension of central retentive pulp cavity isn't clearly determined especially with extensive loss of tooth structure where only 1-2 mm of intact tooth structure above cementoenamel junction .The depth of pulp cavity with resulting intracoronal extension has obvious effect in surface area available for adhesive retention and transmission of masticatory force.[5]

Vita Enamic material is appeared as recent type of CAD/CAM material designed to combine the benefits of both ceramic and composite materials and known as polymer infiltrated ceramic. It composed of duel network of dominant ceramic network reinforced by polymer network.[1]Each network penetrates another to create hybrid ceramic. Polymer infiltrated ceramic material is characterized by elastic modulus similar to dentin enabling stress absorption. The high similarity between mechanical properties of both the selected restorative material and sound tooth structure has favorable effect on restorative system reliability. [1,14,15] It also provides wellprotection of opposing teeth from excessive wear and fast machining by CAD /CAM machines.[1,3]

Although several trails exist to compare the fracture resistance of endocrown restoration with different CAD/CAM material, studying the effect of the preparation depth combined with margin design on fracture resistance of endocrown restoration fabricated by CAD/CAM material still under research. The current study was aimed to investigate and compare the effect of different preparation marginal design and depth on fracture resistance of polymer infiltrated ceramic endocrown restorationon anin vitrostudy. The null hypotheses tested were that the values of fracture resistance as well as failure modes wouldn't be influenced either bydifferent preparation marginal designs and depths.

II. Material and Methods

Forty extracted human upper premolarswere collected from oral surgery department, Faculty of Dentistry, Mansoura University. The inclusion criteria are a completed root formation, absence of root visible fracture lines and carious lesions. The dimensions of all selected teethwere nearly similar at the cemento-enamel junction (CEJ) (buccolingually: 7.2±10mm and mesiodistally: 5.0±0.5mm) and root length of 13±1.0mm, determined by a digital caliper. [16]All external debris was removed with an ultrasonic scaler, the cleaned teeth were stored at room temperature in normal saline solution till use. [17]

Endodontic treatment:

The access cavity of all teeth was prepared by water cooled round bur (No.271) following its pulp chamber morphology.[18] The working length is determined visually by size of 10 K-file inserted in teeth roots to determine the working length. Then the root canals preparation were performed with manual K-files 10, 15, 20 (Dentsply-Maillefer) as well as rotary nickel titanium instruments (ProTaper, Dentsply-Maillefer), following instructions of manufacturer. [19]Rotary file sizeF3 wasused as both canals master file. [18] 2.5% sodium hypochlorite was used for root canals irrigation during the preparation after each used file.[20]Canals obturation has been completed by using Protaper paper points, size F3 guttapercha (ProTaper, Dentsply-Maillefer) and resin based root canal sealant(ADseal, META).Red hot condenserallowedthe removal of the excess guttapercha.

Specimen fixation:

All ETT were fixed at the upright position in cylindrical plastic ring filled with acrylic resin material by using centralization device (obtained from fixed prosthodontic department at faculty of dentistry of Mansoura University). Each tooth fixed to the vertical metal rod using sticky wax. The cylindrical ring were placed inside the Teflon ring of device and filled with self-curing acrylic resin material. The margin of the acrylic resin material was placed below the CEJ by 3mm corresponding to mark into the tooth root. Then the tooth placed into the filled cylindrical ring till complete polymerization of self-cure acrylic resin material.[2,6]

Specimen preparation and grouping:

Computerized Numerical Control milling machine (CNC) was used to achieve preparation standardization of all ETT. It was used to remove the occlusal surface of all ETT horizontally leaving 2 mm above the CEJ from their proximal surfaces. It prepared each group according to its own group preparation criteria with a retention pulp chamber cavity of 8 ° divergence of the walls. [3]

ALLendodontically treated teeth (ETT) were randomly divided into two main groups(n=20) according to their marginal design into butt-joint group (B) and (1mm) shoulder finish line group (S).The two main group were subdivided into two subgroups (n=10) according to the extension depth of pulp cavity into:
Group (B2):indicating butt-joint marginal design and 2mm pulp cavity extension depth.
Group (B4):indicating butt-joint marginal design and 4mm pulp cavity extension depth.
Group (S2):indicating shoulder finish line marginal design and 2mm pulp cavity extension depth.
Group (S4):indicating shoulder finish line marginal design and 4mm pulp cavity extension depth.
The digital caliper was used to confirm the dimensions of prepared teeth for verification.

