Vol 5 | Issue 4 | 2015 | 249-261.

e-ISSN 2248 – 9142
print-ISSN 2248 – 9134

International Journal of
Current Pharmaceutical & Clinical Research

www.ijcpcr.com

INFLUENCE OF SURFACE TREATMENT AND TYPE OF INLAY RESTORATION ON FRACTURE RESISTANCE OF TOOTH CROWN: AN IN VITRO STUDY

Hisham I. Wali [1*], Ma'an M. Nayif [2], Abduladheem R. Sulaiman [3]

[1]General Practitioner, Ministry of Health, Mosul.
[2]Assistant professor, Department of Conservative Dentistry, College of Dentistry, University of Mosul, Mosul.
[3]Lecturer, Department of Conservative Dentistry, College of Dentistry, University of Mosul, Mosul.

ABSTRACT

Aims to evaluate the effect of two types of surface treatments and three types of indirect ceramic inlays on fracture resistance of tooth crown. Eighty sound human maxillary first premolars were randomly divided into four groups (n=20) as follow: Control group: The teeth were divided in to two subgroups (n=10) as follow: Positive control (PCON): The teeth were left intact without preparation. Negative control (NCON): The teeth were prepared but not restored. Group A (EM): The teeth were restored by leucite reinforced ceramic inlays (IPS Empress Esthetic ingots).Group B (E): The teeth were restored by lithium disilicate glass ceramic inlays (IPS e max Press ingots).Group C (Z): The teeth were restored by zirconia inlays (ICE Zirkon).Groups A, B and C were subdivided into two subgroups (n=10) according to the type of surface treatment applied to the inner side of the inlays as follows: 1. Sanblasting (S) with aluminum oxide particles of grain size 50 micron.2. Etching (E) with 9% hydrofluoric acid gel. The specimens were subsequently submitted to an axial compression test, using a six mm steel rod until their fracture. The average compression force causing cuspal fracture in the eight experimental groups was as follow: PCON= 818 Newton; NCON= 296 (N); EMS= 878 (N); EME= 1012 (N); ES= 1016 (N); EE= 1104 (N); ZS= 984 (N) and ZE= 780 (N). Statistical analysis showed that cavity preparation significantly weakened the remaining tooth structure. However, no significant difference was found between all the treatment groups and PCON. When etching was used, significant differences existed among treatment groups. Etching and sandblasting did not produce any significant differences in the fracture resistance within the same treatment groups (EM, E and Z). Cavity preparation significantly weakens the remaining tooth structure. The indirect ceramic inlays luted by resin cement may restore fracture resistance of teeth weakened by MOD cavity preparation, regardless of surface treatment.

Key words: Fracture resistance**,** Surface treatment, Ceramic inlay.

INTRODUCTION

Reduced tooth structure resulting from caries, trauma, and cavity preparations has a negative influence on the fracture resistance of teeth [1]. Restorations that merely fill the preparation without adhesion, such as amalgams or gold inlays, do not reinforce weakened tooth structure [2]. Therefore, a restorative material should not only replace the lost tooth structure but also increase the fracture resistance and promote effective marginal sealing [3].

The physical and mechanical properties of ceramic restorations when combined with adhesive technology favor reinforcement of extensively damaged teeth increasing fracture resistance of the single tooth restoration complex [4].

Several conditioning methods have been suggested for ceramic surface pretreatment, such as sandblasting, chemical etching and silica coating [5].

Corresponding Author :- **Hisham I. Wali** Email:- hisham_976@yahoo.com

Recent developments in modern surface conditioning methods have resulted in improved resin-to-ceramic bond strengths [6]. In addition to retaining the restoration in the cavity, the luting agent seals the margins, decreases stress concentration on the restorative material and dental structure and supports the buccal and lingual cusps [7]. Choosing between the use of a direct or indirect technique, when placing a posterior restoration is difficult and involves esthetic, biomechanical, anatomical, and financial considerations. When an indirect restoration is determined to be the best treatment option, the clinician must then determine the type of restorative material used and the type of surface treatment before performing adhesive cementation.

Dental ceramics are considered to be esthetic restorative materials with desirable characteristics, such as translucence, fluorescence, and chemical stability [8, 9]. They are also biocompatible, have high compressive strength, and their thermal expansion coefficient is similar to that of the tooth structure [8]. Zirconia is a crystalline dioxide of zirconium. Its mechanical properties are very similar to those of metals, and its color is similar to tooth color. Zirconia crystals can be organized in three different patterns: monoclinic, cubic, and tetragonal [10]. Yttrium-stabilized zirconia, also known as tetragonal zirconia has become available for use in dentistry through computer-aided design/computer-aided manufacturing (CAD/CAM) and provides excellent mechanical performance, superior strength, and fracture resistance compared to other ceramics [11, 12].

In spite of their many advantages, ceramics are fragile under tensile strain, making them susceptible to fracture during the luting procedure and under occlusal force [13, 14]. This dichotomy raises an important question as to which is the best ceramic material and the best surface treatment method to be used during restorative procedure.

The null hypothesis to be tested in this study was that:

1. There is no difference in fracture resistance values between the intact teeth and prepared unrestored teeth, between intact teeth and treatment groups and between prepared unrestored teeth and treatment groups.
2. Sandblasting affects the fracture resistance of teeth regardless of the type of inlay material.
3. Hydrofluoric acid etching affects the fracture resistance of teeth regardless of the type of inlay material.
4. The type of surface treatment affects the fracture strength of teeth restored with the same type of inlay material.

