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EFFECT OF PULPAL EXTENSION ON THE FRACTURE RESISTANCE OF ENDODONTICALLY TREATED MOLARS RESTORED WITH DIFFERENT CAD/CAM CERAMIC ONLAYS

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ABSTRACT

Purpose: The aim of this study was to investigate the effect of pulpal extension with different CAD/CAM onlay materials on the fracture resistance of endodontically treated molars.

Materials and Method: Thirty five intact mandibular molars were selected for the study. Thirty molars were endodontically treated and access cavities were filled with light cured composite resin, while five molars were left intact to act as a control group. The thirty endodontically treated molars were prepared for mesio-occlusal-distal (MOD) onlays with 2 mm cavity depth and divided randomly into two equal groups: Group A: without further preparation, Group B: had further deepening of the pulpal floor till the level of cemento-enamel junction. Each group was subdivided randomly into 3 subgroups according to the type of CAD/CAM ceramic restoration used; (1) Vita Enamic (EN), (2) Lava Ultimate (LU), and (3) IPS E.max CAD (EX). The onlays were cemented with dual cure resin cement (Variolink N). Thermo-mechanical aging was done using chewing simulator with thermocycling. All specimens were subjected to axial compressive load using a universal testing machine until failure. Fracture resistance data were analyzed using ANOVA and post hoc test.

Results: Mean fracture resistance of subgroups; (A1) EN (1812.67±311.28 N), (B1) EN-P (2091.67±141.92 N), (A2) LU (1889.83 ±145.68 N) and (B2) LU-P (2010.50±46.09 N) were not significantly different from each other ($p>0.05$), but significantly lower than control (2419.17±253.46 N), subgroups; (A3) EX (2492.17±179.47 N), and (B3) EX-P (2528.33±95.33 N) ($p<0.05$). A3 and B3 subgroups were not significantly different from each other and from the control group ($p>0.05$).

Conclusions: Within the limitation of this study, it was concluded that the extension of all-ceramic restorations into the pulp chamber had no significant effect on the fracture resistance. Endodontically treated molars restored with IPS E-max CAD MOD onlay had a significantly higher fracture resistance than the other tested subgroups and there was no significant difference with the sound molars (control). There was no significant difference between Vita Enamic and Lava Ultimate subgroups but they were significantly lower than E-max CAD subgroups.

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INTRODUCTION

According to literatures, the endodontically treated teeth are less resistant to fracture than vital teeth, which present challenges for the prosthodontist. This is because of tooth structure loss due to caries removal and endodontic access cavity preparation[1,2]. In endodontically treated posterior teeth, the occlusal loading generated stresses and may lead to fracture of unprotected cusps[3]. Strengthening of endodontically treated posterior tooth by extracoronal or intracoronal restoration with cuspal coverage is important to protect them against fracture [1,4].

All-ceramic materials have been used in dentistry as inlays, onlays, veneers, crowns, and bridges due to their improved strength, biocompatibility and natural appearance with high patient acceptance[5,6]. Bonded ceramic based inlay/onlay has been suggested to reinforce the remaining hard dental tissue. It is considered an indirect esthetic restoration which maintains better anatomic forms, marginal integrity, and color stability in the oral cavity [5]. Restorations of endodonically treated teeth with ceramic inlays/onlays have been reported in many literatures [7,8,9].

However, bulk fracture remains the most reason of failure in ceramic restorations[10]. Fracture of ceramic inlays/onlay restorations may be due to; improper cavity design [11] insufficient restoration thickness[12], internal defects in the ceramic like pores and cracks [13], and cementing agents [14].

Several materials of all ceramics from several companies have been developed for milling in the forms of blocks through the computer-aided design/computer aided manufacturing (CAD/CAM) process. These CAD/CAM ceramic blocks were introduced in attempt to further improve their fracture resistance and optimise the material manufacturing[15]. Among the CAD/CAM materials that indicated for onlay restorations are lithium disilcate glass-ceramics and composite-based ceramics.

IPS E.max CAD is a lithium disilicate glass ceramics designed for CAD/CAM which combines good esthetics, high flexural strength and fracture toughness [16]. On the other hand, composite-based ceramics, like Lava ultimate and Vita Enamic, have been recently introduced as an alternative indirect restorative material having greater ability to absorb impact stresses than do ceramics [17]. Lava Ultimate is a resin nano-ceramic, consisting primarily of ceramic. The manufacturer claims that lava ultimate is less brittle than glass ceramic, can be repaired intraorally, have high flexural strength and excellent polish retention for lasting esthetics. All of these factors make resin nano-ceramic materials a promising option in CAD/CAM dentistry [18]. Vita Enamic is a hybrid ceramic with a dual-network structure. This integrated structure includes dominant fine-structure ceramic network strengthened by a polymer network [19]. The manufacturer claimed that this hybrid material ensures unique balance between strength and elasticity and provides high absorption of masticatory forces.