Fabrication of endocrown restoration :

Ceramill motion 2 (x5) (AmannGirrbach, Germany) CAD/CAM system was used for fabrication of 40 endocrown restorations. The restorations were milled from polymer infiltrated ceramics VITA ENAMIC blocks 2M2-HT-E-i14, (VITA-Zahnfabrik, Bad Säckingen, Germany). This CAD/CAM system consists of two separate components: an imaging unit and milling unit. The steps for fabrication were performed according to manufacture's recommendations as the following:

(a)Scanning for optical impression

The prepared teeth within their acrylic resin blocks were secured on the scanning tray then scanned by AmannGirrbach scanner (Ceramill Map 400 scanner) to obtain an optical impression. More images of the prepared teeth within their acrylic resin blocks were captured along the long axis of prepared teeth and from different angles around them. After that these images were computed together to form the final image. The digital photo of the impression appeared then converted into animated photo.

(b)Designing the endocrwon restoration

CAD/CAM software (Ceramill Mind, AmannGirrbach) was used for designing the endocrown restoration. Type of restoration, endocrown margins, wall thickness and cement space were identified and the data file was sent to the milling machine unit. No editing of the original shape produced by the software has been done to standardize the form and the anatomy.

(c) Milling procedure:

The milling procedure was performed using a computered controlled milling unit (Ceramill motion 2 (x5) (AmannGirrbach, Germany). The Vita Enamic blocks were fixed into its place in the milling chamber then the order was given to the milling machine. The milling process run fully automated without any interference. ENAMIC Polishing set used for restoration polishing.

Endocrown restoration cementation and Thermal cycling :

All endocrown restorations have been cleaned for 3 min using an ultrasonic cleaner.Pumice slurry was used to clean all prepared teeth, thoroughly rinsed with water and dried with moisture-free compressed air. The endocrowns bonding surfaces were etchedby 8 % hydrofluoric acid gel (Porcelain etch, DentoBond Porcelain Fix Itena Products, France) for 20 sec. then endocrowns were washed with running water for 20 sec and dried with moisture-free compressed air for 30 sec. Porcelain Silane (DentoBond Porcelain Fix Itena Products, France) was applied into the endocrowns etched surfaces, left for 60 sec till dry. Preparedteeth surfaces were etched by 37 % phosphoric acid (Meta Etchant Gel) for 15 sec, washed 20 sec and dried by oil free air for 5 sec.

All Vita Enamicendocrowns were cemented with self-adhesive resin cement (RelyXUnicem clicker, 3M ESPE, Germany).This cement is provided in two pasts (base and catalyst) in one clicker dispenser that applied into the fitting surface of each endocrown. After cement application, the endocrowns were seated on their corresponding prepared teeth statically by finger pressure then each one loaded axially using special loading device under constant load 1kg for 5 min. After that these cemented endocrowns were light cured for only 2 sec.

The residual excess cement at the endocrowns margins were removed with acotton pellet, after that light curing was completed for 20 sec at each side. Finally, they were stored for 24 hours in 37ºC distilled water before thermal cycling. All specimens were submitted to 2500 cycles in water bath between 5 ºC and 55 ºC in a thermocycling machine (Thermocycler, Robota, Alexandria, Egypt). Dwell time of exposure to each bath was 30 sec and transfer time between two baths was 5 sec.

Fracture testing and failure analysis :

Fracture strength test was performed by a universal testing machine. All specimens were loaded individually and fixed to lower fixed compartment of the testing machine. A special stainless steel rod with round end of 2.5mm diameter was fixed to the upper moving arm of the testing machine. It was used to apply a compressive load along the specimens long axis within the middle of occlusal surface where the stylus adjusted to contact both facial and lingual cusp inclines at cross-head speed of 0.5mm/min. The load at which fracture occurred, was recorded in Newton (N). Mode of fracture was analyzed for each specimen visually and photographically with a digital camera. The fracture modes were classified into: favorable (repairable) or unfavorable (irreparable).The favorable fracture was considered as the restorable failure was above CEJ or within endocrown. On the other hand, the failure was considered unfavorable if the tooth fracture was below the CEJ including vertical root fracture.

Statistical analysis:

Data were analyzed usingSPSS (version 20). The normality of data was first tested with Shapiro–Wilk test. Continuous variables were presented as mean ± SD (standereddeviation). Two way ANOVA test was used to detect effect of each variable (marginal designs and preparation depths) on fracture resistance. Tukey (HSD) honest significant difference was used for multiple comparison between different groups.

