An evaluation of the influence of different finishing lines on the fracture strength of full contour zirconia CAD/CAM and heat press all-ceramic crowns.

Ahmed Ibrahim Khalaf Al-Joboury, B.D.S. [(1)]
Ma'an Rasheed Zakaria, B.D.S., M.S., Ph.D. [(2)]

ABSTRACT

Background: One of the major problems of all ceramic restorations is their probable fracture against the occlusal forces. The objective of this in vitro study was to evaluate the effect of two gingival finishing lines (90°shoulder and deep chamfer) on the fracture resistance of full contour CAD/CAM and heat press all-ceramic crowns.

Materials and Methods: Thirty two maxillary first premolars were prepared to receive full contour CAD/CAM (zolid) and heat press (Cergo Kiss) ceramic crowns using a special paralleling device (Parallel-A-Prep). The teeth were divided into four groups according to the type of finishing line prepared. Each crown was cemented to its corresponding tooth using self-etch, self-adhesive dual cure resin cement. Following storage for 1 week in distilled water at room temperature, teeth were subjected to thermal cycling. Fracture resistance was determined using a universal testing machine, and the samples were investigated microscopically from the point of view of the origin of the failure. Statistical analysis was carried out using the one-way ANOVA and Student's t-tests.

Results: The mean values of fracture resistance for CAD/CAM group showed 1367.250+178.967 N for 90°shoulder margins and 1109.250+252.455 N for the deep chamfer margins. ANOVA test results revealed high significance between and within the groups. The mean values of fracture resistance for heat press group were 548.562+272.471 N for 90°shoulder margins and 247.912+96.995 N for the deep chamfer margins expressing statistical significance.

Conclusions: The results of this study pointed to a relationship between the design of the cervical finishing line and the fracture strength of the full CAD/CAM crowns and the full heat press ceramic crowns. Both 90° shoulder and deep chamfer finishing lines are suitable for zolid crowns while the 90° shoulder is more suitable for the Cergo Kiss crowns than the deep chamfer preparation.

Key words: Full contour, All-ceramic crowns, CAD/CAM, Heat press, Fracture strength. (J Bagh Coll Dentistry 2015; 27(1):54-62).

INTRODUCTION

The increasing demand for esthetics in the posterior region of the mouth and environmental concerns about restorations containing metal were behind the evolution of new techniques for fabrication of posterior inlays, onlays, and crowns. [(1)]

Such restorations have several advantages, including lifelike appearance, biocompatibility,[(2)] wear resistance, and color stability.[(3)] However, their drawbacks include brittleness, especially glass or feldspathic ceramics,[(4)] susceptibility to fracture, causing excessive wear to opposing dentition, requiring more involved tooth reduction, and being technique-sensitive.[(5)] When non-metallic crowns undergo fracture, the fracture typically originates from flaws or defects in the intaglio surfaces. Subcritical crack growth follows, which is enhanced in the aqueous environment. [(6)]

Ceramic materials are particularly susceptible to the tensile stresses, and mechanical resistance is also strongly influenced by the presence of superficial flaws and internal voids. Such defects may represent the sites of crack initiation.

(1)Master student, Department of Conservative Dentistry, College of Dentistry, University of Baghdad.
(2)Professor in Fixed Prosthodontics & Occlusion, Department of Conservative Dentistry, College of Dentistry, University of Baghdad.

superficial flaws and internal voids. Such defects may represent the sites of crack initiation.

This phenomenon may be influenced by different factors such as marginal design of the restoration, residual processing stress, magnitude and direction and frequency of the applied load, elastic modulus of the restoration components, restoration–cement interfacial defects, and oral environmental effects.[(7)] The introduction of computer-aided design / computer-aided manufacturing (CAD/CAM) technology in dentistry enabled dentists to use new treatment modalities and changed the design and application limits of all-ceramic restorations as the demand for esthetics in the posterior region of the mouth has increased. Recent zirconia restorations have provided functional, biocompatible, and esthetic demands [(8)] with superior mechanical properties than conventional porcelain restorations. [(9)] The strength of an all-ceramic restoration depends not only on the fracture resistance of the material, but also on a suitable preparation design with adequate material thickness. [(10)]

All ceramic restorations using the pressed ceramic technique have shown better fracture toughness values than those of the conventional porcelain veneering technique. [(11)] It was proposed that both shoulder, chamfer and deep chamfer finishing lines are considered to be adequate for the fracture strength of all-ceramic restorations [12], but it was found that the fracture strength of zirconia crowns prepared with chamfer finish line (0.9-1.2 mm) was greater than those prepared with 1.2 mm rounded end shoulder and 1.2mm shoulder finish line. [13] On the other hand, it had been suggested that a shoulder margin caused a greater fracture resistance than deep chamfer and chamfer margins. [14]