Aims of the study

The aims of the present study were to evaluate:

1. The effect of surface treatment (sandblasting with aluminum oxide particles and hydrofluoric acid etching) of ceramic inlays on fracture resistance of maxillary first premolar crown.
2. The influence of type of ceramic inlay on the fracture resistance of maxillary first premolar crown.
3. The fracture mode to be obtained according to the type of inlay material and surface treatment.

MATERIALS AND METHODS

Specimens' preparation

Eighty sound human maxillary first premolar teeth extracted for orthodontic purposes were selected for the study. Any calculus and soft tissue deposits were removed from the selected teeth by hand scaler and polished with fine pumice (Bilkim LTD Co, Turkey) water slurry. The teeth were stored in distilled water at 37°C in an incubator (Binder, Germany) for three months after extraction until completion of the study [15]. Teeth with nearly similar dimensions were selected by measuring buccolingual and mesiodistal widths of the crown in millimeters allowing a maximum deviation of less than 10% from the determined mean. The teeth selected for study fell in the following measurement criteria: buccolingually 9 ± 0.8 mm, mesiodistally 7 ± 0.8 mm [16].

The teeth were examined for defects like cracks under visible light curing unit [17] and teeth having cracks or structural defects were excluded from the study. Through the study, the teeth were stored in distilled water at 37°C. By the aid of vertical arm of dental surveyor, the teeth were mounted with their roots embedded in polyvinyl chloride tubes (2 cm diameter × 2.5 cm height) filled with autopolymerized acrylic resin to a level 1mm apical to the cementoenamel junction [2].

The mounted teeth were placed in cold water before complete curing of acrylic resin to avoid the effect of heat generated from the exothermic reaction of acrylic resin curing. After that the teeth were again examined using visible light curing unit to exclude the presence of cracks.

Specimens' grouping

The specimens were divided into eight groups (n=10) as follow:

Positive control (PCON): The teeth were left intact without preparation.

Negative control (NCON): The teeth were prepared for mesio-occlusal-distal (MOD) cavity preparation but not restored.

EMS: MOD cavity preparation and restoration with leucite reinforced ceramic inlay (IPS Empress Esthetic indirect ceramic ingots, Ivoclar Vivadent, Schaan, Liechtenstein) sandblasted with aluminum oxide particles of grain size 50 micron.

EME: MOD cavity preparation and restoration with leucite reinforced ceramic inlay (IPS Empress Esthetic indirect ceramic ingots, Ivoclar Vivadent, Schaan, Liechtenstein) etched with 9% hydrofluoric acid.

ES: MOD cavity preparation and restoration with lithium disilicate glass ceramic inlay (IPS e max Press ingots, Ivoclar Vivadent, Schaan, Liechtenstein) sandblasted with aluminum oxide particles of grain size 50 micron.

EE: MOD cavity preparation and restoration with lithium disilicate glass ceramic inlay (IPS e max Press ingots, Ivoclar Vivadent, Schaan, Liechtenstein) etched with 9% hydrofluoric acid.

ZS: MOD cavity preparation and restoration with zirconium inlay (ICE Zirkon, Zirkonzahn) sandblasted with aluminum oxide particles of grain size 50 micron.

ZE: MOD cavity preparation and restoration with zirconium inlay (ICE Zirkon, Zirkonzahn) etched with 9% hydrofluoric acid.

The experimental groups, their coding and surface treatments are shown in (table 1).

Cavity preparation

For the preparation of mesio-occlusol distal cavity, five degree tapered diamond burs (Diadatum dental inustrument, Japan) were used in a high speed hand piece (Quayle Dental, England) mounted in a modified surveyor under copious air-water cooling [18]. The burs were replaced after four preparations in order to ensure high cutting efficiency. The dimensions of the prepared cavities were evaluated with the aid of digital caliper and periodontal probe. Dimensions of the preparations were as follow: The depth of occlusal preparation was 2 mm from the palatal occlusal cavosurface margin. The width of occlusal preparation was half the intercuspal distance of each tooth. The width of proximal boxes at the level of gingival seat was equal to half the buccolingual distance of each tooth. The depth and height of axial wall were 1.5 and 1 mm respectively. Axiopulpal and internal line angles were rounded to avoid stress concentration and cavosurface margins were prepared at 90 degree. Figure (1) shows the finished cavity preparation.

Study model fabrication

A perforated special tray made from autopolymerized acrylic resin was made to take impression for the prepared teeth. Impression was taken for each prepared tooth with heavy and light body silicon based condensation curing impression materials using the two stage putty wash technique. First, the special tray was filled with heavy body impression material (Zetaplus Putty, Zhermack, Itally) after mixing it with the catalyst paste and the impression was taken and after its set, the impression was removed from the tooth and the superficial layer of the impression was removed using number 15 surgical blade, then a thin layer of light body impression material (Oranwash light, Zhermack, Itally) was added, after mixing it with the same catalyst paste, to the first impression and the loaded tray was replaced over the tooth. After its setting the impression was removed from the tooth and poured after one hour using stone material (Elite stone, Zhermack, Itally) according to manufacturer instructions.

