EVALUATION OF FRACTURE RESISTANCE OF MAXILLARY PREMOLAR TEETH RESTORED WITH CAD/CAM INLAYS AND ONLAYS (IN-VITRO STUDY)

Samar G. Abdel Ghany[1]* *BDs* Hany AG. Kehela[2] *PhD*, Wegdan M. Abdel-Fattah[2] *PhD*

ABSTRACT

INTRODUCTION: Teeth fracture resistance is affected by cavity design and restorative material. Furthermore, combining ceramic and polymer phases yielded materials with improved properties that can be used for CAD/CAM fabrication of indirect restorations.
OBJECTIVE: To evaluate the effect of different cavity designs and different CAD/CAM materials on fracture resistance and mode of fracture of maxillary premolars.
METHODS: Forty-five sound human maxillary premolars were used. Nine specimens were left intact as control group (Group I). The rest were divided into two groups (n=18); MOD inlay (Group II) and MOD onlay (Group III). Each group was subdivided into two subgroups (n=9) according to the materials used; VITA Enamic (VE) and Lava Ultimate (LU). Cementation was done by self-adhesive resin cement RelyX™ U200. Specimens were subjected to thermocycling and fracture resistance test was done using a universal testing machine. Mode of fracture was detected by stereomicroscope. Data was analyzed using Two Way ANOVA and Tukey's test. Fracture mode was compared using Monte Carlo simulation of Pearson Chi Square test.
RESULTS: Statistical significant difference was found between control group and VE onlays and LU onlays, without any significant difference among other groups. Fracture in restoration only was shown mostly in the onlays while VE inlays demonstrated fracture in both restoration and tooth structure and most LU inlays showed fracture in both restoration and tooth structure and through the long axis.
CONCLUSIONS: Inlays showed the highest fracture resistance. Vita Enamic and Lava Ultimate showed comparable results regarding fracture resistance, regardless of the preparation design.
KEYWORDS: Inlay, Onlay, Fracture resistance, Vita Enamic, Lava Ultimate
RUNNING TITLE: Fracture resistance of maxillary premolars CAD/CAM restorations.

1 BDS, Faculty of Dentistry, Alexandria University, Alexandria, Egypt.
2 Professor of Operative Dentistry, Conservative Dentistry Department, Faculty of Dentistry, Alexandria University, Alexandria, Egypt.

* *Corresponding Author:*
E-mail: dr.samar_gamal90@yahoo.com

INTRODUCTION

Tooth fracture resistance is influenced by a variety of factors such as tooth anatomy, cavity design, restorative material, and technique (1,2).
Cavity preparation results in a reduction in cusp stiffness (3). During cavity preparation, removal of tooth structure decreases tooth strength as the cavity width and depth increase (4). The most controversial issue in cavity preparation design for posterior teeth is cuspal coverage. It is a viable solution for reinforcement of badly destructed teeth with weakened cusps. When the occlusal isthmus is half or more of the intercuspal distance, cuspal coverage is needed to minimize the risk of fracture (5).
The prevalence of fracture in maxillary premolars is higher than molars and mandibular premolars due to their anatomy and to the occlusal forces that appear to differentiate the buccal and lingual cusps (6). Absence of one marginal ridge in premolar teeth weakens the cusps by 40% and the loss of both marginal ridges weakens the cusps by 60% (7).
Indirect restorations like inlays and onlays can be fabricated either in the laboratory or chairside using computer aided design/computed aided manufacturing (CAD/CAM) technology (8). For CAD/CAM restorations, glass ceramics and resin composites are commonly used. Glass-matrix ceramics have many drawbacks including brittleness and abrasion on opposing dentition, despite of their improved mechanical and optical properties (9).
The combination of ceramic and polymer phases together has resulted in hybrid materials with greater flexural strength, elasticity, and hardness close to natural tooth structure (10,11). The involvement of a polymer network aids in absorbing the chewing forces more than glass ceramics (9). As compared to conventional ceramic materials, these hybrid materials have better edge stability allowing for minimal thickness, economical machinability, and reduced brittleness (12).
Resin matrix- ceramics are examples of these materials. They are comprised of an organic matrix highly filled with ceramic