III. Results

The statistical analysis of fracture resistance values for different marginal designs and preparation depths of the endocrown restorations were showed in (Table 1). The highest mean fracture load value (562.67N) showed inGroup (S4) while the lowest value (403.24N) showed in Group (B2).The results of two-way ANOVA test revealed that there is a significant difference of both variables.Multiple comparisons were used to find outthe significant difference between all tested groups as shown in (Table 2).Tukey HSD tests showed that the mean difference of endocrowns marginal designs between (B2 and S2) or between (B4 and S4) was significant different ($p < 0.05$). As for the effect of preparation depths of the restorations, the results showed that the difference between (B2 and B4) or between (S2 and S4) wasn't significant different ($p > 0.05$) (Table 3). Chi square test was conducted for evaluation of the fracture modes and revealed that there was no significant difference between the modes of failure of all tested groups. The most common mode of failure of all tested groups was shown as percentage within (Table 4).

Table(1):Showing mean ± standard deviations of fracture resistance values (N) resulted from different preparation depthsand marginal designs.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
B2	10	403.2400	64.82738	20.50022	356.8653	449.6147	321.20	481.70
B4	10	437.0000	21.62560	6.83862	421.5300	452.4700	408.10	464.00
S2	10	534.1400	45.75372	14.46860	501.4098	556.8702	473.90	591.40
S4	10	562.6759	23.07388	7.29660	546.1699	579.1820	526.86	590.08

B2=butt joint marginal design with 2mm depth and **B4**= butt joint marginal design with 4mm depth.**S2**=Shoulder finish line marginal design with 2mm depth, **S4**= Shoulder finish line marginal design with 4mm depth.

Table (2): Showing two way ANOVA test for the effect of different margin designs and preparation depths on the restoration fracture resistance.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	174348.176a	3	58116.059	31.862	.000
Intercept	9380464.016	1	9380464.016	5142.754	.000
Marginal design	164577.997	1	164577.997	90.228	.000
Preparation depth	9701.952	1	9701.952	5.319	.027
Error	65664.562	36	1824.016		
Total	9620476.753	40			
Corrected Total	240012.738	39			

a. R Squared = .726 (Adjusted R Squared = .704)

Table (3): Showing Tukey HSD test for the significantdifference between the tested groups at a significance level of $p < 0.05$.failure mode analysis percentage.

groups	N	Subset for alpha = 0.05	
		1	2
b2	10	403.2400	
b4	10	437.0000	
s2	10		534.1400
s4	10		562.6759
Sig.		.305	.452

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.
b. The relation between colums (1&2) is significant different.

Table (4): Showing failure mode analysis percentage

Groups	Favorable fracture	Unfavorable fracture
G(B2)	20%	80%
G(B4)	40%	60%
G(S2)	70%	30%
G (S4)	80%	20%

The favorable fracture is the restorable failure was above CEJ or within endocrown. The unfavorable fracture is tooth fracture was below the CEJ including vertical root fracture.

IV. Discussion

New therapeutic options forendodontically treated teeth(ETT) restoration have been introduced with the advancement of adhesive dentistry to increase the application of minimally invasive principles.[20] Among these options, endocrown restoration has been discovered as, more conservative treatment modalities for restoring ETT.[1] This is attributed to its ability to seal the access to root canal, preventing bacterial microleakage that may inversely affect the favorable long-term prognosis of an ETT. Moreover, if an endodontic failure is happened, more easily reinterventions can be performed. [20] Additionally the endocrowns are being a conservative technique due to no longer necessity for macroretentive design if ETT have sufficient surfaces available for bonding.[1] Beside this conservation role ,it plays its main role in the restoration of coronal anatomy with better mechanical character ,biocompatibility and efficiency. Therefore, endocrowns currently considered as an esthetic and conservative restorative alternative. [1,20]

Vita Enamic material was selected as a recent type of CAD/CAM material designed to combine the benefits of both ceramic and composite materials. More favorable advantages have been reported for Vita Enamic material such as the reasonable index of brittleness that allows the material to be a suitable CAD/CAM candidate. Also it can be manipulated in one step without requiring additional firing such as some partially sintered CAD/CAM materials. This result in final products with a higher degree of dimensional accuracy. Comparing with traditional porcelains, the lower material hardness provide better protection of opposing teeth against excessive wear as well as more rapid machining in CAD/CAM milling machines.[1]

In the present study the effect of different marginal designs and preparation depths were tested for upper premolar endocrown restorations fracture strength and failure modes. The null hypotheses tested were that values of fracture resistance as well as failure modes wouldn't affected by either different marginal designs or preparation depths. The first null hypotheses concerned with the effect of different marginal design on the fracture resistance is rejected. According to our results, the endocrown restoration with shoulder finish line marginal design had higher mean of fracture resistance values while, the endocrown restoration with butt-joint marginal designs had lower one. The mean values between both marginal designs were statistically significant difference. These results indicated that the fracture resistance of endocrown restoration affected by different marginal design.