MATERIALS AND METHODS

Thirty-two sound and crack free maxillary 1st premolars extracted for orthodontic treatment with no evidence of caries or restorations were collected from patients of ages ranging between 15 to 20 years. Both calculus deposits and residual periodontal tissues were removed by ultrasonic scaler. All teeth were examined under optical microscope at x40 (Olympus, Japan) to detect cracks before including them in the study. The teeth were kept hydrated in distilled water as this storage solution does not seem to alter dentine permeability.[15] The storage solution was changed every one week and the teeth were stored at 4°C in a refrigerator.[16]

To simulate periodontal ligament, root surfaces were dipped into molten wax in a dipping wax machine (Bego, Germany) by using a dental surveyor (Bego, Germany) to which the tooth was attached and dipped to a point 2.0 mm apical to the cementoenamel junction, resulting in a 0.2- to 0.3 mm thick wax layer.[17] Then all teeth were embedded along their long axes using a surveyor in mixed cold cure acrylic (at dough stage) (Triplex®SRCold, Ivoclar Vivadent AG, Schaan, Liechtenstein) 2.0 mm below the cementoenamel junction using a custom-made split metal mold (30 mm diameter and 30 mm height).[18] After the first signs of polymerization, teeth were removed from the acrylic blocks along their long axes using the surveyor, and the wax was removed from root surfaces by using a surgical blade. An additional silicone-based light body impression material (Aquasil Ultra LV, Dentsply, USA) was injected into the acrylic resin blocks using a mixing gun, and the teeth were reinserted into the resin cylinders. A standardized silicone layer that simulated periodontal ligament was created.[19]

To standardize teeth preparation, a vacuum pressed polyethylene plastic template (Biostar, Scheu-Dental, Germany) was fabricated for each tooth before preparation using a vacuum forming machine (Biostar, Scheu-Dental, Germany). parallelometer (Parallel.A.Prep®, Dentatus USA, NY, USA) was used to control the handpiece orientation during tooth preparation.

The holding tray of the Parallel.A.Prep® was secured to one side of a custom-made metal maxillary jaw with heavy body condensation silicon. The special horizontal metal template of the parallelometer was adjusted to ensure standardized horizontal occlusal plane free from any tilting during tooth preparation. Then, the metal rod of the parallelometer was used to standardize the long axis of the attached bur to the high-speed handpiece with the tooth. The metal rod was aligned at the middle line of a plastic protractor resembling the long axis of tooth[8] (Fig.1). Then maxillary first premolars were prepared using a high speed handpiece (Topair 796, W&H, Austria) with air-water coolant and using diamond burs for deep chamfer (Lot No. 746546, Komet, Germany) and 90° shoulder (Lot No. 709449, Komet, Germany) finishing lines (Fig.2).

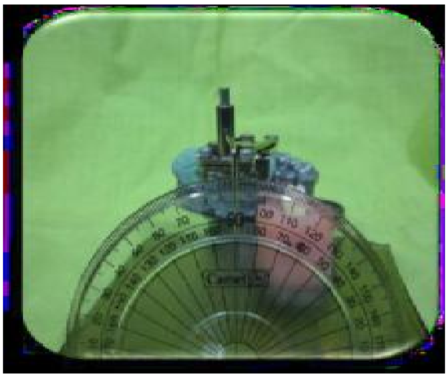

Figure 1: The metal rod of the parallelometer device is aligned at the middle line of the protractor.

Figure 2. The handpiece controlled by the parallelometer is aligned parallel to the tooth by aid of the protractor.

The axial taper angle used in the present study was 6 degrees.[20] Therefore, to achieve a 6-

degree axial taper preparation, the high speed handpiece was secured to the apparatus so that the attached tapered diamond bur was oriented at a 3-degree angle to the vertical axis of the tooth. This, in addition to the 3-degree taper of the tapered bur, resulted in a total axial taper angle of 6 degrees corresponding to a convergence angle of 12 degrees (Fig.3 a & b).

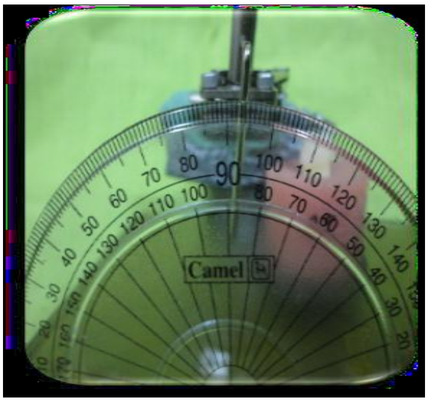

Figure 3a. The metal tip of the parallellometer is set at 3 degrees.