Inlay Fabrication

IPS Empress Esthetic and IPS e max Press inlays were made from IPS Empress Esthetic and IPS e max Press ingots respectively. Three layer of spacer was applied to the stone die up to the preparation margin. Then wax up was performed using inlay wax (Tho wax, Yeti dental, Germany) and attached to a sprue at 45 degree angle. IPS Empress Esthetic speed and IPS press VEST speed investment materials (Ivoclar Vivadent, Schaan, Liechtenstein) were used for investing IPS Empress Esthetic and IPS e max Press inlays respectively. The corresponding IPS silicone ring with matching ring gauge (Ivoclar Vivadent, Schaan, Liechtenstein) was used for that purpose.

After attaching the sprued wax up to the investment ring base, the IPS silicone ring was carefully placed on it the without damaging the wax up. Then the investment ring was carefully filled with investment material up to the marking and the ring gauge was positioned with a hinged movement over the investment ring. After the investment material has set, the investment ring was prepared for preheating by removing the ring gauge and ring base with a turning movement and carefully pushing the investment ring out of the IPS silicone ring. Preheating was performed by placing the investment ring in the furnace for 45 minute at a temperature 850°C according to manufacturer instructions. Pressing was performed using the press furnace Programat EP 3000 (Ivoclar Vivadent, Schaan, Liechtenstein). The press program for IPS e.max Press and IPS Empress Esthetic were selected accordingly. First the ingots then the aluminum oxide plungers were placed in the investment ring and the latter was quickly positioned in less than 1 min in center of the furnace.

The button start was pushed to start the selected program. When the pressing program has completed, the investment ring was removed from the furnace and allowed to cool to room temperature on a cooling grid. Divesting was performed by first marking the length of the alumina plunger on the cooled investment ring. After that the investment ring was separated using a separating disk (Edenta, Italy) mounted on slow speed hand piece (Maraton, Korea) and the investment ring was broken at the predetermined breaking point. Rough and fine divestment was carried out with glass polishing beads at 4 and 2 bar pressure respectively. Glaze firing was accomplished by mixing IPS glaze paste with IPS glaze and stain liquids according to manufacturer instructions and applying them to the inlays. Then after the inlays were placed on honey comb firing tray and the loaded tray was placed in Programat P 500 furnace for firing at 730 °C for

2 hours. A CAD CAM unit system adopting Exocade zirkonzahn software was used to fabricate ICE Zirkon inlays. The stone model of each prepared tooth was placed in zirkonzahn scanner by the aid of its clamp holder. First the zirkonzahn archive of the software system was opened and the job menu was selected and then the type of the tooth was determined by marking on the upper first premolar followed by marking inlay as the type of restoration to be fabricated. The digital image was performed by taking eight shots of the stone model by the aid of two optimizer cameras of the scanner. The inlay restoration was designed by a process called modeling in which the margins of the prepared cavities were accurately defined on the digital image. After that an ICE Zirkon blank was placed inside the milling unit to mill the inlays according to the previously recorded data. The milled inlay was sintered in zirconofen furnace at 1500°C for 12 hours and then glazed and fired in the same furnace at 950°C for 7 hours.

Surface treatment of the inlays

After their fabrication the inlays were carefully tried in their respective teeth to ensure proper seating and check their fitness. The prepared teeth were polished using fine water pumice slurry prior to cementation of the inlays. EMS, ES and ZS groups were sandblasted with aluminum oxide particles of grain size 50 micron (Quantum, Dental-Strahlmittel, Germany) under pressure of 2.5 bars for 10 seconds from a distance 10 mm from the inlay. After that the inlays were washed with distilled water for 10 seconds and air dried for 30 seconds using triple syringe. EME, EE and ZE groups were etched according to manufacturer instructions with 9% hydrofluoric acid (Cera etch, Moravon dental materials and equipments, Iran). The etching time for IPS e max Press inlays was twenty seconds while that of IPS Empress Esthetic and ICE Zirkon inlays was sixty seconds. After that the inlays were washed with distilled water for 10 seconds and air dried for 30 seconds using triple syringe.

Adhesive placement of ceramic inlays

In order to adhesively cement the inlays, Multilink Automix resin cement System pack (Ivoclar Vivadent, Schaan, Liechtenstein) was used for this purpose. The cementation process was performed according to the manufacturer instructions in the following manner: Each inlay was held by a ministick (Optrastick, Ivoclar Vivadent, Schaan, Liechtenstein) and Monobond Plus (Ivoclar Vivadent, Schaan, Liechtenstein) was applied to its pretreated surface with minibrush (Ivoclar Vivadent, Schaan, Liechtenstein) and left to react for 60 seconds. Subsequently, it was air dried for 30 seconds. Self-etching and self-curing Multilink Primer A and B (Ivoclar Vivadent, Schaan, Liechtenstein) were used to treat the prepared tooth cavity. The two primer liquids were mixed together in a mixing plate in a 1:1 ratio (1 drop Primer A and 1 drop Primer B), applied onto the entire bonding surface of the tooth using a mini brush, starting with the enamel surface, and scrubbed in for 30 seconds. The excess mixture was dispersed with blown air until the mobile liquid film was no longer visible.