The bonding of intracoronal ceramic restorations using adhesive systems together with composite resin cements have been proved to reinforce the restored tooth units in terms of decreasing cuspal flexure and strengthening of the remaining tooth structure [20,21]. In order to avoid post-retained crown restoration towards more conservative technique using the benefits of CAD/CAM technology, the ceramic inlays, onlays, endocrowns together with adhesive techniques are used nowadays as alternative restorations for endodontically treated molars, depending on the availability of remaining tooth [22-24].

It has been suggested that extending of ceramic inlays into the pulp chamber without base material may add more retention and resistance [25]. On the other hand, it may adversely affect the biomechanical behaviour of the restored tooth unit [26]. Many authors recommended using base materials under ceramic inlays for the following reasons: sealing endodontic access cavities, eliminating undercuts,and providing the proper internal tapered cavity design[19]

So, this *in vitro* study was designed to evaluate the effect of pulpal extension with different CAD/CAM onlay materials on the fracture resistance of endodontically treated molars after thermo-mechanical aging using chewing simulator as it influence the strength of the restored teeth.

MATERIALS AND METHOD

Preparation of tooth specimens

Thirty five recently extracted caries-free human mandibular first molar teeth were selected for this study. The teeth were of approximate dimensions and free from any defects. They were scaled for calculus and cleaned with a rubber cup and fine pumice-water slurry, and stored in saline solution at room temperature. Each tooth was perpendicularly mounted and embedded in a mould filled with an auto-polymerizing acrylic resin (Acrostone, Acrostone dental factory, Industrial zone, Cairo, Egypt) to a level 2 mm below the cemento-enamel junction.

Thirty molars were endodontically treated and access cavities were filled with light cured composite resin, while 5 molars were left intact to act as a control group.

Root canal treatment

After access cavity preparation and working length determination for root canals of each molar, root canal preparation was performed using machine-driven rotary file (Revo-S, Micro-Mega, France). After each file, the canal was rinsed with sodium hypochlorite solution. The canals were dried with paper points (Spident, Incheon, Korea), and obturated using lateral condensation with gutta-percha points (Meta Biomed Co, Ltd, Chungbuk, Korea) and a resin based root canal sealer (Adseal, Meta Biomed Co, Ltd, Chungbuk, Korea). Excess gutta percha was removed at the root canal orifices. The access cavity for each endodontically treated tooth samples was fully restored with composite resin (Tetric N-Ceram, Bulk fill, Ivoclar Vivadent, Liechtenstein) after etching and bonding. Then, composite filling was light-cured for 40 seconds from each direction using LED light curing unit (Monitex Blue Lex, Taiwan).

Onlay cavity preparation

MOD onlay cavity preparation was made by the milling machine (NOUVAG AF30 milling machine, Swizerland) using a tapered diamond stone with round end. Cavities of rounded internal angles were prepared and the cavity walls were flared at 8 degrees. All preparations were completed along the longitudinal axis of the teeth. The occlusal isthmus width was 2 mm. The pulpal floor was prepared to a depth of 2 mm from the occlusal surface (from the deepest pit of the fossae). The depth was measured by a periodontal probe (Hu Friedy, Chicago, IL). The bucco-lingual widths on the mesial and distal boxes were similar to that of occlusal isthmus. Each box had a butt joint gingival floor with a width 1.5 mm and an axial wall height of 2 mm. A 2 mm reduction was done on the buccal (functional) cusps with 1 mm gingival floor width and 1 mm on the lingual (non-functional) cusps [9] (figure 1-a).

The thirty prepared teeth were then divided randomly into two equal groups: Group A: without further preparation, Group B: With further deepening of the pulpal floor till the level of cemento-enamel junction [8] (figure 1-b).

