AL-AZHAR
Assiut Dental Journal

The Official Publication of The Faculty of Dental Medicine, Al-Azhar Assiut University, Egypt

AADJ, Vol. 3, No. 1, April (2020) — PP. 7:18

ISSN 2682-2822

Effect of Cavity Design and Cusp Inclination on Fracture Resistance of Indirect Overlay Restorations In Maxillary First Pemolars: An In Vitro Study

Roqaia M. Alassar*[1], Amira M. Samy,[2] and Rania A. Amin[1]

Codex : 02/2020/04

Aadj@azhar.edu.eg

KEYWORDS

Cavity Design, Cusp Inclination, Fracture Resistance, Overlay, Restorations, Premolars.

1. Department of Crowns and Bridges, Faculty of Dental Medicine)Girls), Cairo, Al-Azhar University, Egypt
2. Department of Conservative Dentistry, Faculty of Oral and Dental Medicine, Modern University for Technology & Information, Cairo, Egypt

* Corresponding Author e-mail: roqaiaalassar.26@azhar.edu.eg

ABSTRACT

Aim: to evaluate the effect of cavity design and cusp inclination on fracture resistance of indirect overlay restorations in maxillary 1st premolars. **Subjects and Methods:** Hundred extracted human maxillary 1st premolars were selected and divided into ten groups; **Gr1:** control group (CG), **Gr2:** shoulder design with normal cusp inclination, **Gr3** & **Gr4:** shoulder design with 33° & 22° cusp inclinations (respectively, **Gr5:** butt joint design with normal cusp inclination, **Gr6** & **Gr7:** butt joint design with 33° & 22° cusp inclinations respectively, **Gr8:** Anatomical design with normal cusp inclination, **Gr9** & **Gr10:** Anatomical design with 33° & 22° cusp inclinations respectively. All restorations were fabricated indirectly and cemented by RelyX Ultimate adhesive resin cement. Samples were stored for 24 hrs in distilled water at 37°C and then thermocycled for 5000 cycles. Universal testing machine was used to measure fracture loads. Samples were examined for determination of failure mode using a magnifying lens. **Results:** ANOVA test revealed that the difference between groups was statistically significant (p=0.00). Tukey's post hoc test revealed no significant difference between Sh/33°CI, Sh/22°CI, B/33°CI, B/22°CI, A/NCI and A/33°CI. **Conclusions:** The teeth restored with cusp shoulder designs exhibited the highest percentages of restorable fractures (70-90%). Anatomical design presents the highest fracture resistance. However, 70-100% catastrophic failure is suspected. Fracture resistance increases significantly by decreasing cusp inclination of overlay restorations.

INTRODUCTION

In retrospective studies and reviewed articles, the incidence rate of maxillary premolar fractures were reported as quite common, particularly in teeth with large intracoronal restorations.(1-4) It was reported that buccal cusps fractured more frequently than palatal cusps in maxillary premolars and most of the teeth with cusp fractures were associated with restored teeth and most of them were vital.(2,3) The reduced amount of dentin supporting the cusps of a restored tooth is thought to be the direct cause of cusp fracture,(5) while the indirect cause is suggested to be related to degree of cusp inclination.(6) In group function occlusion, as a result of high and steep cusps, maxillary premolars are exposed to repeated oblique occlusal forces that are translated into high lateral forces.[6] This situation is the worst for maxillary premolars as the risk of tooth fracture and restoration debonding is much higher.[7-11]

Therefore, for restoring vital maxillary premolars with limited remaining coronal dentin, crown restoration is not considered as a conservative line of treatment. Instead, overlay restoration with modified occlusal scheme is suggested to protect the supporting units and the restoration from overload.[12] It is highly recommended minimizing the lateral forces to reduce the risk of fracture.[13]

Overlay (or partial crown) is an indirect esthetic restoration for vital posterior teeth characterized by MOD inlay portion extended to cover the whole occlusal surface to protect all cusps.[14] The construction method depends on the selected restorative material. Nano-ceramic composite can be used indirectly for overlay construction according to manufacturer recommendation.