particles. They are subdivided into many subgroups according to their inorganic composition. Among these subgroups, there are resin nanoceramic that consists of a highly cured resin matrix reinforced with approximately 80% by weight nanoceramic particles, and glass ceramic in a resin interpenetrating matrix that can be referred to as a hybrid ceramic and is composed of a dual network: a feldspathic ceramic network (86% by weight) and a polymer network (14% by weight) (13).

Since fracture resistance defines the maximum strength and pressure that a restorative material and a tooth can withstand until any damage occurs, it can assist clinicians in evaluating various restorative materials and deciding which type of restorative material and preparation to select (14).

The purpose of this study is to evaluate both the effect of different cavity designs and two different CAD/CAM restorative materials on the fracture resistance and the mode of fracture of maxillary premolars.

The null hypothesis of the study is that no significant difference would be found between maxillary premolars restored with polymer infiltrated ceramic and resin nano ceramic CAD/CAM MOD inlays and onlays regarding fracture resistance and mode of fracture.

MATERIALS AND METHODS

Preparation of tooth Specimens

The study was conducted after receiving the approval of the ethical committee at faculty of dentistry, Alexandria University, Egypt.

A total of forty-five sound human first maxillary premolars freshly extracted for periodontal or orthodontic reasons were selected for this study. Teeth were collected from an Egyptian population at the outpatient clinic of the Oral Maxillofacial Surgery Department in Alexandria University according to the selection criteria that ensured being free of cracks and other defects. Calculus deposits and soft tissues were removed. The teeth were stored in 0.2% Thymol for disinfection and the solution was renewed every five days until the onset of the experiment (15).

Simulation of periodontal ligament and alveolar bone support

To simulate the periodontal ligament, the roots of all teeth were dipped into melted wax (Cavex Holland BV, The Netherlands) to produce a 0.2 to 0.3mm layer, then embedded in a cylindrical PVC ring (1.4 x 2 cm) filled with autopolymerizing acrylic resin (Acrystone Dental Factory, England) up to 2 mm below the cement-enamel junction (C.E.J). Wax spacer was removed from the root surface using hot water and a wax knife.

Polyether impression material (Impregum soft, 3M ESPE, St. Paul, Minnesota.) was delivered into the acrylic resin space (alveolus) and allowed to set (16).

The teeth were divided into four groups according to restorative procedures:

Group I: (n=9) Teeth were left intact as the control group.

Group II: (n=18) MOD inlay preparation. They were subdivided into two subgroups according to the CAD/CAM material used:

Group IIa: (n=9) Restored with inlays fabricated from Vita Enamic hybrid ceramic CAD/CAM blocks.

Group IIb: (n=9) Restored with inlays fabricated from Lava Ultimate resin-based CAD/CAM composite material.

Group III: (n=18) MOD onlay preparation with functional and non-functional (palatal and buccal) cusps reduction. They were subdivided into two subgroups according to the CAD/CAM restorative material:

Group IIIa: (n=9) Restored with onlays fabricated from Vita Enamic CAD/CAM blocks.

Group IIIb: (n=9) Restored with onlays fabricated from Lava Ultimate CAD/CAM material.

Cavity Preparation

For groups II and III, a standardized MOD inlay cavity preparation was prepared by a high-speed hand piece (Allegra TE-95, W&H GmbH, Bürmoos, Austria) under water cooling using fissure diamond instruments of Inlay Preparation Set 4261 (Komet, Lemgo, Germany) to make a 6-degree taper cavity. Diamond instruments were replaced every five preparations and teeth preparations were done by the same operator. A bur stopper and calipers were used for standardization and repeatability of preparations.

