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EFFECT OF INTRA-CHAMBER EXTENSION OF LITHIUM DISILICATE ENDOCROWNS ON THE FRACTURE RESISTANCE AND FAILURE MODES IN ENDODONTICALLY TREATED MOLARS (IN-VITRO STUDY)

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ABSTRACT

Statement of problem: Although endocrowns have proven their clinical success in many situations, the intra-chamber endocrown extension and the proportion between the clinical crown height and the radicular stump and their effects on their fracture resistance and mode of failure have not yet been verified.

Purpose: Assess the effect of intra-chamber extension of lithium disilicate endocrowns on the fracture resistance and failure modes in endodontically treated molars after thermo-mechanical loading.

Material and Methods: Forty extracted molar teeth were selected and divided into 5 groups (n=8) as follows: unprepared natural teeth (NAT; control); post and core supported crowns (PCC); teeth with 4 mm intra-chamber extension (EC4); 2 mm intra-chamber extension (EC2); 1 mm intra-chamber extension (EC1). Endocrowns were subjected to 5000 thermal cycles then 1,200,000 chewing cycles. Surviving specimens were vertically loaded in a universal testing machine until fracture. Data were analyzed by 1-way ANOVA, followed by pair-wise comparaisons with the Bonferroni post-hoc test ($p \leq 0.05$). The mode of failure was determined by visual inspection.

Results: Natural teeth had statistically significantly lower fracture resistance than groups with crowns ($p= 0.002$). However, there were no statistically significant differences between the crown groups with mean fracture resistance ranging from 2502.5 N to 2843.8 N. Endocrowns exhibited mainly unfavorable fracture failure. The amount of teeth destruction related to the group EC4 was less than that related to the group EC1.

Conclusions: Endocrowns with greater intra-chamber extension provided insignificantly higher fracture resistance but more protection of underlying tooth structure than endocrowns with lesser extension.

KEYWORDS: Endocrowns, intra-chamber extension, lithium disilicate, CAD/CAM, fracture resistance.

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INTRODUCTION

The optimal restoration of endodontically treated teeth has always been very crucial because they are more subjected to failure than vital teeth.[1] This fact is most probably due to reduced amount of remaining sound tooth structure as well as restorative procedures.[2,3] Various approaches were used to restore lost tooth structure, protect and strengthen the remaining part.[4] Post and core supported restorations - through different types[5,6] - became the classical and traditional way to restore endodontically treated teeth.[3,7] Recently evolved adhesive concepts allow the preservation of sound tooth structure by omitting aggressive tooth structure removal and destructive preparation.[8]

Endocrowns are single monolithic restorations that are adhesively bonded to the remaining tooth structure of endodontically treated teeth with luting resins.[8,9] Using endocrowns, there is no need for root posts and complications associated with post-core system are prevented.[9,10] Endocrowns are especially indicated in situations where there is an extensive loss of coronal tooth structure and obtaining an adequate ferrule (as in deep subgingival preparations) is not possible.[11] The classical tooth preparation features to receive an endocrown restoration include 3 mm or more cuspal reduction, 90 degrees cervical butt joint margins, 6 to 10 degrees coronal divergence, rounded internal line angles and a relatively flat pulp chamber floor.[12]

Most studies on endocrowns followed the original design having a coronal portion with adequate occlusal thickness and an intra-chamber extension inserted inside the prepared pulp chamber.[9,12] However, the effect of macromechanical retention on fracture resistance and modes of failure after long term thermal and dynamic loading has not been determined in detail yet.[13] This study will focus on applying different proportions between clinical crown height and intra-chamber extension of endocrowns and evaluate the effect of intra-chamber stump extension on the fracture resistance and mode of failure in molars. The null hypothesis was that there will be no significant difference in the fracture resistance of lithium disilicate full crowns or endocrowns.