Indirect esthetic restoration is a clinical decision daily practiced by many dentists. There are specific guidelines for this decision. When a restoration is too difficult to make directly as in cases of cusp fracture and large defective size, or when optimal form and esthetics are required, an indirect restoration can be more successful. In addition, for predictable full mouth rehabilitations, a preoperative diagnostic wax-up is of a great importance for reconstructions by indirect techniques.[15]

In general, indirect techniques have many advantages, especially when ceramic materials of high fracture strength are used. With improvements in dental adhesive systems, the indirect restorations are expected to have better longevity than direct restorations. Using composite materials indirectly leads to controlled polymerization shrinkage and less microleakage, as well.[15]

To save clinical time, ensure excellent marginal fit, ideal proximal contacts, optimal occlusal relationship, reduced polymerization, high fracture resistance, high wear resistance, optimal aesthetic and better color stability, some clinicians prefer construction of composite restoration indirectly rather than inside patient's mouth.[16] After cavity preparation, the indirect technique includes bite registration, impression taking, pouring into cast and mounting on an articulator, restoration building up, light curing, finishing and polishing. Finally, adhesive cementation and rechecking occlusion are a must.

An in-vitro study compared the fracture strength of teeth restored with bonded ceramic overlays to sound teeth and reported that the fracture strength of teeth restored with ceramic overlays was similar to that of intact teeth.[17] In 2014, the effect of different cusp coverage patterns on fracture resistance of maxillary premolar teeth in MOD composite restorations was studied. It was concluded that coverage of both buccal and lingual cusps in large MOD composite restorations of maxillary premolars significantly increases the fracture resistance of teeth compared to the coverage of one cusp or no cusp coverage.[18] In addition, the fracture resistance and failure pattern of inlay, onlay and overlay cavity designs restored with monolithic zirconia were evaluated. Overlays had shown a significant increase in the fracture resistance than the sound teeth.[19] Moreover, in 2018, the relation between cracked teeth with different cusp inclination and maximum resistance strength was investigated and found that when cusp inclination decreases to a certain angle, resistance strength is increased and the possibility of cracking will decrease.[20]

Therefore, the aim of this in vitro study was to evaluate the effect of cavity designs and cusp inclinations on fracture resistance of maxillary 1st premolars restored with overlay restorations. The null hypothesis tested was that cavity design and cusp inclination have no influence on fracture resistance of maxillary 1st premolars restored with overlay restorations.

MATERIALS AND METHODS

To conduct the present study, hundred human maxillary 1st premolars freshly extracted for orthodontic reasons, approximately similar in size and free of any attrition signs were selected in accordance with guidelines from research ethics committee approval of Faculty of Dental Medicine for Girls, Al Azhar University. The teeth were rinsed thoroughly under running water, cleaned and stored in 0.1% thymol sol. Roots were imbedded in acrylic resin blocks (Acrostone, Egypt) with a stimulated periodontal ligament created by using light body rubber base impression material (Zetalabor; Zhermack SPA, Italy) to allow adequate stabilization of the teeth during testing procedures.

1. Samples grouping;

The samples were randomly divided into ten groups (n=10) according to cavity design and degree of buccal cusp inclination. Grouping of samples was illustrated in figure 1. Group 1 was positive control group (intact teeth).

2. Teeth preparation;

Ninety teeth were divided into 3 groups to receive standardized MOD inlay preparations, in accordance with general principles for esthetic inlay restorations.[21] For overlay preparations, buccal and palatal cusps were reduced with three different designs; cusp shoulder, butt joint, and anatomical designs. (Fig 1)

Cavity preparation guidelines:

Centroid milling machine (CNC, USA) with two diamond stones selected from the Inlay/Onlay preparation Kit (Zhengzhou Smile Dent Equip, China) was used to perform standardized preparations. The occlusal cavity occupied 3mm bucco-lingually and 5mm mesio-distally. The depth was adjusted at 2mm measured from central groove. Proximal cavities were extended with flared buccal and lingual walls (4mm bucco-lingually). The proximal box was 4 mm long and 1.5mm deep. Occlusal divergence angle was set at 10°-12°. Cavosurface margins were finished in butt joints with no bevels. Internal line and point angles were rounded. Buccal and palatal cusps were 2mm occlusally reduced with 1mm cusp shoulder for Gr 2,3,4 and with butt joint for Gr 5,6,7, while in Gr 8,9 and 10, cusps were 2mm anatomically reduced following the contour of buccal and palatal cusp inclinations. Prepared dentin was sealed with an adhesive system (Single bond, 3M, USA) to prevent contamination. (Figs 2)