Figure 3b. The handpiece orientation during tooth preparation controlled by the parallellometer device to ensure the same convergence angle for all preparations.

After the completion of axial preparation, the gingival finishing line was 1 mm for deep chamfer and 1.2 mm for 90° shoulder measured using a digital caliper (Prokit's Industries Co., Ltd.,Taiwan). Then the occlusal surface of the tooth was cut flat, a pencil was used to mark the prepared tooth 4 mm above the margin and the occlusal surface was flattened with a diamond wheel (Komet, Germany) to the marked line which resulted in a preparation with 4.0 mm height from the gingival finishing line.(21) After that, a plastic template coping was placed on each prepared tooth and a hole was made against each axial wall so that a periodontal probe was inserted through each hole to ensure standardized amount of teeth preparation. Those series of reductions resulted in a standardized teeth preparation with 6-degree axial taper, a 1 mm deep chamfer and 1.2 mm shoulder margin, and total preparation height of 4.0 mm.

Prepared teeth were assigned into four groups (n = 8) according to their type of preparation and type of crown received as follows:

1. Group I: Shoulder finishing line with full contour zirconia CAD/CAM crowns.
2. Group II: Shoulder finishing line with full contour Heat press crowns.
3. Group III: Deep chamfer finishing line with zirconia full contour CAD/CAM crowns.
4. Group IV: Deep chamfer finishing line with full contour Heat press crowns.

Heat press group manufacturing (Cergo Kiss, DeguDent, Hanau-Wolfgang, Germany)

Stone dies were constructed for the prepared teeth of groups II and IV using heavy and light body polyvinylsiloxane silicone impression material (Zeta plus, Zhermack, Italy) which were poured with type IV dental stone (elite®rock, Zhermack, Italy).

In order to standardize the wax design, wax patterns were made on the stone dies utilizing the plastic templates and were checked using a wax gauge (Aesculap, Germany). Three layers of die spacer were painted on each die 0.5 mm short of the preparation to achieve a thickness of approximately 45µm of internal relief.(22) Each wax pattern was sprued (8mm gauge and 6 mm length) following the manufacturer's instructions.

The muffle ring was placed on the muffle former; the investment material (Cergo fit speed investment) was mixed by using auto mixer device (DeguDent, Hanau-Wolfgang, Germany) followed by light vibration of the muffle to avoid bubbles formation until all objects were completely covered with the investment. Then the muffle was left to rest until the investment had set. After a setting period of 15 minutes for the investment, the muffle was placed in the pre-heating oven together with the aluminum oxide pressing die. The muffle was heated from room temperature to 850°C.

After activating the pressing program, the muffle was removed from the pre-heating oven once the starting temperature of 700°C had been reached ceramic pellets were placed in the muffle channel and the pressing die was positioned. Immediately, the muffle was placed in the pressing oven and the pressing program was started. Once the pressing process was completed (after approximately 45 minutes), the muffle was removed from the pressing oven and allowed to slowly cool to room temperature.

By indicating the position of the pressed objects, a deep cut into the investment compound was made using a diamond-covered and sintered large carbide disc. The part of the muffle containing the aluminium oxide pressing die was separated from the rest of the muffle by turning in opposite directions. A jet polisher (Kavo, Germany) was used to remove the investment all the way to the pressed objects. Once the objects were visible, abrading across the area using Al_2O_3 (50 µm/70 mesh, Renfert, Germany) at reduced pressure (2 bars) was continued; then the pressing die was cleaned by rinsing with distilled water.

Each sprue was cut using a fine diamond disc while holding the ceramic crown with a wet sponge to avoid over heating of the crown. Attachment point of the sprue was removed with a fine diamond bur at low speed using a straight handpiece attached to an inlab micromotor (Marathon, Korea) with no pressure under water cooling. Each pressed ceramic crown was carefully fitted on its die. Any interfering irregularities were checked by covering the die with a thin layer of a stain paste, then the crown was placed again on its die and the investing irregularities were carefully removed with a fine diamond bur from the inside of the crown under water cooling. A steam cleaner was used to clean all heat pressed crowns following the manufacturer's instructions. A dial caliper was used to measure and check the thickness of each wall of each completed crown.

CAD/CAM group manufacturing (zolid, Ceramill Systems, Amann Girrbach GmbH, Pforzheim, Germany)

Each tooth block was placed into a special plastic tray (fabricated by the company to grasp the tooth block to be scanned) and the whole assembly was secured in the model holder of the surveyor. Then the teeth were scanned by using scanning device of Ceramill InLab, with the help of the Ceramill 3D InLab Software; three-dimensional images were displayed on the computer monitor so that all surfaces and finishing lines were clearly shown.