As the primer is solely self-curing, no light-curing was necessary. In order to apply constant pressure and standardize it for all inlays during their cementation so that uniform distribution of resin cement is guaranteed, the vertical arm of the dental surveyor was modified by removing its spring and adding metal rings and a round ended rod which was perpendicularly held on the inlays during their cementation. The weight of the modified vertical arm was 100 gram. Multilink Automix resin cement (Ivoclar Vivadent, Schaan, Liechtenstein) was dispensed from the automix syringe and applied directly to the inlays. While applying constant pressure imparted by the 100 gram modified surveyor's vertical arm, the seated inlays luted with the resin cement were light cured using spectrum 101 light cure device (Quayle Dental, England) with a light intensity of 800 mW/cm^2 for 3 seconds from occlusal, mesial and distal sides to obtain initial polymerization of the resin cement. Excess cement was removed by sharp no.15 surgical blade and then liquid strip /air block was applied to the margins of the preparations to avoid incomplete polymerization of resin cement which occurs as a result of oxygen inhibition.

Then final curing was performed by light curing for 20 seconds for each side; mesial, occlusal and distal and liquid strip was rinsed off with air water spray. Figure (2) shows the finished inlay after its cementation to the prepared tooth.

Thermocycling

After adhesive cementation of the inlays to the prepared teeth has been completed, all the specimens were stored in closed plastic tubes filled with distilled water at 37°C for two weeks. After that period all the specimens were submitted to manual thermal cycling for one hundred cycles between 5° and 55°C with a dwell time of 30 seconds.

Axial compression test

Each sample was placed in a special holder to hold it during axial loading and to prevent its slippage and to ensure the orientation of forces on the longitudinal axis of the sample. Axial loading was applied using an Instron universal testing machine with a 6 mm rounded end stainless steel rod that was attached to the cross head of the testing machine and the load was applied on the buccal and palatal inclines of each tooth and not to the inlays (figure 3) until the tooth fractures. The force at which the tooth fractured appeared on the meter, which was already connected to the universal testing machine was recorded in Newton.

Fracture pattern

The fracture pattern was evaluated based on a standard ranking developed by Habekost et al. (2006) [19] as follow:

1. Pattern I: Fracture restricted to the restoration.
2. Pattern II: Fracture of the dental structure, but not through the long axis of the tooth.
3. Pattern III: Fracture of the tooth and the restoration but not through the long axis of the tooth.
4. Pattern IV: Fracture through the long axis of the tooth, being in the tooth/ restoration or only at the tooth.

Statistical analysis

Two sample T-test was used to analyze the results obtained within the same group while one way ANOVA and Duncan's multiple range tests were used to evaluate the results among the treatment groups.

RESULTS

Descriptive analysis of fracture resistance mean values revealed that the highest score was obtained in the EE subgroup (1104 N) whereas the lowest fracture value was obtained in the NCON subgroup (296 N). Table (2) and figure (4) show the results for all treatment groups. Regarding the control group, two sample T test showed that the PCON subgroup had significantly higher fracture resistance value (818 N) than NCON subgroup (296 N) as shown in table (3). One-way ANOVA between PCON and treatment subgroups showed no significant differences (Table 4). The PCON had no significant difference when compared with all treatment subgroups, although all the treatment subgroups except ZE obtained higher scores than the PCON (Table 5). One-way ANOVA and Duncan's multiple range tests between NOCN and treatment subgroups showed significant differences (Table 6, 7).

Regarding the effect of sandblasting on the fracture resistance of EMS, ES and ZS subgroups, one way ANOVA and Duncan's multiple range test showed no significant differences existing among them (Table 8, 9). One way ANOVA (Table 10) and Duncan's multiple range tests (Table 11) evaluating the effect of 10% hydrofluoric acid etching on the fracture resistance of EME, EE and ZE subgroups revealed significant differences among them. EE subgroup obtained a high fracture resistance value that was significantly different from ZE subgroup while EME subgroup recorded a value that was not significantly different from ZE and EE subgroups. For each of the three restorative material used, there was no significant difference regarding the type of surface treatment (etching and sandblasting) on the fracture resistance (Table 12, 13 and 14).

The different patterns of fracture obtained in this study are shown in figures (5, 6 and 7). The fracture pattern of each subgroup is shown in table (15). Pattern II was predominant in PCON and NCON subgroups. For EMS and EME subgroups, pattern IV was presented in more than half of the specimens. In ES and EE subgroups, pattern II and IV were the most predominant patterns observed. For ZS and ZE subgroups, fracture pattern II was the most predominant.

Table 1. The experimental groups of the study

Experimental groups (n=10)			
Code	Restorative material	Surface treatments	
		HF*etching	Sandblasting
PCON	No preparation, no restoration	-	-
NCON	Prepared, non-restored	-	-
EMS	IPS Empress Esthetic	No	Yes
EME	IPS Empress Esthetic	Yes	No
ES	IPS e max press	No	Yes
EE	IPS e max press	Yes	No
ZS	Zirkonzahn	No	Yes
ZE	Zirkonzahn	Yes	No

*HF: Hydrofluoric acid

Table 2. Descriptive analysis

Groups' code	Minimum*	Maximum*	Mean*	SD
PCON	300	1260	818	363.23
NCON	240	345	296	34.89
EMS	220	1580	878	448.83
EME	710	1230	1012	172.25
ES	480	1550	1016	361.98
EE	330	1510	1104	441.66

ZS	320	2820	984	963.12
ZE	360	1220	780	310.08

*:Newton

Table 3. Two sample T test for control subgroups

Sub group	No.	Mean	SD	t– value	df	Sig.
PCON	10	818	363.22	4.524	18	0.00
NCON	10	296	34.89			

Table 4. One way ANOVA (PCON and treatment subgroups)