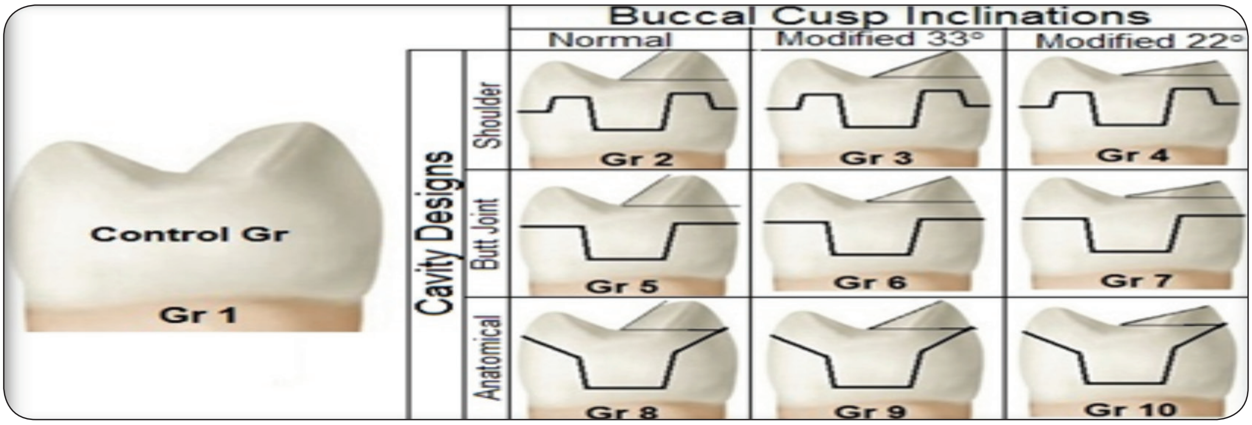

Fig. (1) Samples Grouping.

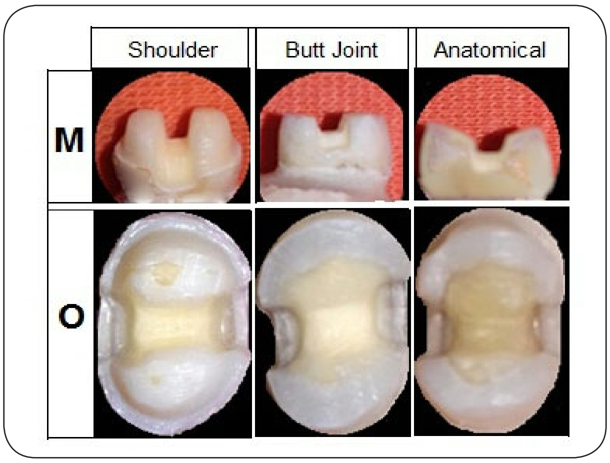

Fig. (2) Different cavity designs.

3. Overlays construction;

Overlays were constructed indirectly from Ceram.X SpherTec (Dentsply) using indices of three different buccal cusp inclinations. To standardize the final anatomy of the restorations, the following procedure was used;

1. Thirty silicon occlusal indices (Zetalabor; Zhermack SPA, Badia Polesine, RO, Italy) of a natural maxillary 1st premolar were taken for fabrication of overlays with normal buccal cusp inclination (Gr 2,5,8).

2. Then, the inclination of the buccal cusp was modified to be 33° using tapered stone (Zhengzhou Smile Dent Equip, China) and thirty silicon indices were taken for fabrication of overlays with modified 33° buccal cusp inclination (Gr 3,6,9).

3. The degree of cusp inclination was measured using VISTA scan Resetter (DURR DENTAL, Safwan, Germany) with software program (DBS WIN_5.7.1_Build_13164) and confirmed by a protractor overlapping the digitized image of the tooth,[22] fig 3.