Each group was subdivided randomly into three subgroups according to the type of CAD/CAM ceramic restoration used as shown in table (1):

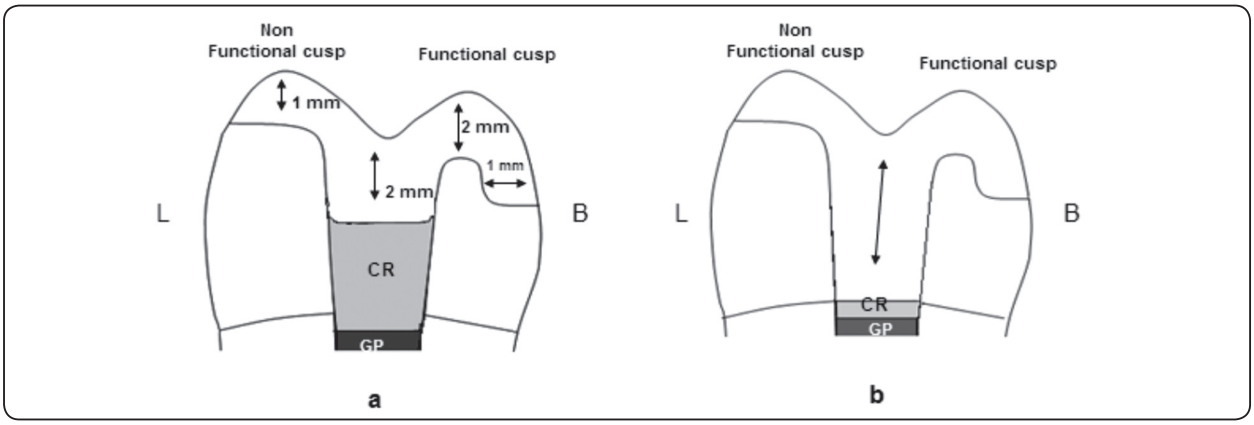

Fig. (1) Onlay preparation design for endodontically treated mandibular molar:
a) Depth with 2 mm. b) Depth with pulpal extension till cej.

TABLE (1) Samples grouping

Groups	Sub-groups	CAD/CAM Material	No. of samples
Control	Sound		5
(A) MOD onlay without pulpal extension	**A1** (EN)	Vita Enamic	5
	A2 (LU)	Lava Ultimate	5
	A3 (EX)	IPS E.max CAD	5
(B) MOD onlay with pulpal extension	**B1** (EN-P)	Vita Enamic	5
	B2 (LU-P)	Lava Ultimate	5
	B3 (EX-P)	IPS E.max CAD	5

Ceramic onlay restoration fabrication

The all-ceramic onlay restorations were constructed from CAD/CAM ceramic blocks using Zirkonzahn CAD/CAM machine (Zirkonzahn. Worldwide, 39030 Gais/South Tyrol, Italy). Each prepared tooth sample was scanned by 3D optical scanner (S600, Zirkonzahn, Italy) (figure 2). Using CAD software, each onlay of the corresponding tooth sample was designed (figure 3) and imported to the milling machine, then ceramic block was milled.

For A1 and B1 subgroups, the restorations were constructed from Vita Enamic CAD blocks (Vita Zahnfabrik, Bad Säckingen, Germany). For A2 and B2 subgroups, Lava Ultimate CAD blocks (3M ESPE, Seefeld, Germany). For A3 and B3 subgroups, IPS e.max CAD, CAD blocks (Ivoclar Vivadent, Schaan, Liechtenstein). Tested materials are listed in table (2), which obtained from manufacturer’s data.

Bonding procedure

The intaglio surfaces of vita enamic and lithium disilicate onlay restorations were etched using 9 % buffered hydrofluoric acid (Ultradent Porcelain Etch, Ultradent Products, Inc USA) for one minute, washed for one minute, then, air dried. Intaglio surfaces of lava ultimate onlays were sandblasted with 25 μm aluminium oxide particles, then cleaned

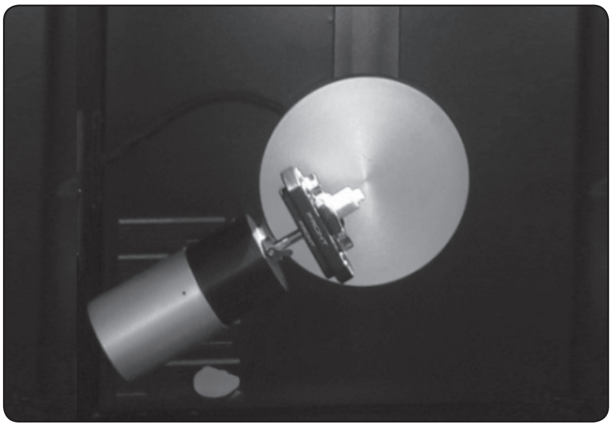

Fig. (2) 3D optical scanning of the prepared tooth sample.