SOV	SS	df	MS	F-value	Sig.
Between	84094.286	6	140165.714	0.590	0.737
Within	14950000	63	237377.238		
Total	15800000	69			

Table 5. Duncan's multiple range tests (PCON and treatment subgroups)

Subgroups	Number	Subset for alpha = 0.05
		1
ZE	10	780
PCON	10	818
EMS	10	878
ZS	10	984
EME	10	1012
ES	10	1016
EE	10	1104
Sig.		0.207

Table 6. One way ANOVA (NCON and treatment subgroups)

SOV	SS	df	MS	F-value	Sig.
Between	4468000	6	744691.429	3.405	0.006
Within	13780000	63	218703.175		
Total	18250000	69			

Table 7. Duncan's multiple range tests (NCON and treatment subgroups)

Subgroups	N	Subset for alpha = 0.05	
		1	**2**
NCON	10	296	
ZE	10		780
EMS	10		878
ZS	10		984
EME	10		1012
ES	10		1016
EE	10		1104
Sig.		1	0.182

Table 8. One way ANOVA (EMS, ES and ZS)

SOV	SS	df	MS	F-value	Sig.
Between	104346.667	2	52173.333	0.129	0.879
Within	10880000	27	402935.852		
Total	10980000	29			

Table 9. Duncan's multiple range tests (EMS, ES and ZS)

Subgroups	N	Subset for alpha = 0.05
		1
EMS	10	878
ZS	10	984
ES	10	1016
Sig.		0.651

Table 10. One way ANOVA (EME, EE and ZE)

SOV	SS	df	MS	F-value	Sig.
Between	557546.667	2	278773.333	4.73	0.042
Within	1591306.552	27	58937.28		
Total	2148853.219	29			

Table 11. Duncan's multiple range tests (EME, EE and ZE)

Subgroups	N	Subset for alpha = 0.05	
		1	2
ZE	10	780	
EME	10	1012	1012
EE	10		1104
Sig.		0.124	0.535

Table 12. Two sample T test for Empress Esthetic group

Sub group	No.	Mean	SD	t– value	df	Sig.
EMS	10	878	448.83	-0.881	18	0.39
EME	10	1012	172.25			

Table 13. Two sample T test for IPS e max Press group

Sub group	No.	Mean	SD	t– value	df	Sig.
ES	10	1016	361.98	-0.487	18	0.632
EE	10	1104	441.66			

Table 14. Two sample T test for ICE Zirkon group

Sub group	No.	Mean	SD	t– value	df	Sig.
ZS	10	984	963.12	0.654	18	0.527
ZE	10	780	310.08			

Table 15. Fracture pattern of experimental subgroups

Experimental subgroups								
Fracture pattern	**PCON**	**NCON**	**EMS**	**EME**	**ES**	**EE**	**ZS**	**ZE**
I	-	-	-	-	-	-	-	-
II	10	8	-	2	6	4	8	8
III	-	_	4	2	-	2	2	-
IV	-	2	6	6	4	4	-	2

Figure 1. Finished cavity preparation

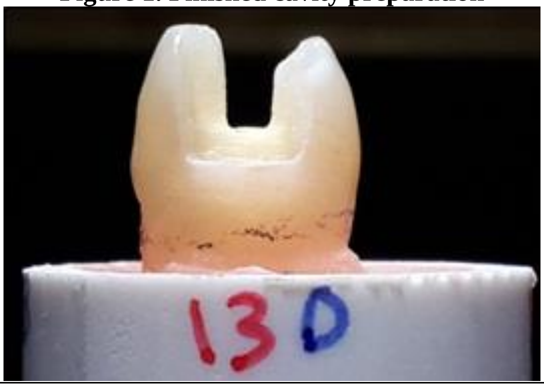


Figure 2. A, Proximal view of cemented inlay. B, Top view of cemented inlay

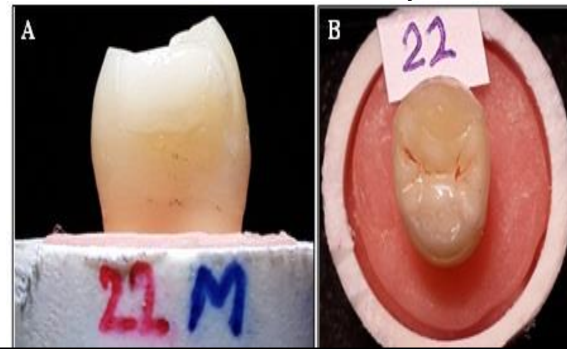


Figure 3. Axial load application

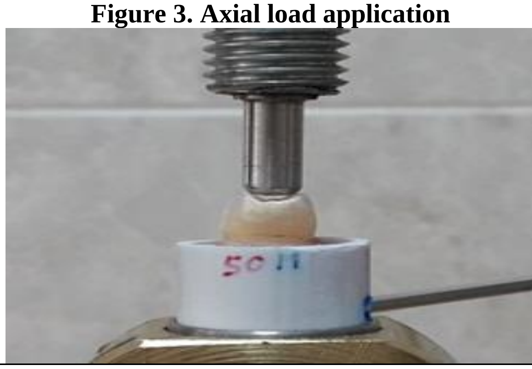


Figure 4. Bar chart of fracture resistance values

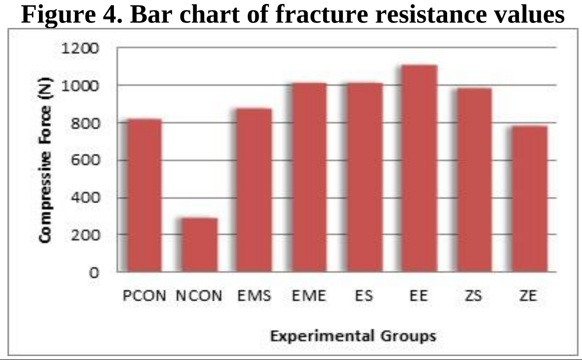


Figure 5. Fracture pattern II. A, Top view. B, proximalview.