Biomechanically, when the forces are applied over the endocrown restoration, these restoration adapted to them in the form of strain at the bonded surfaces and distribute these forces as compression over the cervical butt-joint or as shear force within axial walls. Endocrown restorations prepared with butt-joint marginal design, provided a stable surface parallel to occlusal plane with subsequent compressive stress resistance while endocrown restorations prepared with shoulder finish line provided additional short axial wall counteracting the shear stress with better marginal load distribution allowing better load control on the pulpal floor. Also, the relation between the amount of resin cement thickness and overall bulk of ceramic material has been decreased at shoulder finish line marginal design than the butt-joint one, with subsequent reduction in the polymerization and thermal shrinkage.[1] This result was in agreement with study of Taha et al.,(2018) [1] that found that adding an axial wall of shoulder finish line marginal design to endodontically treated molar teeth restored with Vita Enamic endocrown restoration can increase their fracture resistance.

The second null hypotheses concerned with the effect of different preparation depths on the fracture resistance is accepted. According to our results, the mean difference between the two different extension depth (2mm and 4mm) wasn't statistically significant difference in the same marginal design. The non-significant difference in the statistical analysis of the two different depths may be returned to the close range between the extension depth (2mm) and (4mm).

The slightly higher mean fracture resistance values of 4mm intracoronal extension depth groups than 2mm may be returned to the increased contact area between different extensions of endocrowns inside pulp chamber to the remaining tooth structure. Increasing the contact between them lead to an increase in assumption available space inside pulp chamber with subsequent increase in stability and retention of the endocrown restoration. The friction against the pulp cavity extension walls in the deeper preparation design provide extra macro-mechanical retention. On the other hand the 2mm pulp cavity extension depth groups reported slight decrease in the mean fracture resistance values as it depended mainly on pure adhesion. The decreased surface area of 2mm than 4mm extension depth groups provide them greater possibility of rotating endocrowns during function load. (19)The results of current study were in agreement with Rocca et al., (2018) (19) who demonstrated the effect of endo-core (2mm and 4mm) length on the fatigue resistance of endocrown restoration for severely damaged endodontically treated premolar. They reported that there was no significant difference between both endo-core length (2mm and 4mm).The results of the current study were comparable to Pedrollo et al., study (2017)(16) on endocrown restoration for endodontically treated premolars. They reported that, there was significant difference between the effect of 2.5 mm and 5mm deep on Cerasmart endocrown fracture resistance. This study methodology differed from that of the present study in the load to failure that applied at different direction (oblique to the long axis of the tooth rather than axially) during fracture testing and in the endocrown restoration material.

Analysis of the fracture mode of the endocrowns restored teeth is as important as considering the loss of fracture.Comparing between the groups in the marginal preparation design, the higher percentage of unfavorable fracture is recorded for butt-joint groups (2mm and 4mm).Conversely, the higher percentage of favorable fracture is recorded for shoulder groups (2mm and 4mm. It may be returned to that the shoulder finish line marginal design allowed axial wall addition to endocrown restoration. This resulted in reduced endocrown thicknessand the stresses transferred to remaining tooth structure. Although the decreased endocrown thickness allow their dislodgement more easily at a future stage, would reduce the risk of future tooth fracture that considered more catastrophic than cohesive failure. The effect of depth on the fracture mode may not be apparent as the preparation margin do. This is may be due to the near similarity of the data ranges. (21)

This explanation was in agreement with the Zhu et al., (2017) (21) that investigated the effect of remaining tooth structure and restorative material type on stress distribution in endodontically treated maxillary premolars with a finite element analysis. They compared between 3 different thickness of restoration (1.0 mm, 2.0 mm, and 3.0 mm). They reported that the decreased thickness of (1mm) endocrown restoration resulted in decrease in the von Mises stress in coronal dentin and the risk of tooth fracture.

V. Conclusion

Within the limitation of this in vitro study, the following conclusions could be drawn:

1- The fracture failure mode obtained by this study, was affected by both marginal design (shoulder finish line &butt-joint).
2- Clinical acceptable values of fracture resistance can be obtained by the use of polymer infiltrated ceramic material due to its inherent crack prevention property.
3- The shoulder finish line marginal design increases the fracture resistance of endocrownsthan butt-joint marginal design.
4- Thepreparation depth within therange of (2mm& 4mm) has not significant effect on the fracture strength of Vita Enamicendocrowns for upper premolar.

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