The dimensions of cavity preparation **(Figure 1)** were as follows:

- The occlusal box: 3 mm deep and 2.5 mm in the bucco-lingual width. Cavities had rounded internal angles, diverging buccal and lingual walls (6°) and cavo-surface angles were approximately 90 degrees.
- The proximal box: 2.5 mm width, 1.5 mm depth and 2 mm height.
- To prepare the onlays of group III, the palatal cusps of the prepared MOD cavities were reduced by 2 mm according to the anatomical shape of the occlusal surface and a 1.5 mm wide chamfer finish line was placed 2 mm cervical to the palatal occlusal reduction using long round-ended taper diamond #850-023 (FG x5, Komet, Germany). The buccal cusp was also reduced by 1.5 mm and a 1.5 mm wide chamfer finish line was placed 2 mm cervical to the buccal occlusal reduction (17,18). **(Figure 2 & 3)**

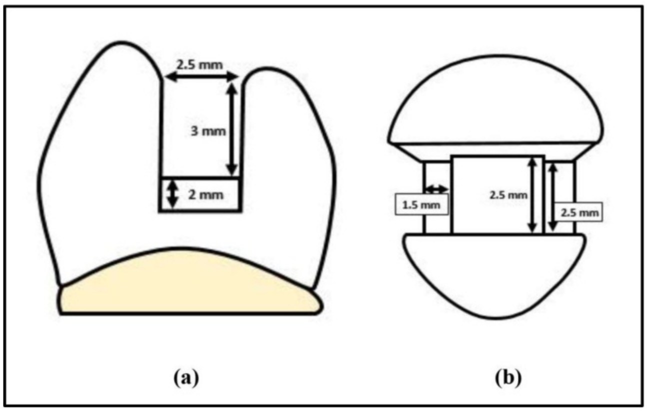

Figure 1: Diagram illustrating the dimensions of MOD inlay cavity preparation. (a) Proximal view and (b) Occlusal view.

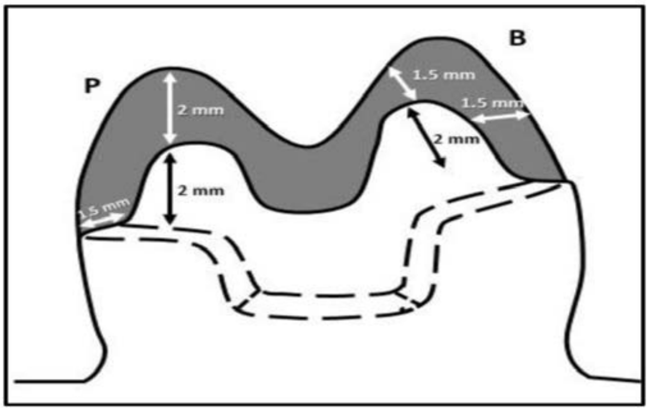

Figure 2: Diagram illustrating MOD onlay with palatal and buccal cusp reduction with a chamfer finish line.

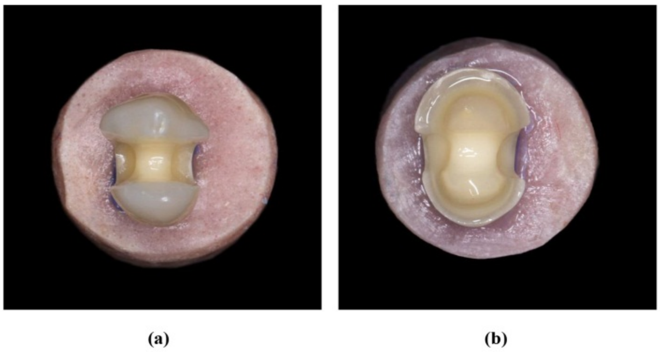

Figure 3: Cavity preparation design (a) Inlay cavity design and (b) Onlay cavity design.