MATERIALS AND METHODS

After ethical approval, forty recently extracted human molars from periondontal patients ranging from 20 to 50 years old were collected at the Oral and Maxillofacial Surgical Department of Faculty of Dentistry, Cairo University. The teeth were intact, free from caries or any fillings, without cracks, fractures or significant wear. Teeth were cleaned and stored in normal saline at room temperature. Teeth were embedded in autopolymerizing epoxy resin (Kemapoxy 150; CMB; Germany) blocks 2 mm below the cementoenamel junction (CEJ). Specimens were divided into 5 groups with 8 specimens each. The control sound teeth group NAT remained intact. The other teeth were trimmed perpendicular to the long axis 2 mm coronal to the proximal CEJ using a coarse diamond disc under copious irrigation with water. Then they were subjected to a standard endodontic treatment.[14] Obturation was made with 6% taper gutta percha (#25; #30; Spident; Meta Biomed; Cheongju; Korea) using lateral condensation technique with a eugenol free resin sealer (AD Seal; Meta Biomed). Teeth were then stored in distilled water at room temperature.

For the teeth randomly chosen to receive endocrowns (groups EC4, EC2, EC1), a butt joint design 2 mm above CEJ was used. Cavity preparation was made with copious water cooling using a custom-made parallelometer (AF 30; Nouvag AG; Goldach; Switzerland) holding a high-speed handpiece with a rounded end diamond tapered stone (Mani; Japan) having 10° taper to ensure a standardized 10° coronal divergence. Bulk fill composite material (Tetric EvoCeram Bulk fill; Ivoclar Vivadent; Schaan; Liechtenstein) was bonded using universal adhesive (Adhese Universal; Ivoclar Vivadent) to the pulp chamber floor in order to achieve the 3 different intra-chamber extensions of the proposed endocrowns as shown in Fig. 1.

For the teeth designed to receive post and core supported crowns (group PCC), a 1 mm rounded shoulder finish line and 1 mm ferrule located above the CEJ by 1 mm were applied with a total of 10° occlusal convergence angle. Preparation of the post spaces was done with a low-speed corresponding reamer drill. Titanium posts (i-Post; Itena; Paris; France) of 12 mm length were selected to be inserted inside the largest canal. The post spaces were rinsed with a 3% sodium hypochlorite solution, irrigated with 70% ethanol and dried with paper points.[14] A self-etch primer (ED Primer II; Kuraray; Osaka; Japan) was applied to the coronal and post access cavity using a microbrush. After 30 seconds, the primer was gently air-dried and excess primer was removed with paper points. Titanium posts air-abraded with 50 μm alumina particles were adhesively cemented using luting resin (Panavia F2.0; Kuraray). The core build up was made with composite resin (MultiCore Flow; Ivoclar Vivadent) and light-polymerized for 10 seconds (Bluephase Style light cure; Ivoclar Vivadent) with approx. 1,100 mW/cm^2 light intensity. The crown preparation was made using a tapered rotary diamond bur[14] resulting in a height of 3.5 and 3 mm from the shoulder finish line to the prepared teeth cusp tips and central grooves, respectively (Fig. 1).

A CAD/CAM system (CEREC 4.4; Sirona; Bensheim; Germany) and lithium disilicate ceramic (e.max CAD; Ivoclar Vivadent) were used for the construction and fabrication of all restorations (Fig. 2). The biogeneric individual design mode of IPS e.max CAD was selected. CEREC Omnicam (Sirona) was used to scan the prepared teeth to receive full crowns and endocrowns. CAD/CAM software designing (CEREC Software 4.4; Sirona) with comparable outer dimensions was made. For