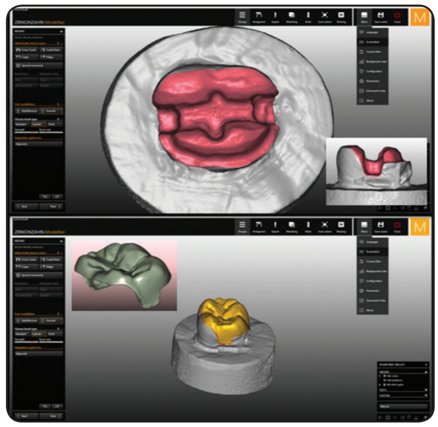

Fig. (3) Designing onlay restoration using CAD software.

TABLE (2) The materials tested in this study

Code	***Material***	***Manufacturer***	***Ceramic type***	***Fracture toughness (MPa m½)***	***Modulus of elasticity (GPa)***
EN	Vita Enamic	Vita Zahnfabrik	Feldspathic ceramic with polymer network	1.5	30.0
LU	Lava Ultimate	3M ESPE	Resin nanoceramic	2.0	12.8
EX	E.max CAD	Ivoclar Vivadent	Lithium disilicate glass ceramic	2.6	81.0

with alcohol and dried with air. A silane coupling agent was applied to all restorations for one minute (Ultradent Silane, Ultradent Products, Inc USA) and allowed to evaporate completely, followed by application of adhesive agent (Tetric N-Bond universal, Ivoclar Vivadent, Liechtenstein).

The prepared onlay cavities were etched with 36% phosphoric acid gel (Total Etch, Ivoclar Vivadent, Liechtenstein). The gel was applied to the prepared enamel for 30 seconds and on the dentin for 15 seconds. Then, the etching gel was removed with water spray and air dried. A bonding agent was applied to the tooth surfaces and left unpolymerized (to be polymerized after restoration placement). A dual cure resin cement (Variolink N, Ivoclar Vivadent, Liechtenstein) base was mixed in equal parts with its catalyst on a mixing pad for 20 seconds, and then applied to the intaglio surface of ceramic restoration.

Each ceramic onlay restoration was seated into its corresponding preparation of tooth specimen using finger pressure and excess cement was removed using a dental probe. Specimens were light-cured with light curing unit for 20 seconds from each direction. Cement margin was finished using flexible polishing discs (Sof- Lex XT Pop-On, 3M ESPE). All specimens were stored in distilled water until testing.

Aging with the chewing simulator

Before fracture resistance test, all samples were subjected to aging. The thermo-mechanical aging test was conducted using the newly developed Robota chewing simulator integrated with thermocyling protocol operated on servo-motor (AD-TECH, Germany). The chewing simulator has four chambers simulating the vertical and horizontal movements simultaneously in the thermodynamic

TABLE (3) Test parameters of chewing simulator

Cold/hot bath temperature:	5°C/55°C	Dwell time:	60 s
Vertical movement:	2 mm	Horizontal movement:	3 mm
Rising speed:	90 mm/s	Forward speed:	90 mm/s
Descending :	40 mm/s	Backward speed:	40 mm/s
Cycle frequency:	3 Hz	Weight per sample:	5 kg

condition. Each of the chambers consists of an upper hardened steel stylus holder that can be tightened with a screw for use as antagonistic materials and a lower plastic sample holder filled with distilled water in which the specimen was embedded. Each specimen with its acrylic resin block was fixed in the lower sample holder. A weight of 5 kg, which is comparable to 49 N of chewing force, was exerted. The aging test was repeated 60,000 times to clinically simulate the 3 months chewing condition, accompanying thermocycling according to previous studies [27, 28].

Fig. (4) Axial compressive loading on a tooth specimen in universal testing machine.

Fracture resistance measurement

All samples were individually mounted on a computer controlled universal testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA). Each sample was secured to the lower fixed compartment of testing machine by tightening screw. Fracture test was done by axial compressive mode of load applied occlusally at the middle of crown using a metallic rod with 5.6 mm diameter spherical tip (figure 4). The metallic rod was attached to the upper movable compartment of testing machine and the load applied at cross-head speed of 1.0 mm/min. A tin foil sheet was inserted between the rod and occlusal surface to achieve homogenous stress distribution and minimization of the transmission of local force peaks. The load at failure was manifested by an audible crack and confirmed by a sharp drop at load-deflection curve. The load required to fracture was recorded in Newton (N).