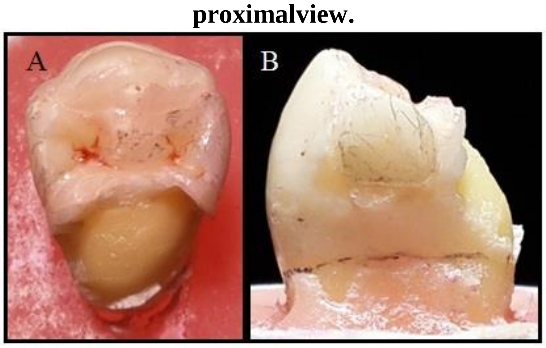


Figure 6. Fracture pattern III. A, Top view. B, proximal view

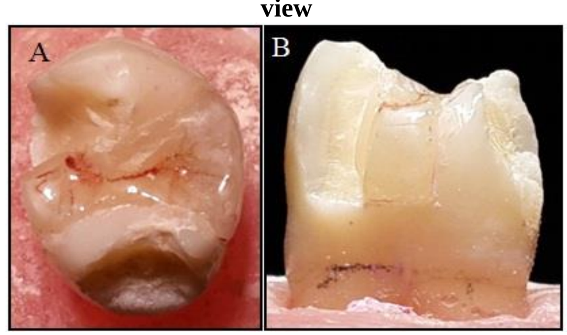
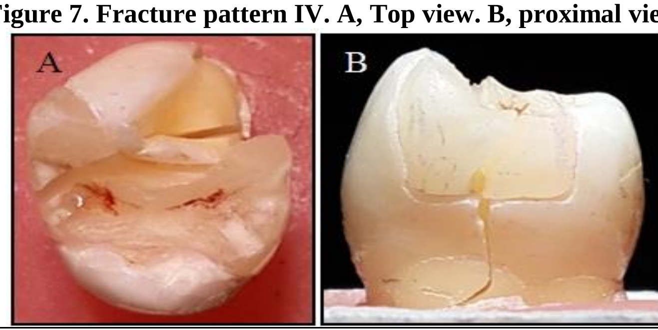


Figure 7. Fracture pattern IV. A, Top view. B, proximal view.



DISCUSSION

Resistance to fracture is a critically important issue with teeth where mechanical fracture tests are performed to numerically quantify the influence of restorative material types [9, 20-24], luting procedures [25, 26] and preparation characteristics [27, 28] for resistance to fracture when submitted to a concentrated and increasing load. These tests usually produce failure loads that exceed the load limit exerted by normal stomatognathic system movements [29]. Performing in vitro experiments that aim to analyze indirect restoration failures, characterized by the fracture of either the restorative material or dental structure, is an important method for improving restorative procedures [9, 21- 23, 25, 30]. Even though in vitro studies are not an actual reproduction of a typical chewing stroke, in that they apply a continuously increasing force until the tooth fractures, they represent an important source of information on the structural integrity of the tooth. They also identify the weakest component, whether it is inherent properties of the restoration or the fatigue of the brittle tooth tissues at the adhesive interface [31].

There are a number of factors that may interfere with fracture resistance test, such as the tooth embedment method, type of load application device, and crosshead speed [32]. Thus, the experimental methods used for in vitro analyses do not faithfully represent real clinical conditions, in which failures occur primarily due to fatigue [16]. In this study, tooth embedment method was performed using acrylic resin without simulation of periodontal ligament. Soares et al. (2005) [33] showed that simulation of periodontal ligament has no effect on fracture values. Instead, it can affect the fracture pattern of experimental teeth. The experimented teeth were vertically embedded in autopolimerizing acrylic resin 1 mm below cement- enamel junction to simulate alveolar bone level [34]. Burke et al. (1993) [32] stated that if steel sphere is going to be used for load application difficulties will be encountered in maintaining the sphere on the occlusal surface of teeth and preventing its slippage or movement during load application. For these reasons, a stainless steel rod was used in this study. Maxillary first premolars were used in this study for many reasons: they need esthetic restorations; under occlusal loading, the cusps receive high tensions; their anatomy facilitates flexion and fracture [35]. In addition, these teeth are commonly employed, facilitating the comparison among studies [19]. Teeth with comparable sizes and shapes were selected by crown dimensions after measuring the buccolingual and mesiodistal widths to avoid the error in the experimental groups [36].

Teeth preparations were made with a standardized cavity preparation using high speed handpiece attached to a modified dental surveyor in order to avoid bias and methodological errors [4]. Intact teeth were used as positive control group to observe the effect of the esthetic inlays and adhesive cementations on the fracture strength of the restored tooth in comparison to the intact teeth [2]. Second group was prepared and not restored were used to determine the role of the ceramic and composite inlays in the reinforcement of the tooth after cavity preparation in comparison to the unrestored teeth [15].