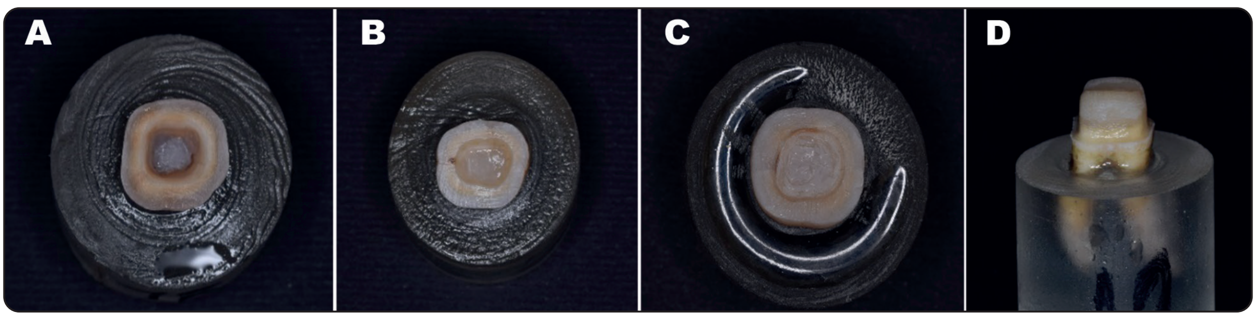

Fig. (1) Preparation design of test groups: (A) EC4 (B) EC2 (C) EC1 (D) PCC. (Composite figure)

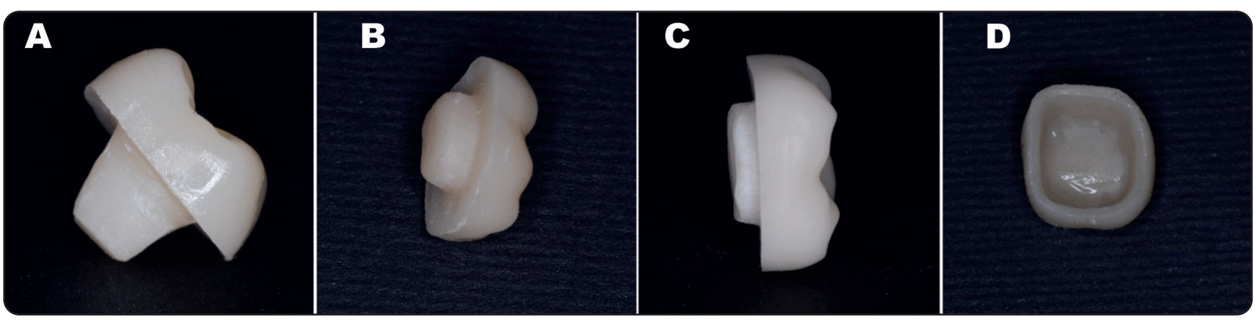

Fig. (2). Endocrown design of test groups: (A) EC4 (B) EC2 (C) EC1 (D) PCC. (Composite figure) the endocrown groups, the restoration thickness from the cusp tip to the butt joint was standardized to 4 mm and from the central fissure to the butt joint it was 3 mm, while 4 mm, 2 mm or 1 mm for the intra-chamber extension was added for groups EC4, EC2 and EC1, respectively. Post and core supported crowns (group PCC) had a thickness of 2 mm from the restoration cusp tips to prepared tooth cusp tip and 1.5 mm from restoration central grooves to prepared tooth central groove. After the try-in, all restorations received crystallization and glazing (e.max CAD glaze paste; Ivoclar Vivadent).

For luting, the inner surfaces of the restorations were conditioned in a single step using a self-etching ceramic primer (Monobond Etch & Prime; Ivoclar Vivadent) applied with a microbrush for 20 seconds then left to react for another 40 seconds. It was followed by vigorous water spray rinsing for 20 seconds and finally dried for another 20 seconds. Surface treatment of prepared natural teeth was done by etching the surface with 37% phosphoric acid gel (Total etch; Ivoclar Vivadent) for 30 seconds on enamel and 15 seconds on dentin, followed by rinsing with water air spray and drying with a gentle air stream.

Cementation of restoration was done using an adhesive luting system (Adhesive Universal/ Variolink Esthetik DC; Ivoclar Vivadent) and a constant load of 3 kg for 5 minutes. After residual cement was removed and glycerin gel (Liquid strip; Ivoclar Vivadent) was applied as oxygen inhibiting layer at the tooth restoration junction, light curing was made on each axial surface of the restoration for 10 seconds (Bluephase Style light cure; Ivoclar Vivadent). Specimens were stored in saline at room temperature. The materials used are listed in Table 1.