Fabrication of CAD/CAM inlays and onlays

Cavity preparations were coated with a special titanium dioxide Shera Scan Spray (Shera Werstoff-Technologie, Germany) and then scanned by Vinyl laboratory scanner (SMART OPTICS, Germany). Restorations were designed in exocad software (exocad GmbH, Darmstadt, Germany) and milled in the Cerec 3 CAD/CAM system using the Vita Enamic (VITA Zahnfabrik, Germany) and Lava Ultimate (3M ESPE, St Paul, MN, USA) CAD/CAM blocks.

Luting Procedure

Internal surfaces of the CAD/CAM fabricated inlays and onlays were subjected to 29-lm aluminum oxide particles at 0.2-MPa air pressure using Aquacare Twin Dental air abrasion unit (Velopex Int, Medivance Instruments Ltd, London, UK.).

For Vita Enamic inlays and onlays, internal surfaces were etched with Ultradent 9% hydrofluoric acid (Ultradent Dental Products, South Jordan, UT, USA) for one minute and rinsed with distilled water for one minute and then silane (Ultradent Dental Products, South Jordan, UT, USA) was applied (19). As for the Lava Ultimate inlays and onlays, Single Bond Universal Adhesive (3M ESPE, St Paul, MN, USA) was applied to the bonding surface and rubbed for 20 seconds, air blown for about 5 seconds until the solvent evaporated completely according to manufacturer's instructions (20).

All inlay and onlay cavities were cleaned thoroughly by pumice and water, rinsed and dried then etched by 37% Eco-Etch (Ivocalar Vivadent AG, Schaan, Liechtenstein) phosphoric acid for 15 seconds, then rinsed and dried. Single Bond Universal Adhesive was applied using a microbrush and rubbed for 20 seconds and air blown for about 5 seconds then light cured using Bluephase Polywave light-emitting diode unit (Ivoclar Vivadent AG, Schaan, Liechtenstein) for 10 seconds.

For cementation, RelyX™ U200 Automix resin cement (3M ESPE, St Paul, MN, USA) was applied to the fitting surface of the inlays and onlays, then the restorations were fully seated to their cavities by light finger pressure to flow excess material followed by a custom made static load device (1 kg force for 2 min) to standardize the cement thickness and ensure a uniform film thickness of resin cement under restoration (21). **(Figure 4)**

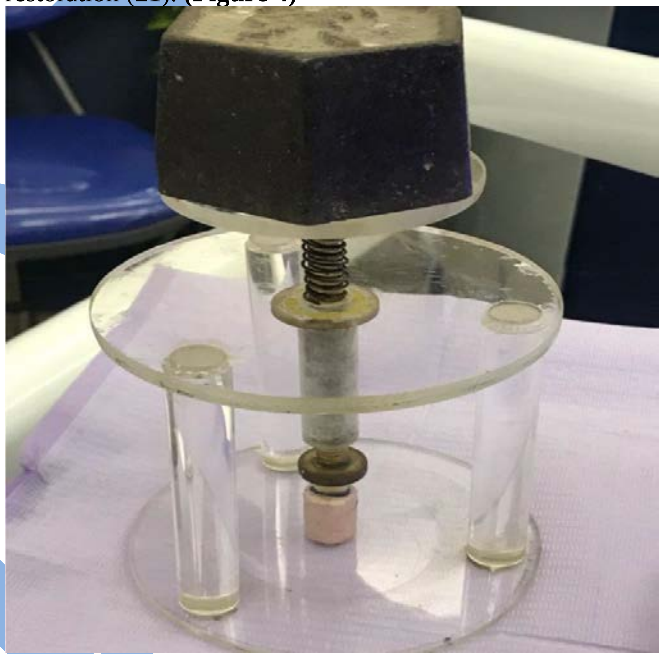

Figure 4: Custom made static load device (1 kg force) to standardize the cement thickness under restoration.