4. Finally, the inclination of the buccal cusp was modified to be 22° and thirty silicon indices were taken for fabrication of overlays with modified 22° buccal cusp inclination (Gr 4,7,10).

5. The indices were filled with ceram.x Sphere TEC™ (Dentsply), placed over the lubricated preparations and light cured (Led, Light Curing Unit, Germany) for forty seconds.

6. The blocks were separated from indices, trimmed, finished and polished with rubber cups and points (Identoflex; Kerr Corp).

7. The overlays were removed from the prepared teeth and ready for cementation. (Figs 4)

8. A bucco-palatally sectioned index and a caliper were used to standardize the thickness of the occlusal surfaces

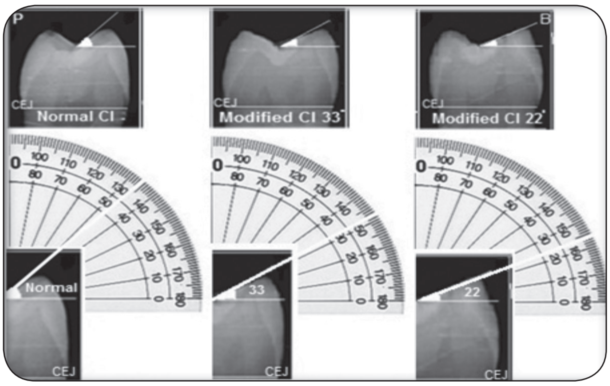

Fig. (3) Normal and modified buccal cusp inclinations.

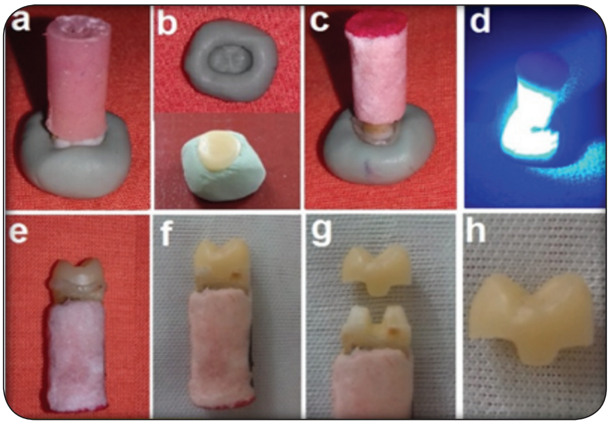

Fig. (4) Overlays Construction.

4. Overlays cementation;

Samples were cemented using RelyX Ultimate resin cement after surface conditioning of the tooth structure and intaglio surfaces of the constructed overlays, in accordance with manufacturer instructions. Figs (5)

Surface treatment of tooth structure by etching for 15 seconds with Blue Etch (36% phosphoric acid, StalowaWola, Polska) then rinsing, drying, and bonding (Single Bond, 3M, ESPE, Germany). Conditioning of the ceram.x SphereTec (Dentsply) intaglio surfaces by sandblasting with aluminium oxide according to manufacturer instructions then cleaned with distilled water in an ultrasonic unit (Bredent, Senden, Germany) for 1 minute and gently air dried. A layer of Single Bond adhesive (3M, ESPE, Germany) was applied using microbrush and allowed to react for 20 seconds.

Fig. (5) Overlays Cementation (Proximal View)

After cementation, samples were stored for 24 hours in distilled water at 37°C, then thermocycled in automatic thermal cycling machine (Ropota, automated thermo- cycling, Turkey) for 5000 cycles in water bath at 5 and 55°C with a dwell time of 30 seconds.

5. Testing Procedures:

All samples were individually mounted on a computer controlled mechanical testing machine (Model 3345; Instron Industrial Products, Norwood,MA, USA) with a loadcell of 5 kN and data were recorded using computer software (Instron® Bluehill Lite Software). Samples were secured to the lower fixed compartment of testing machine by tightening screws. Fracture test was done by compressive mode of load applied occlusally using a metallic rod with round tip (3.8 mm diameter) attached to the upper movable compartment of testing machine traveling at cross-head speed of 1mm/min with 2mm thick tin foil sheet in-between to achieve homogenous stress distribution and minimization of the transmission of local force peaks,[23] fig (6). The load at failure manifested by an audible cracking sound and confirmed by a sharp drop at load-deflection curve recorded using computer software (Bluehill Lite Software Instron® Instruments). The load required to fracture was recorded in Newton.