Specimens were first aged using 5,000 thermal cycles in a water bath between 5 and 55°C (Thermocycler THE-1100; SD Mechatronik GmbH; Feldkirchen-Westerham; Germany). Then mechanical fatigue was applied to groups using a dual axis chewing simulator (SD Mechatronik GmbH; Feldkirchen-Westerham; Germany) for 1,200,000 cycles with a load of 50 N (5 kg) using a 6 mm steatite ceramic ball.[15] The mechanical fatigue was vertical with a 0.3mm lateral sliding movement of the stylus to imitate intraoral lateral forces. All surviving specimens were subjected to static compressive load using a universal testing machine (UTM; Zwick Z010/TN2A; Zwick; Ulm; Germany) and a rounded steel bar with a 6 mm diameter contacting buccal and lingual cusps and a cross-head speed of 0.5 mm/min until fracture. A 0.6 mm thick tin foil was placed on the specimen for even load distribution. Fractured specimens were inspected visually and using an optical microscope (Wild M420; Wild Heerbrugg; Switzerland) up to 35X magnification to detect the mode of failure as follows: type I: restoration fracture only (favorable failure), type II: restoration fracture + coronal tooth fracture above the height of bone level simulation (acceptable failure), type III: restoration fracture + root fracture/crack below the height of bone level simulation (catastrophic failure).

Statistical analysis was performed with software (SPSS Statistics Version 20 for Windows, IBM). Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Fracture resistance data showed normal (parametric) distribution. One-way ANOVA test was used to compare between the five groups. Bonferroni's post-hoc test was used for pair-wise comparisons when the ANOVA revealed significant differences. The significance level was set at $p \leq 0.05$. Based on a previous study by Chang et al. 2009, with a reported fracture resistance of 1163.3 ±163.2 N for post and cores and 1446.7 ±200.3 N for endocrowns, 8 specimens in each group (40 specimens in total) were considered sufficient using an 80 % power and 5% significance level. The sample size was calculated by G power program version 3.1.9.7.

TABLE (1). Materials used for restoration procedures

Materials	Description	Manufacturer
1)IPS-Emax CAD, LT A3/C4	Lithium disilicate glass ceramic blocks	Ivoclar Vivadent; Schaan; Liechtenstein
2)Variolink Esthetik DC	Dual-curing resin cement	Ivoclar Vivadent
3)Adhese Universal	Universal adhesive	Ivoclar Vivadent
4)Tetric EvoCeram Bulk fill	Bulk fill composite material	Ivoclar Vivadent
5)MultiCore Flow	Dual-curing core build-up composite	Ivoclar Vivadent
6)Monobond Etch & Prime	Self-etch ceramic primer	Ivoclar Vivadent
7)i-Post	Titanium posts	Itena, Paris, France
8)ED Primer II	Self-etch primer	Kuraray, Osaka, Japan
9)Panavia F2.0	Dual-curing resin cement	Kuraray

RESULTS

Only one specimen in group NAT showed an open coronal crack after the artificial aging process and was rated as a failure. All other specimens survived the thermo-mechanical loading with no cracks detected and were subjected to the final fracture test. The mean fracture load values and the standard deviations (SD) are shown in Table 2. One-way ANOVA test results showed that there was a statistically significant difference among groups (p=0.002). Pair-wise comparisons between groups revealed that group NAT showed statistically significantly lowest fracture resistance (1670.6 N) than the other groups while there were no significant differences between the other groups (Table 2). They ranged from 2502.5 ±555.9 N to 2843.8 ±427 N. Modes of failure of the groups are presented in Table 3. Endocrowns exhibited mainly unfavorable fracture failure (type III). Less amount of teeth destruction was associated with endocrowns with greater intra-chamber extension (Group EC4). Modes of failure are shown in Fig. 3(A-C).