Positive control subgroup versus negative control subgroup

The results of the present study showed that the fracture resistance of PCON subgroup was significantly higher than NCON subgroup. These data are consistent with those of Mondelli et al. (1980) [27]; Ausiello et al. (1997) [37]; Dalpino et al. 2002 [38] whose studies pointed out the weakening effect of cavity preparation procedures. The different parameters in a preparation such as cavity depth and width, number of involved surfaces play individual or group roles in the weakening effect of prepared tooth [2]. Since there was a difference between these subgroups, the hypothesis was rejected.

Positive control subgroup versus treatment subgroups

All the treatment subgroups except ZE recorded higher values than PCON recovering the lost fracture strength of teeth due to cavity preparation. This comes in agreement with Brunton et al. (1999) [39]; Bremer and Geurtsen, (2001) [23]; Cotert et al. (2001) [24]; Dalpino et al. (2002) [38]; Hannig et al. (2005) [40]; Camacho et al. (2007) [41]; Ragauska et al. (2008) [42]; and Morimoto et al. (2009) [43]. On the contrary, the study disagrees with Santos and Bezerra, (2005) [15]; Soares et al. (2008) [4] who have found that endodontically treated maxillary premolars restored with leucite reinforced glass ceramic (IPS Empress) inlays recorded value significantly lower than intact teeth. This study also disagrees with Huda and Inas, (2012) [44] who showed that intact first premolar teeth recorded values significantly higher than teeth restored with lithium disilicate (IPS e max CAD) ceramic inlays. This could be attributed to differences in experimental design where different teeth were used, cavity preparations with different parameters were performed and the inlays were surface treated with different parameters.

In ceramic materials, the mechanism of crack propagation, leading to fatigue, is sufficiently distinct [45]. The resistance to crack propagation results from two mechanisms: intrinsic, which occurs in the crack and is related to the growth and propagation of a crack; and extrinsic, which is related to the retardation of the crack propagation [46]. The behaviour under fatigue of these materials is a function of the competition between intrinsic parameters related to the mechanisms of structural degradation and extrinsic factors related to the discontinuation of the crack propagation. Thus, this would be one of the factors that could justify the success of treatment subgroups, which presents a greater number of crystals of a homogeneous format that limits crack propagation through the process of energy absorption [47]. The resistance of the material is related the type of load, which would explain the biggest capacity of this material to resist tension. Most likely, the presence of crystals of leucite and lithium disilicate was responsible for the results found in the study, presenting higher values to intact teeth. IPS Empress Esthetic and IPS e max press ceramics are reinforced by introducing a high crystalline content into their microstructure to enhance crack resistance. A higher thermal expansion crystalline phase embedded in lower-expansion matrix material results in compressive stress at the crystal–matrix interface. Such stresses have been shown to deflect crack fronts and increase fracture resistance [48]. It is worthy to mention that the long term success of ceramic restorations not only depends on the structure of restorative material, but also depends mainly on the strength and durability of the bond of the luting composite to the tooth and the ceramic substrates [26]. A strong and durable bond between hard dental tissues and restorative material provides improved marginal adaptation and enhances the fracture resistance of the tooth restoration complex [49]. According to the results obtained, the hypothesis was accepted.

Negative control subgroup versus treatment subgroups

The fracture resistance of NCON subgroup was significantly lower than all the treatment subgroups. Similar results were obtained with Bremer and Geurtsen, (2001) [23]; Cotert et al. (2001) [24]; Santos and Bezerra, (2005) [15]; Soares et al. (2008) [4]; Huda and Inas, (2012) [44]. However, Stappert et al. (2006) [50] has obtained different results demonstrated by the insignificant difference between the prepared unrestored teeth and treatment subgroups which could be attributed to differences in experimental design since the authors used maxillary molar teeth, performed more conservative cavity preparation design, surface treat the inlays with different parameters and used different luting agent for adhesive cementation. Due to the previous discussion, the hypothesis was rejected.

Sandblasted IPS Empress Esthetic, IPS e max Press and ICE Zircon subgroups

In this study, sandblasting was performed using small aluminum oxide particle size and at relatively low pressure in order not to damage the ceramic surfaces and to avoid the creation of micro cracks in ZS subgroup. However, ES and ZS subgroups have recorded slightly higher values but not significant than EMS subgroup. Lithium disilicate glass ceramic material has a high crystalline content and exhibits significantly higher bond strengths than leucite reinforced ceramic material independent from surface conditioning [51]. The differences in the microstructure of the ceramic materials used in the study may have resulted in differences in the adhesion of these materials to tooth surface as stated by Torres et al. (2009) [52]. In addition, IPS e max Press and ICE Zirkon have higher mechanical properties than IPS Empress Esthetic such as flexural strength and fracture toughness, this may further explain the results of the study. Due to the previously mentioned reasons, the hypothesis was rejected.

Etched IPS Empress Esthetic, IPS e max Press and ICE Zircon subgroups

The fracture values of EME and EE where higher than that of ZE which can be explained due to the differences in effect of hydrofluoric acid etching on the microstructure of these restorative materials. IPS Empress Esthetic and IPS e max Press contain silica phase in their composition which is selectively etched by using hydrofluoric acid and the final result is a surface rich in irregularities for micromechanical retention [8]. This could explain the results of the study. The results of this study disagree with those of Saridag et al. (2013) [53] who found that teeth restored with zirconia inlays recorded higher values but not significant than those restored with lithium disilicate inlays. The discrepancy between the results may be attributed to the differences in the experimental conditions where the authors used molar teeth in their study, performed conservative cavity preparation and used different luting agent. Due to the previously mentioned reasons, the hypothesis was accepted.