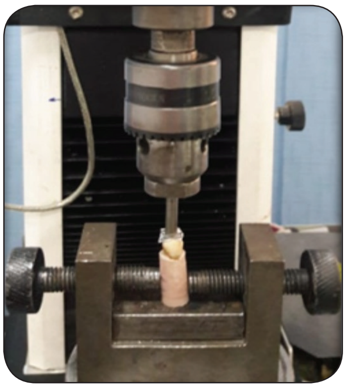

Fig. (6) Fracture resistance test in universal testing machine.

Failure mode assessment

The fractured samples were examined using a magnifying lens (10X, Optics Co, Ltd, China) to determine the fracture patterns according to location of the fracture, based on previous publications,[24,25] as follows; type I; Restorable coronal fractures above the CEJ, and type II; Catastrophic vertical coronal/root fractures below the CEJ.

Statistical analysis

Statistical analysis was then performed using a commercially available software program (SPSS 18; SPSS, Chicago, IL, USA). Values were presented as mean and standard deviation (SD. Data was explored for normality using Kolmogorov-Smirnov test of normality). Obtained values were parametric and were compared between groups using one way analysis of variance (ANOVA) test, followed by Tukey's post hoc test when ANOVA revealed a significant difference. The level of significance was set at P < 0.05.

RESULTS

I- Comparison of all groups

The highest mean fracture load value was recorded in CG, followed by A/22°CI, then Sh/22°CI and B/22°CI, then A/33°CI and Sh/33°CI, then B/33°CI and A/NCI, then sh/NCI, with the least value recorded in B/NCI. ANOVA test revealed that the difference between groups was statistically significant (p=0.00). Tukey' s post hoc test revealed no significant difference between Sh/33°CI, Sh/22°CI, B/33°CI, B/22°CI, A/NCI and A/33°CI. (Table 1, Fig 7)

Table (1): *Comparison of fracture load (N) in different groups and control (ANOVA test)*

Group/Subgroup	Mean	SD	P
CG	1114[a]	120.6	0.00*
sh/N CI	758.63[d]	80.2	
sh/33° CI	880.467[c]	90.4	
sh/22° CI	994.3[c]	91.3	
B/N CI	711.9[e]	69.9	
B/33° CI	860[c]	89.4	
B/22° CI	976.2[c]	100.6	
A/N CI	810.2[c]	83.2	
A/33° CI	925.3[c]	94.3	
A/22° CI	1032.3[b]	105.2	

*Significance level p<0.05, *significant*

Tukey's post hoc test: means sharing the same superscript letter are not significantly different

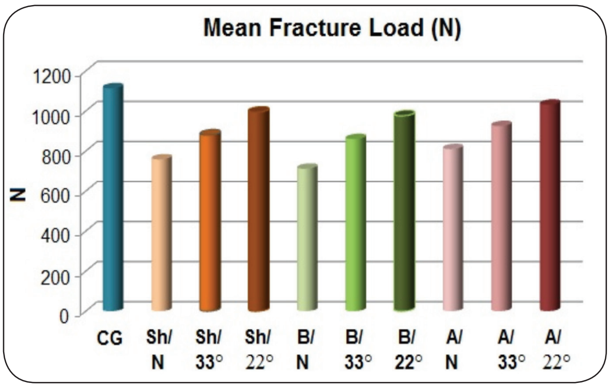

Fig. (7) Bar chart illustrating mean fracture load (N) in all groups

II- Comparison according to cavity design;

The highest mean fracture value was recorded in anatomical design, then shoulder design, with the least value in butt joint design. ANOVA test revealed that the differences were not statistically significant (p=0.28 & p=0.44), regarding 33°& 22° CI, respectively. However, the difference was statistically significant in N CI groups (p=0.03). Tukey's post hoc test revealed no significant difference between shoulder and butt joint designs. (Table 2, Fig 8)