TABLE (2) The mean fracture load values for all groups (N) and results of one-way ANOVA test

Group	Mean	SD	95% CI		*P*-value
			Lower bound	Upper bound	
NAT	1670.6 ^{B}	476.6	1229.8	2111.3	
PCC	2843.8 ^{A}	427	2486.8	3200.7	
EC4	2706.3 ^{A}	708.9	2113.6	3298.9	0.002*
EC2	2613.8 ^{A}	477.6	2214.5	3013	
EC1	2502.5 ^{A}	555.9	2037.8	2967.2	

Statistically different means (P≤0.05) are indicated by different superscript letters.

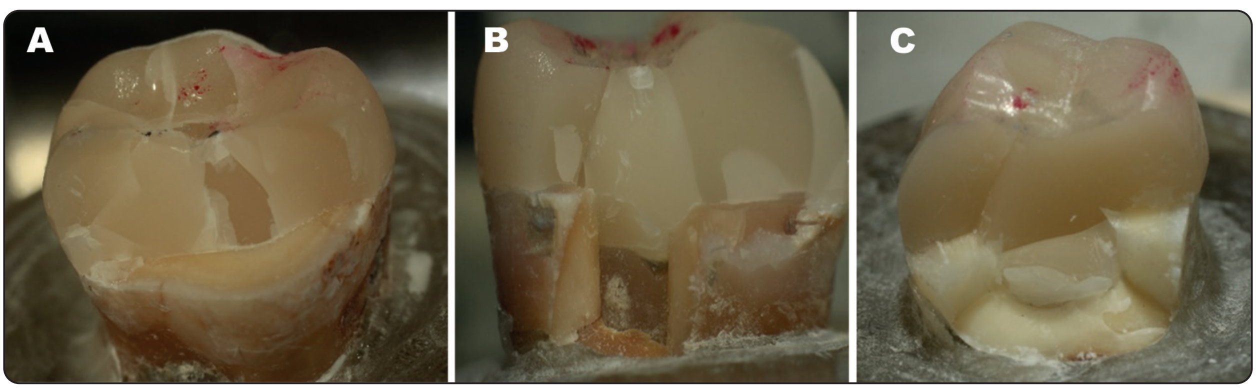

Fig. (2). Endocrown design of test groups: (A) EC4 (B) EC2 (C) EC1 (D) PCC. (Composite figure)

DISCUSSION

The null hypothesis of the study was accepted as there were no significant differences in the fracture resistance between the groups with full crowns or endocrowns. This study simulated the condition where there is an extensive loss of tooth structure and it is not possible to extend the preparation more subgingivally to create a ferrule for post and core supported crowns.

Teeth preparation was conducted according to the clinically followed criteria using a special milling machine to ensure standardization. Bulk fill composite was used instead of flowable composite as a base at pulp chamber floor due to its higher strength especially when a considerable thickness of base material was needed in the EC1 endocrown group. Titanium posts were used instead of fiber posts due to their higher transverse post strength and the greater resistance to failure than other post systems when bonded to the teeth.[16]

Conducting thermal and dynamic mechanical loading prior to the fracture resistance test is considered clinically relevant as it might significantly reduce the fracture resistance of ceramic retorations.[17,18] Only one previous study[19] subjected lithium disilicate endocrowns to high thermomechanical cycling combining 5000 thermal cycles and a 1.2 million dynamic loading cycles imitating 5 years of clinical service.[20] However this latter study was performed on premolar teeth.

Even endocrowns in group EC1 withstood the thermal and fatigue loading without any failure suggesting that endocrowns with shallower intra-chamber extensions as in severe loss of coronal sound tooth structure could be clinically durable. This condition could be applied intraorally especially when the restoration is not subjected to severe shear and dislocating forces. The mean fracture loads for all groups were by far beyond the reported maximum masticatory forces.[21] Therefore, it can be assumed that all tested lithium disilicate restorations are able to withstand the maximum intraoral masticatory forces.