Statistical analysis

Data were recorded using computer software (Nexygen-MT- 4.6; Lloyd Instruments) and analyzed statistically with one way analysis of variance (ANOVA) and post hoc tests to determine the presence of statistically significant differences among the groups. Differences were considered significant at $P<0.05$.

RESULTS

Mean fracture resistance and standard deviations (SD) of the tested groups are recorded and displayed in table (4) and graphically drawn in figure (5).

One way analysis of variance (ANOVA) showed significant differences between the various groups. Comparison within the subgroups by multiple comparisons post-hoc tests is displayed in table (5). The values obtained for Vita Enamic onlay (EN), Vita Enamic onlay with pulp chamber

TABLE (4) Fracture resistance results (Mean values ± Standard Deviations) of all groups in Newton (N)

Groups	No.	Mean	SD	Min	Max
Control	**5**	2419.17 [b]	253.46	2100.00	2788.00
(A1) EN	**5**	1812.67 [a]	311.28	1200.00	2100.00
(B1) EN-P	**5**	2091.67 [a]	141.92	1997.00	2311.00
(A2) LU	**5**	1889.83 [a]	145.68	1700.00	2100.00
(B2) LU-P	**5**	2010.50 [a]	46.09	1972.00	2101.00
(A3) EX	**5**	2492.17 [b]	179.47	2202.00	2665.00
(B3) EX-P	**5**	2528.33 [b]	95.33	2431.00	2660.00

Different letters indicating significant between groups (p<0.05)

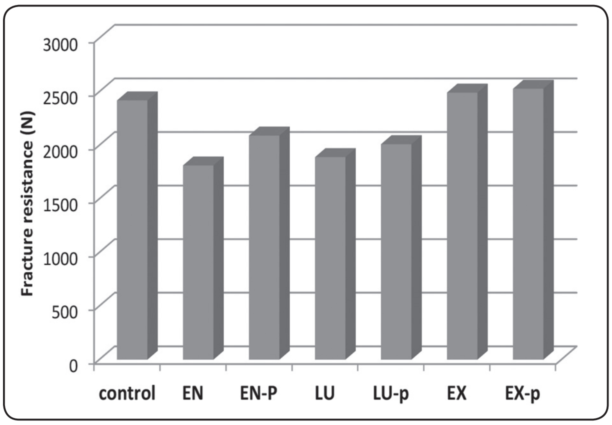

Fig. (5) Mean fracture resistance values (N) for the restored tooth with MOD onlays as function of ceramic material and extension into the pulp chamber

extension (EN-P), Lava Ultimate onlay (LU) and Lava Ultimate onlay with pulp chamber extension (LU-P) were not significantly different from each other (p>0.05), but significantly different from the values obtained for IPS E.max CAD onlay (EX) and IPS E.max CAD onlay with pulp chamber extension (EX-P) (p<0.05).

The values of groups (EN), (EN-P), (LU), and (LU-P) were significantly different from the values obtained for the control group (p<0.05). Whereas, the values for (EX) and (EX-P) groups were not significantly different from each other and from the control group (p>0.05).

TABLE (5) Post Hoc test for comparisons within subgroups

(I) Group	(J) Group	P-value
Control	**A1** (EN)	0.000*
	B1 (EN-P)	0.025*
	A2 (LU)	0.000*
	B2 (LU-P)	0.012*
	A3 (EX)	1.000
	B3 (EX-P)	1.000
A1 (EN)	**B1** (EN-P)	0.300
	A2 (LU)	1.000
	B2 (LU-P)	1.000
	A3 (EX)	0.000*
	B3 (EX-P)	0.000*
B1 (EN-P)	**A2** (LU)	1.000
	B2 (LU-P)	1.000
	A3 (EX)	0.015*
	B3 (EX-P)	0.006*
A2 (LU)	**B2** (LU-P)	1.000
	A3 (EX)	0.000*
	B3 (EX-P)	0.000*
B2 (LU-P)	**A3** (EX)	0.002*
	B3 (EX-P)	0.001*
A3 (EX)	**B3** (EX-P)	1.000

****The mean difference is significant at (p≤ 0.05).***

- Non significant (p> 0.05).