Photopolymerization was performed initially for three seconds (tack curing) followed by careful removal of the cement excess, then each surface was light cured for 20 seconds.

Finally, finishing and polishing of the restorations was performed with Sof-Lex Spiral finishing and polishing wheels (3M ESPE, St Paul, MN, USA).

All specimens were thermocycled at temperatures of 5°C and 55°C for a total of 5000 cycles with a dwell time of 30 seconds and stored in distilled water at 37 ± 1°C for 24 hours before fracture testing.

Fracture Resistance Test and Fracture Mode

Specimens were loaded axially on their occlusal surface at a crosshead speed of 0.5 mm/min in a universal testing machine (Instron, Model 3345, England). A plunger with a steel ball (4-mm diameter) that made a tripod contact with the cusps was used to transmit the compressive force until fracture occured. The force, at which the tooth fractured, was recorded in Newton as the fracture resistance (22).

Mode of fracture of the specimens was detected and evaluated under the stereomicroscope (Nikon MA 100, Japan) and assigned to the following categories based on the pattern of failure (18); **Pattern I:** Fracture restricted to the restoration, **Pattern II:** Fracture of the dental structure, but not through the long axis of the tooth, **Pattern III:** Fracture of the tooth and the restoration but not through the long axis of the tooth and **Pattern IV:** Fracture through the long axis of the tooth, being in the tooth/restoration or only at the tooth.

Statistical analysis

Sample size was estimated based on the following assumptions: confidence level= 95% and study power= 80%. Based on a study conducted by Taha et al., (23), fracture resistance of preparations restored with Vita Enamic CAD/CAM inlays was 1241.5 ± 249.8 N. And according to Papadopoulos et al., (15), fracture resistance of teeth restored with Lava Ultimate CAD/CAM inlays was 1869.86 ± 529.4 N. To detect a difference between these two groups, the least required sample size was calculated to be 8 per group. Sagsoz et al., (24) reported that onlays restored with Vita Enamic showed fracture resistance of 950.89 ±123.11 N while Lava Ultimate – restorations had fracture resistance= 1525 ± 394 N. At least, 6 teeth per group would be required to detect a difference between these. To ensure adequate power to detect various differences, the minimum sample size was calculated to be 8 teeth per group. This was increased to 9 teeth to make up for laboratory processing errors. The total sample size = number of groups × number per group= 5×9= 45 teeth.

Data Normality was checked using Shapiro Wilk test, histogram and descriptive. Normal distribution was approved for fracture resistance that was compared using one-way ANOVA and followed by post hoc Tukey’s test. Two-way ANOVA analysis was used to detect the effect of difference in cavity preparation design and type of restorative material on the teeth fracture resistance. Pattern of failure was compared using Monte Carlo simulation of Pearson Chi Square test. Significance level was set at p value 0.05. Data were analyzed using SPSS version 23.

RESULTS

Fracture resistance analysis

The lowest fracture resistance values were shown in Group IIIb of Lava Ultimate onlays (721.55 ±118.26 N) followed by Group IIIa of Vita Enamic onlays (748.49 ±161.34 N). However, Lava Ultimate inlays exhibited higher values (Group IIb; 895.51 ±231.74 N) than Vita Enamic inlays (Group IIa; 867.78 ±195.46 N). The control Group I demonstrated the highest values (Group I; 1102.04 ±378.88 N). **(Figure 5)**

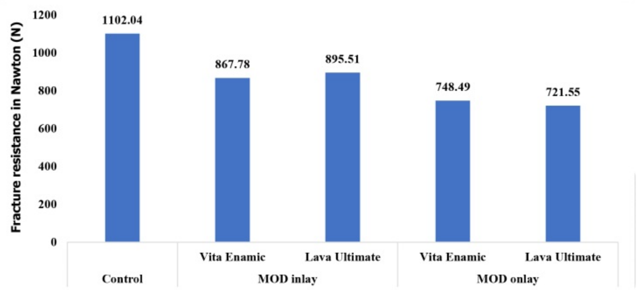

Figure 5: Fracture resistance among the study groups in Newton (N).