These results are consistent with the results of many previous studies that applied vertical load perpendicular to the long axis of test specimens. The mean fracture loads of endocrowns with butt joint design ranged between 2000–3000 N.[22] However, Chang et al[10] reported a lower fracture resistance (1446 N) of lithium disilicate endocrowns but these results could be due to the use of smaller and therefore weaker premolars. The mean fracture resistance of sound teeth (group NAT) was significantly lower than that of the lithium disilicate restorations. This might be due to the denatured biological nature of the teeth after extraction and being deprived of nourishment supply as clinically observed.[23,24]

The outcome of endocrown restorations were nearly similar to those of post and core supported crowns which suggests that endocrowns might be a valid treatment alternative.[10] There were no significant differences between the three endocrown groups (EC4, EC2, EC1). These results are consistent with those of Hayes et al.[12] which demonstrated no significant differences between intra intra-chamber depth extensions of 2, 3 and 4 mm. In contrast, in a study conducted by Dartora et al.[25] the least fracture resistance (1268 N) was obtained within the shallowest tested intra-chamber extension group (1 mm extension) compared with 2008 N within the 5 mm extension group.

The effect of decreased macromechanical retention on the survival rate for adhesively cemented restorations has been mentioned few times in the literature.[26] However, the first numerical trial to study the effect of intra-chamber depth extension of endocrowns on molar fracture resistance was conducted by Hayes et al.[12] where they established pulp chamber floors at 2, 3, and 4 mm from the occlusal table while standardizing the coronal portion height. The difference was that the load was applied obliquely to the specimens without performing thermomechanical cycling prior to fracturing. Dartora et al.[25] followed also this idea by establishing pulp chamber floors at 1, 3, and 5 mm from the occlusal table. A glass ionomer cement barrier was used as a base in the pulp chamber floor which might explain the differences in results.

Many studies assume that the deeper intra-chamber extension, the greater the macromechanical retention and contact area that could aid in the retention and stability of the endocrown.[15,25] However, bond strength is controlled through many other factors as the remaining macro-retention, the structure of enamel and dentin of an individual preparation and its variation with location, depth of preparation, tooth type, cementation system and technique in addition to restoration properties.[26,27] So it is not possible from preparation surface area only to determine whether the retentive capacity will be adequate.[27]

Interestingly, many teeth did not show catastrophic root fracture due to high ability of lithium disilicate restorations to withstand and absorb loads through multiple cracks or compression curls first that could be easily seen on the restoration surface. Then the load effect could be seen transferred to the underlying tooth structure as coronal, root fracture or a root crack. This supports the concept to protect weakened teeth with some kind of overlay as onlays, endocrowns, occlusal veneers or crowns of proper thickness.

Less amount of teeth destruction was associated with endocrowns with greater intra-chamber extension (Group EC4). The number of cracks or compression curls on the restoration surface was high, as were non-uniform fractures. This could be due to their higher ceramic thickness and greater contact area with the tooth structure compared to those with a shallow intra-chamber extension. Increasing ceramic thickness is reported to be related to an increase in the fracture resistance.[9] Also, wider contact area with the tooth structure leads to better distribution of the stresses over its wider surface area and altering the direction of fracture propagation. These observations are consistent with the those found by Dartora et al.[25]

One of the limitations of this study, is that shear forces which tend to dislodge the restoration from its place were not examined. The study itself being in vitro could be one of the limitations as restorations performance in vivo could differ than their in vitro performance.

CONCLUSIONS

Under the conditions of the present research, the following conclusions can be drawn:

1) Lithium disilicate endocrowns with very shallow intra-chamber extension as in severe loss of coronal sound tooth structure could be clinically durable.
2) Lithium disilicate endocrowns were able to withstand long-term thermomechanical cycling without being significantly affected.
3) Endocrown restorations seem to be a valid treatment alternative when compared to post and core supported crowns for the restoration of endodontically treated teeth.

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