Table (2) *Comparison of fracture load (N) in different groups (ANOVA test)*

	Shoulder design (Sh)		Butt joint design (B)		Anatomical design (A)		P
	Mean	SD	Mean	SD	Mean	SD	
N CI	758.633[B]	80.2	711.9[B]	69.9	810.2[A]	83.2	0.03*
33° CI	880.467	90.4	860	89.4	925.3	94.3	0.28[ns]
22° CI	994.3	91.3	976.2	100.6	1032.3	105.2	0.44[ns]

*Significance level p<0.05, *significant, ns=non-significant*

Tukey's post hoc test: means sharing the same superscript letter are not significantly different

III- Comparison according to cusp inclination;

The highest mean value was recorded in 22° CI, then 33° CI, with the least value in N CI. ANOVA test revealed that the difference was statistically significant (p=0.00) in all designs. Tukey's post hoc test revealed a significant difference between each two cusp inclinations in shoulder and anatomical design groups. However, regarding butt joint design, there was no significant difference between 22°CI & 33°CI. (Table 3, Fig 8)

Table (3) *Comparison of fracture load (N) in cusp inclination within the same group (ANOVA test)*

	Shoulder design (Sh)		Butt joint design (B)		Anatomical design (A)	
	Mean	SD	Mean	SD	Mean	SD
N CI	758.633[c]	80.2	711.9[b]	69.9	810.2[c]	83.2
33° CI	880.467[b]	90.4	860[a]	89.4	925.3[b]	94.3
22° CI	994.3[a]	91.3	976.2[a]	100.6	1032.3[a]	105.2
P	0.00*		0.00*		0.0001*	

*Significance level p<0.05, *significant*

Tukey's post hoc test: means sharing the same superscript letter are not significantly different

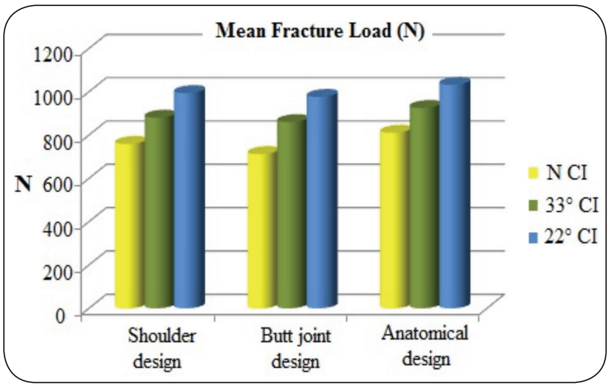

Fig. (8) Bar chart illustrating mean fracture load (N) in different cusp inclinations and cavity designs

IV- Failure mode assessment

The intact teeth predominantly fractured with restorable patterns. The most common failure pattern in shoulder design samples was Type I (Restorable). The highest restorable fracture rate (90%) was observed in Sh/22°CI overlays. Conversely, the most common failure pattern in anatomic and butt joint design samples was Type II (Catastrophic). (Table 4, Fig 9)

Table (4) *Failure patterns and percentages of restorable failure in each group*

Cavity design	Cusp inclination	Failure Pattern		Restorable fracture (%)
		Type I	Type II	
Control Group		8	2	80%
Shoulder design	N CI	7	3	70%
	33° CI	7	3	70%
	22° CI	9	1	90%
Butt Joint design	N CI	4	6	30%
	33° CI	3	7	30%
	22° CI	3	7	40%
Anatomical design	N CI	3	7	30%
	33° CI	0	10	0%
	22° CI	1	9	10%

Fig. (9) The most common failure patterns; **a)** shoulder design showed 70-90% restorable fracture, **b&c)** butt joint and anatomic design showed 60-70% and 70-100% catastrophic fracture, respectively.

DISCUSSION

The anatomy of maxillary premolars is susceptible to cusp deflection and fracture under excessive occlusal forces.[26] It is necessary to protect cusps when the width of the cavity isthmus is greater than 2/3 of the inter-cuspal distance or 1/2 of the bucco-lingual distance.[17] Therefore, this study was conducted to evaluate the fracture resistance of maxillary 1st premolar overlays with different preparations at different cuspal inclinations.