The post hoc test revealed significance difference (P<0.05) between Group I (control group) and Group IIIa (Vita Enamic onlays) (P=0.022) and Group IIIb (Lava Ultimate onlays) (P=0.011), while the remaining differences were not statistically significant (P>0.05). **(Table 1)**

Table 1: Post hoc comparison between pairs regarding fracture resistance

Groups	Compared to	*P* value
Control	MOD inlay (Vita Enamic)	0.233
	MOD inlay (Lava Ultimate)	0.351
	MOD onlay (Vita Enamic)	0.022*
	MOD onlay (Lava Ultimate)	0.011*
MOD inlay (VitaEnamic)	MOD inlay (Lava Ultimate)	0.999
	MOD onlay (Vita Enamic)	0.817
	MOD onlay (Lava Ultimate)	0.680
MOD inlay (LavaUltimate)	MOD onlay (Vita Enamic)	0.675
	MOD onlay (Lava Ultimate)	0.523
MOD onlay (VitaEnamic)	MOD onlay (Lava Ultimate)	0.999

*Statistically significant at *p* value ≤0.05

Two-way ANOVA revealed that difference in cavity preparation design and difference in restorative material did not have significant effect on fracture resistance and no significant interaction between them was detected.

Mode of fracture analysis

When the fracture modes were analyzed, the number of teeth with pattern IV fractures (fracture through the long axis of the tooth, being in the tooth/restoration or only at the tooth) was most evident in Group IIb (Lava Ultimate inlays). The highest rate of pattern III fractures (fracture of the tooth and the restoration but not through the long axis of the tooth) was shown in Group IIa (Vita Enamic inlays). While the highest rate of pattern I (fracture restricted to the restoration) was in Group IIIa (Vita Enamic onlays) and Group IIIb (Lava Ultimate onlays) equally. (**Table 2 & Figure 6)**

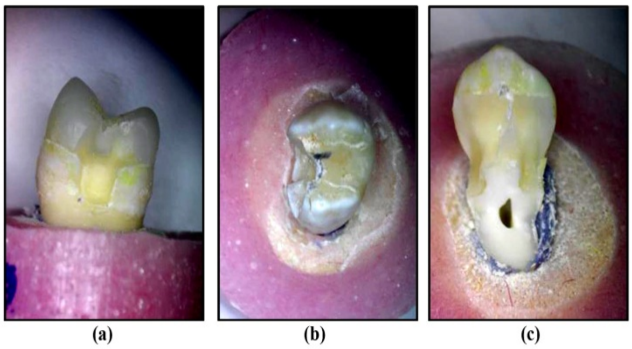

Figure 6: Patterns of mode of fracture: (a) Pattern I: Fracture in restoration only (Lava Ultimate onlay "Group IIIb"), (b) Pattern III: Fracture in both restoration and tooth structure (Vita Enamic inlay "Groub IIa") and (c) Pattern IV: Fracture in both restoration and tooth structure and through the tooth long axis (Lava Ultimate inlay "Group IIb").

Table 2: Pattern of fracture mode between the study groups

	MOD inlay		MOD onlay	
	Vita Enamic (n=9)	Lava Ultimate (n=9)	Vita Enamic	Lava Ultimate (n=9)
	n (%)			
Pattern I	1 (11.1%)	3 (33.3%)	6 (66.7%)	6 (66.7%)
Pattern II	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Pattern III	6 (66.7%)	0 (0%)	2 (22.2%)	2 (22.2%)
Pattern IV	2 (22.2%)	6 (66.7%)	1 (11.1%)	1 (11.1%)
X^2	18.900			
***P* value**	0.002*			

*Statistically significant at *p* value ≤0.05

The post hoc comparison between pairs showed a significant difference (P≤0.05) between Group IIa (Vita Enamic inlays) and Group IIb (Lava Ultimate inlays) (P=0.015). There was also significant difference between Group IIb and Group IIIa (Vita Enamic onlays) (P=0.025) and Group IIIb (Lava Ultimate onlays) (p=0.026). And there was no significant difference among the rest of tested groups (P>0.05).