Sandblasted versus etched IPS Empress Esthetic subgroups and sandblasted versus etched IPS e max Press subgroups

The treatment subgroups conditioned with hydrofluoric acid recorded higher values than those conditioned with sandblasting although the difference between them was not significant. The reason could be related to the composition of the ceramic material used in the study which contained a high percent of glass making them more susceptible to hydrofluoric acid etching than sandblasting. The effect of hydrofluoric acid etching may have resulted in deeper irregularities which produced better adhesion with the luting agent [54] thereby increasing fracture resistance of these subgroups. According to the results obtained, the hypothesis was rejected.

Sandblasted versus etched ICE Zirkon subgroups

ZS subgroup has recorded higher fracture value than ZE subgroup which may be related to the nature of zirconium inlay devoting glass in its microstructure making zirconia resistant to acid etching. Wolfart et al. (2007) [55] has shown that sandblasting results in a stronger bond than acid treatment on zirconia based ceramics. Also, Torres et al. (2009) [52] showed that sandblasting zirconia produced deeper micromechanical pores than acid etching which resulted in better bond strength and adhesion of luting agent to zirconium inlay. This may explain why ZS recorded slightly higher values than ZE. However insignificant difference was found between ZS and ZE which may be attributed to the increased wettability of zirconia when hydrofluoric acid etching was performed [56]. This in turn may result in enhanced adhesion of the ceramic primer (Monobond Plus) to ICE Zircon inlay’s surface. Monobond Plus is sometimes called a universal primer or ceramic primer which contains a silane and a phosphate monomer [57]. Saridag et al. 2013 [58] stated that primers containing phosphate monomer can establish a reliable bond to zirconia materials. It can be conferred that in treatment subgroups restored with ICE Zircon, the ceramic primer and as a result the luting agent, had done the major role in the adhesion to tooth while surface treatments performed a secondary role. Due to the previously mentioned reasons, the hypothesis was rejected.

It may be interesting to note that the prepared and restored specimens had fracture strength higher than 725 N which represents the maximum biting force for posterior single teeth reported in the literature [29, 59].

Fracture pattern

As mentioned previously, the fracture pattern may be affected by the tooth embedment method, type of load application and the mechanical properties of the restorative material. In this study more catastrophic fractures occurred in the groups restored with IPS Empress Esthetic and IPS e max Press than those restored with zirconia.

Soares et al. (2005) [33] stated that when the teeth were embedded directly in resin cylinders, stresses seemed to get concentrated around the tooth region localized at the cylinder top. Rigid attachment of the root is not found in nature and may alter the fracture pattern; this could be clearly seen in the fracture mode analysis. A great number of fractures characterized by failure at the union between the resin cylinder and tooth coronal structure occurred since the periodontal ligament was not simulated.

This behavior was also demonstrated in the present study, in which premolars restored with IPS Empress Esthetic and IPS e max Press presented a larger number of catastrophic fractures. The lower elastic modulus of these materials promoted less restoration stiffness, greater absorption of load and less stress distribution to adjacent tooth structures [60]. Conversely; zirconia restorations have a higher elastic modulus. The differences in modulus of elasticity of zirconia from that of tooth structure my resulted in less severe fracture patterns in zirconia subgroups [58].

The mechanical properties of materials used to restore teeth may influence the behaviour and fracture progression within the tooth/restoration complex under test conditions [4].

Limitations

This study has some limitations. The continuous vertical load applied to the teeth in this study is not typical of clinical loading [61]. In terms of in vivo loading; the masticatory cycle consists of a combination of vertical and lateral forces, subjecting the ceramic to a variety of off-axis loading forces [62].

Another limitation of this study was the lack of specimen aging and fatiguing. Although mechanical and destructive experimental tests are frequently used, they have limitations in providing ultra-structural and biomechanical information on the behaviour of specimens at the moment preceding fracture. Therefore, it is suggested that these findings be related to non-destructive laboratory analyses, such as finite element analysis and strain gauge tests, to analyze cusp deformation and the biomechanical aspects of stress distribution [4]. Short thermal cycling and storage in water did not allow water saturation of the luting cements. It is likely that hydrolytic effects might influence the bond strength negatively after longer water storage and thermal cycling.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions are drawn:

1. The fracture strength of premolar teeth prepared with MOD cavity preparation can be restored with adhesively cemented ceramic inlays.
2. For leucite and lithium disilicate reinforced ceramics, hydrofluoric acid etching is more effective than sandblasting for adhesive cementation of these inlays.
3. For zirconia based ceramics, sandblasting and hydrofluoric acid etching have nearly the same effect regarding their role in the adhesive cementation of these types of inlays.
4. Although zirconia inlays produced lower values of fracture resistance than other two types, zirconia inlays had a more favorable fracture pattern making subsequent treatment more feasible than that required for catastrophic fracture patterns associated with leucite and lithium disilicate reinforced ceramics.
5. From clinical point of view, the more destructive crown preparation on premolars may be substituted by adhesively cemented inlays as they restored fracture strength of these teeth.

ACKNOWLEDGEMENT: None

CONFLICT OF INTEREST:

The authors declare that they have no conflict of interest.

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