According to manufacturer, ceram.x Sphere TEC™ a nano-hybrid universal composite is the ideal for durable stress bearing posterior restorations. Being less expensive than ceramics, selection of ceram.x Sphere TEC was simply based on the fact that the use of bonded cuspal coverage composite restorations support the remaining tooth structure, prevent additional tissue loss and exhibit more homogeneous distributions of occlusal forces.[17,27-30] Consequently, ceram.x supports the conservative approach in terms of function and esthetics. In this study, ceram.x Sphere TEC overlays were cemented with RelyX Ultimate resin cement, as etching and adhesive techniques are known to reinforce the dental structure and enhance resistance to fracture.[17,31]

The results of the present study revealed that both cavity design and cusp inclination affect fracture resistance, thus the null hypothesis tested was rejected.

In this study, control group showed fracture resistance of 1114 N that almost coincided with previous studies.[32-35] The fracture resistance values recorded in this study ranged from 758 to 1032 N. In clinical literature, it was reported the normal force at the premolar region varies from 222 to 445 N,[36] but from 520 to 800 N[36] during clenching. Therefore, these results are within the clinically accepted limit.

Regarding cusp inclination, by reducing the degree of inclination to 22°, fracture resistance increased. This was directly attributed to better stress distribution.[22,37] When vertical loads are applied on occlusal surfaces with a steeper cusp inclination, increased lateral forces are produced result in decreasing fracture load. Therefore, decreasing cusp inclination is considered one of strategies of reducing lateral forces in implant-supported crowns.[22] These findings are consistent with Antenucci et al[37] study, in which the stresses on the tooth/restoration interface decreased with decreasing cusp inclination. Similar results found by Rocha et al[22] who confirmed that the crowns with reduced cusp inclination exhibited significantly higher fracture load than those with standard cusp inclination.

On natural maxillary premolars, the relation between different cusp inclination and maximum resistance was studied and concluded that the resistance increases as cusp inclination decreases.[20] According to Liu et al,[38] modifying the occlusal design has many advantages to improve the mechanical stability and long-term success of restorations of maxillary premolars with large amount- dentin loss. First, it is important to decrease oblique forces by reducing the lateral occlusal contact area and by preventing contact on the top of buccal cusp, hence protecting the remaining dentin from fracture. Second, in case of maxillary premolars with palatal dentin loss (i.e. when teeth have defect where the load is applied), two options suggested to avoid the risk of overloading; reducing the buccal cusp inclination or keeping occlusal contact at the bottom of a high cusp where oblique load to be applied.[38]

Regarding cavity design, the anatomical[24] or sometimes called concave[25] design showed the highest fracture resistance followed by cusp shoulder design, while the least resistance recorded by butt joint (horizontal or flat)[24,25] design. This is most likely due to the axial direction of the cusp reduction design, which would lead to a favorable distribution of occlusal forces that perpendicularly transfer to the occlusal surface when a compressive load is applied.[24] Consequently, less forces analysis occurs. Furthermore, the anatomical design maintains the most occlusal thickness in the center of the restorations.

Moreover, although the anatomic design is more wedge-shaped than the flat and the shoulder designs, it recorded the highest resistance. It might be attributable to the improved resistance to fracture related to the selected restorative material and cusp inclination, as well. The mechanical properties of the materials selected to restore a tooth can influence the behavior of stress distribution at the tooth/restoration interface.[36] It was reported that composites have a 57% greater ability to absorb impacts than ceramics.[39] With overlay restorations, favorable cusp inclinations guarantees better resistance to fracture.[40-43]

This is agreed to Kalay et al [24] who compared the anatomic overlay design at three different occlusal thicknesses (1.5, 2.5 and 3.5 mm) to the butt-joint design. The anatomic design recorded higher fracture resistances than butt-joint design at all occlusal thicknesses. On contrary, these findings are inconsistent to Al Khalifah [25] study, in which the different overlay preparations had no effect on fracture resistance. This difference could be explained by the different restorative materials used to construct overlays on molars, not premolars as in the current study.