DISCUSSION

The current study aimed at evaluation of the effect of cavity preparation design and different CAD/CAM restorative material on the fracture resistance and fracture mode of maxillary premolar teeth restored with MOD inlays and onlays.

Maxillary premolar teeth were selected for this study because they are more prone to fracture than other posterior teeth due to their anatomy as their cuspal inclination renders them susceptible to fracture under occlusal forces, in addition to the unfavorable crown to root ratio. Moreover, because of their position in the dental arch, they are exposed to shear and compressive forces (25).

Results showed that there was no statistically significant difference in the fracture resistance between the control group (intact teeth) and Group IIa (Vita Enamic inlays) and Group IIb (Lava Ultimate inlays). This may be credited with the quite conservative inlay cavity preparation used in the study which is less invasive and more conservative with no occlusal reduction.

Cuspal coverage is often recommended to enhance the fracture resistance of the restored teeth (26). It has been suggested that onlays that cover more than one cusp provide favorable distribution of stress and hence, reducing the risk of tooth and restoration fracture (27, 28). And that is why onlay preparation with both buccal and palatal cusp coverage was chosen to test its impact on the fracture resistance of the maxillary premolars in this study.

Based on the results of the study, it was found that there was a significant difference between Group I (control group) and the onlays (Group III); Group IIIa (Vita Enamic onlays) and Group IIIb (Lava Ultimate onlays), while there was no statistically significant difference between the inlays (Group II) and the onlays (group III).However, the current results also showed that fracture resistance of the MOD inlays was superior over the MOD all-cusp onlays.

These results were not in accordance with Ön Salman et al., (27) who used larger sample size of mandibular molar teeth and preparations were: functional cusps reduction, functional cusps reduction with rounded shoulder finish line, all cusps reduction and all cusps reduction with rounded shoulder finish line. Restorations were fabricated using VITA Enamic, GC Cerasmart and Lava Ultimate. Although there was no significant difference between all groups, all-cusps reduction preparation showed higher fracture strength than the only functional cusps preparation group.

Also, the current study results were not in accordance with Harsha et al., (28) who used restorations fabricated from monolithic Zirconia. Preparations were inlays, partial onlays and complete onlays. The fracture test was performed with a steel ball of diameter 3.5 mm at a crosshead speed of 0.5 mm per minute on the center of the buccal cusp slope at an angle of 30° to the long axis of the tooth using a universal measuring machine. While in the current study, specimens were loaded on their occlusal surface in the universal testing machine at a crosshead speed of 0.5 mm/min. The compressive force was transmitted using a plunger with a steel ball (4 mm diameter) in tripod contact with the cusps until fracture occurred.

However our results are consistent with those reported by Habekost et al., (18) who evaluated fracture resistance of premolars restored with three different designs of partial ceramic restorations; inlay, onlay with lingual cusp coverage only and onlay with both buccal and lingual cusp coverage. Results were also in accordance with Saridag et al., (29) who studied the effect of two different cavity preparation designs (inlay and onlay with buccal cusps reduction) and ceramic restorative materials on the fracture resistance of mandibular third molars. Both studies found that the fracture resistance of the inlay cavity design was higher than that of the onlay design.

Both Vita Enamic and Lava Ultimate, used in this study, are hybrid CAD/CAM materials. The VITA ENAMIC, which is also called "hybrid dental ceramic", consists of two interlocking phases, a porous sinterized feldspathic ceramic (75%) and an infiltrating reinforcing methacrylate polymer comprising 25% of the material. It was previously called "polymer infiltrated-feldspathic ceramic-network material" (12).