DISCUSSION

Weakened tooth structure and the increased susceptibility to fracture have been reported to the endodonticaly treated tooth [29]. Reeh et al [30] reported that the resistance to fracture of endodontically treated posterior teeth is reduced by 69% in cases where MOD cavities are present. However, onlay restorations have been shown to improve fracture resistance when extensive loss of tooth structure has occurred [31] and may become alternative to traditional full coverage restorations [32].

Adhesive dentistry has provided methods for bonding all-ceramics to enamel and dentin. Recent ceramic materials offer highly esthetic, biocompatible, and functional restorations. In this study, the procedures of fabricating and bonding onlays to extracted human teeth were designed to mimic clinical conditions. Sizes of extracted teeth and dimensions of onlay cavities in each experimental group were also controlled.

Composite resin was selected as a base material in this study, as the different elastic moduli of base materials under ceramic inlay/onlay restorations could affect the fracture resistance of endodontically treated teeth [33]. Saridag et al [7] found that restoring endodontically treated first molars with ceramic inlays and a composite base material resulted in higher fracture resistance when compared with zinc phosphate cement and glass ionomer base materials.

Application of mechanical loading and thermocycling are widely accepted methods for testing fracture resistance to simulate aging and stress at the adhesive interface [34]. In this study, Aging was done to clinically simulate the 3 months chewing condition using chewing simulator integrated with thermocycling. Cyclic fatigue loading from mastication was reported to weaken dental restorations [35], including dental ceramics which can be influenced during functional use [36]. Drummond et al [27] investigated the effect of aging on the flexural strength and fracture toughness of six ceramic materials. They found that aging for 3 months caused reduction in the mean flexural strength and fracture toughness.

Vita Enamic is a polymers-infiltrated-ceramic-network with 75% of its volume is feldspathic ceramic and 25% polymer, while, Lava Ultimate is a nano-ceramic resin with 80% of ceramic nano-particles, according to the manufacturer's specifications. In this study, there was no significant difference in the fracture resistance between both Vita Enamic and Lava Ultimate onlay restoration groups, which was in agreement with the results of Albero et al [37]. The elastic modului of composite based ceramics were approximately similar to those of the dental tissues values. He et al [38, 39] described the mechanical properties of these materials and found that they were similar to enamel and dentin. Although composite based ceramics revealed lower fracture resistance than lithium disilicate glass ceramic (E-max CAD), they demonstrated high fracture resistance values because of their resilient structure, which allow the material to bend under load and distribute stresses more evenly. They are considered a good choice for restoring posterior areas with inlays and onlays [40].

IPS E-max CAD is an improved glass ceramic material with relatively high fracture strength. It is a partially crystallized block of 40% lithium meta-silicate crystals. After onlay restoration milling, a recrystallization process was done at 850 ºC for 10 minutes for the transformation of meta-silicate into lithium disilicate crystals. This transformation presents a restoration with its final mechanical properties [41]. The high fracture resistance of IPS e.max CAD may be caused by optimized industrial manufacturing conditions, subsequent minimal voids defects and the use of monolithic lithium disilicate ceramic materials [42]. The high strength and the physical properties of this ceramic material have improved to the point where they can survive high stress-bearing situations such as posterior restorations in endodontically treated teeth [43].

The MOD onlays with E-max CAD and E-max CAD with pulp chamber extension groups showed no significant difference with the intact tooth (control) group. These results demonstrated the importance of material and adhesive onlay restoration in protecting the cusps of endodontically treated tooth and increasing its fracture resistance to the optimum.

The results of this study also, showed no significant difference between each onlay group and onlay with pulp chamber extension group, irrespective of the type of ceramic restoration. The vertically applied compressive force may explain the non significant effect of pulpal floor extension, and it seems that the most significant factor in fracture resistance was cuspal protection. These findings were in agreement with Homsy et al [9] and Seow et al [8], which indicated that the extension of all-ceramic restoration into the pulp chamber of endodontically treated tooth does not provide further increase in the fracture resistance of the restored tooth unit. Further studies may be required to investigate the significance of pulpal floor extension when the teeth are subjected to lateral force.

CONCLUSION

Within the limitation of this study, it was concluded that:

- The extension of all-ceramic restorations into the pulp chamber had non significant effect on the fracture resistance of endodontically treated molars.
- Endodontically treated molars resored with IPS E-max CAD MOD onlay had a significantly higher fracture resistance than the other tested subgroups and there was no significant difference with the sound molars (control group)
- There was no significant difference between Vita Enamic and Lava Ultimate subgroups but they were significantly lower than E-max CAD subgroups.

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