Comparing to butt joint design, the higher fracture resistance recorded by shoulder design samples was attributed to the shoulder margin that seemed to have the effect of ferrule which resulted in better stress distribution.[44,45] In addition, the shoulder design overwrapped or capped the cusps, thus enhanced resistance to fracture. This agreed with Oyar and Durkan[45] who concluded that cavity designs with shoulder margins showed the highest fracture resistance, while butt joint designs had the lowest fracture resistance. On the other hand, cusp capping entails removal of enamel on the outer cusp slopes. Also, having a thin circumferential restoration margin might increase the risk of restoration chipping. That is why 70-90% restorable fracture occurred.

In addition to simplicity, the flat design preserved the outer cuspal slopes and maintained increased restoration thickness at the margins, possibly decreasing chipping and increasing the incidence of catastrophic failure.

The most common mode of failure was catastrophic (70-100%) in the anatomic design groups because this design produced more wedge-shaped restoration resulted in a higher frequency of catastrophic fracture extending below the CEJ than the butt joint. As satisfactory alternative design of 90% restorable fracture rate exists (i.e. cusp shoulder design), there is no reason to use the anatomic design.[25]

The limitation of this study is that no mechanical loading was applied as part of artificial aging process. Future work should determine the interaction between different overlay designs and material type including glass ceramic and zirconia and their impact on failure pattern.

CONCLUSIONS

Within the limitations of this study, the following could be concluded;

1) Cusp shoulder and butt joint designs have comparable fracture resistances, but extremely different effect on failure pattern. **2)** The teeth restored with cusp shoulder designs exhibited the highest percentages of restorable fractures (70-90%). **3**) Anatomical design presents the highest fracture resistance. However, 70-100% catastrophic failure is suspected. **4)** Fracture resistance increases significantly by decreasing cusp inclination of overlay restorations.

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الأزهـــر
مجلة أسيوط لطب الأسنان

النشر الرسمي لكلية طب الأسنان
جامعة الأزهر أسيوط
مصر

AADJ, Vol. 3, No. 1, April (2020) — PP. 18

تأثير التصميم التجويفى وميل النتوء على مقاومة الكسر للحشوات غير المباشرة في الضواحك الأولى للفك العلوي: دراسة في المختبر

رقية محمد العصار1*، أميرة محمد سامى2، رانيا عادل أمين1

1. 1قسم التيجان والجسور، كلية طب الاسنان (بنات) القاهرة، جامعة الازهر ، جمهورية مصر العربية.
2. 2قسم العلاج التحفظى، كلية طب الفم والاسنان ، الجامعة الحديثة للتكنولوجيا و المعلومات ، مصر.

* البريد الالكترونى للباحث الرئيسى: ROQAIAALASSAR.26@AZHAR.EDU.EG

الملخص:

الهدف: تهدف هذه الدراسة المعملية الى معرفة تأثير التصميم التجويفى وميل النتوء على مقاومة الكسر للحشوات غير المباشرة في الضواحك الاولى العلوية.

المواد والاساليب : لقد اجريت هذه الدراسة على مائة ضاحك من الضواحك الأولى للفك العلوي تم تقسيمها الى عشر مجموعات حسب التصميم التجويفى وميل النتوء ولقد تم اجراء التحليل الاحصائى للبيانات لقياس معدل مقاومه الكسر بعد تصنيع التيجان ولصقها بالسيمنت.

النتائج: ولقد اشارت النتائج الاحصائيه الى وجود فروق إحصائية بين المجموعات علما انه لا يوجد فروق احصائيه بين المجموعات المحضرة بزوايا 22و33

الخلاصة : وقد خلصت تلك الدراسة الى أن التصميم التجويفى الكتفى هو التصميم الآمن للضواحك الأولى العلوية مع استخدام زاوية ميل للنتوء قدرها 22 درجة لضمان مقاومة عالية للكسر بالإضافة الى انه في حالة حدوثه فان 90% منه يكون قابلا للعلاج.

الكلمات المفتاحية: التصميم التجويفى، ميل النتوء ،مقاومه الكسر، حشوه غير مباشره، التركيبات ، الضواحك