While Lava Ultimate is called a resin nano ceramic CAD/CAM material which contains 80% nanoceramic particles (silica- and zirconia filler/ cluster filler) bound in a resin matrix.

The mechanical properties of these hybrid materials are very similar to natural dentin and enamel with lower hardness values (10).

Although there was no significant difference between Vita Enamic inlays (Group IIa) and Lava Ultimate inlays (Group IIb), Group IIb showed higher fracture resistance mean value than Group IIa. Also, Vita Enamic onlays (Group IIIa) showed higher mean fracture resistance than Lava Ultimate onlays (Group IIIb), also with no significant difference between them. The explanation for the close values and lack of statistical difference is thought to be due to the comparable properties of Lava Ultimate and Vita enamic, even though the former has a higher flexural strength (30).

In terms of fracture mode distribution among the groups, the statistical analysis revealed there was significant difference between Group IIa (Vita Enamic inlays) and Group IIb (Lava

Ultimate inlays). There was also significant difference between Group IIb and Group IIIa (Vita Enamic onlays) and Group IIIb (Lava Ultimate onlays). And there was no significant difference among the rest of the tested groups. Therefore, based on the findings of this study, the null hypothesis of the study cannot be completely rejected.

Pattern I mode of fracture (fracture in the restoration only) showed highest rate in Group IIIa (Vita Enamic onlays) and Group IIIb (Lava Ultimate onlays) equally. While pattern III (fracture in both restoration and tooth structure but not through the long axis) was mainly in Group IIa (Vita Enamic inlays). And pattern IV (fracture through the long axis in both the restoration and tooth structure or the tooth structure alone), the most catastrophic fracture, was most frequent in Group IIb (Lava Ultimate inlays). The adhesive techniques, the casts fixation, and the direction and angle of the force applied could all influence the type of fracture (25).

The mode of fracture could be attributed to the modulus of elasticity of the restorative materials. Low-modulus materials take the forces and pass them to the adjacent tooth structure, while materials with high modulus of elasticity gather the stresses in their mass and tensile forces evolve below the force application point at the tooth/restoration interface (31). Vita Enamic has a 30 GPa elastic modulus, which is higher than natural dentin, while Lava Ultimate has a 12.77±0.99 GPa elastic modulus, which is twice as low as natural dentin. The difference in modulus between restorative materials and natural dentin results in an unequal transfer of force, resulting in early restoration failure. Since Lava Ultimate has a low elastic modulus, in comparison with Vita Enamic, the elastic deformation of the restorative material would be greater (32).

Periodontal ligament simulation could be one of the influencing factors for fracture resistance presented in this study as comparable results were also found by Saridag et al., (29) using this technique while it was not done by Habekost et al., (18), though their results were in accordance with the results of this study.

This study did not take into consideration important factors such as time or para-functional habits that might alter force distribution patterns. The study depended on applying a compressive load in one direction until failure occurs, that is why it may not reflect other clinical situations.

CONCLUSION

Within the limitations of this in-vitro study it can be concluded that:

1) The inlay restorations showed fracture resistance comparable to that of the intact teeth.
2) Despite the close values, onlays had lower mean fracture resistance than inlays. Hence, cuspal coverage did not reinforce tooth structure.
3) Vita Enamic and Lava Ultimate CAD/CAM materials can be used reliably in fabricating inlays and onlays for restoring premolars as they showed comparable results, regarding fracture resistance, regardless of the cavity design.
4) The majority of Lava Ultimate and Vita Enamic onlays exhibited favorable fracture pattern within the restoration only.
5) Further studies are required to test the effect of different finish line types on the fracture resistance of maxillary premolars restored with CAD/CAM onlays.

Conflict of interest

The authors declare that they have no conflicts of interest.

Funding

The authors received no specific funding for this work.

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