The external and internal margins of each crown and the path of insertion were determined. A minimum wall thickness of (1mm for deep chamfer and 1.2 mm for 90° shoulder), taking care that the cement gap should have 0.05 mm thickness, starting at 1 mm from the margin was determined. Finally the crown was seen in its final design in the monitor. After applying the information for the design to the milling center in software, a suitable blank (height and size) was selected from the blank loaded library of the CAD/CAM system. Then the zolid block was placed in the blank holder and fixed with screws by a screw key, and the milling process was started. All those steps were done following the manufacturer instructions of Ceramill InLab CAD/CAM system. After the milling procedure had ended, the blank was removed from the milling machine and the crown was separated from the blank with a fissure bur in a straight handpiece.

The crown was given its individual color by immersing it in the dye solution. The sintering was carried out in the Ceramill therm high-temperature furnace 1500°C for 9 hours to complete sintering.

Cementation

Internal surfaces of all zolid crowns were grit-etched for 5 seconds with 50 µm Al_2O_3 powder at 80 psi. and the internal surfaces of the Cergo Kiss crowns were etched with hydrofluoric acid for 20 seconds following the manufacturers' instructions. Then all crowns of the four groups were cleaned using distilled water in an ultrasonic cleaner for 60 seconds followed by drying with compressed oil-free air**.**

All crowns were cemented on their respective teeth in the following manner: Each crown was filled with self-adhesive dual-cure resin cement (Set PP, SDI Ltd., Australia) and was seated on its tooth using finger pressure. Excess cement was removed using a sponge pellet leaving a minimal amount of excess for light curing process. Each cemented crown was vertically loaded with a 5 kg static load applied on the vertical arm of the dental surveyor to avoid any internal cement gaps.[14] Light polymerization (Astralis 5, Ivoclar Vivadent AG, Schaan, Liechtenstein) was carried out for 20 sec. per surface following the manufacturer's recommendations. Then each cemented crown was kept under the load for 5 minutes.[8]

One hour after cementation, specimens were stored in distilled water at room temperature for one week [8], and then subjected to 500 thermal cycles between 5-55°C with dwell time of 30 seconds.[16]

Testing procedure

Each tooth with its cemented crown was removed from the storage container, secured in a mounting jig and subjected to testing in a universal testing machine (Tinius Olsen H50KT, UK) (Fig.4). The loading piston was a vertically movable rod with a semispherical head (5 mm in diameter stainless steel ball) applied at the center of the occlusal surface along the long axis of the cemented crowns with a crosshead speed of 0.5 mm/min until fracture occurred.[16, 23-25] A piece of 1 mm thick rubber layer was placed between the loading tip and the crown in order to provide for homogenous stress distribution.[16] After test completion, each crown was examined by a magnifying lens (×10) from the point of view of the origin of the failure (crack) in order to determine the mode of fracture which was classified according to the categories described by Burke and Watts.[26] The fractured crowns were further inspected by an optical microscope (×40, Olympus, Japan) supplied with a digital camera (14.1 mega pixels, Sony, Japan).

Figure 4. Chamber of the loading device where load is applied at 90° to the occlusal surface of the tooth.

RESULTS

The means and standard deviations of fracture strength with minimum and maximum values calculated for each group are shown in (Table 1). The results showed that the lowest mean of fracture strength was scored by group IV while the highest mean belonged to Group I .Further analysis of groups was performed using Student's t-test to examine the difference between the groups (Table 2) which showed statistical significance between groups (GI & GIII, G II & GIV). On the other hand, highly significance occurred between the remaining groups. Examination of the mode of fracture of the tested zolid CAD/CAM crowns) revealed (100%) minimal fracture related to both types of cervical finishing line preparations (Table 3 & Fig.5). The Cergo Kiss heat press ceramic crowns revealed minimum fracture modes (37.5%) with 90º shoulder preparation and (50%) with deep chamfer type(Table 4). More than half of crown was lost with the deep chamfer preparation (37.5%) in comparison to (25%) with 90ºshoulder preparation (Fig.6). The percentage of severe crown fracture (12.5%) was equal for both types of finishing line designs.

Table 1: The mean load at fracture and standard deviation for zolid and Cergo Kiss crowns.

Technique Method	Type of finishing line	No.	Mean (Newtons)	Minim.	Max.	Standard deviation (SD)
CAD/CAM	90°shoulder Group I	8	1367.250	1027	1608	±178.967
zoild	Deep chamfer Group III	8	1109.250	623	1331	±252.455
Heat press	90°shoulder Group II	8	548.562	188.3	923	±272.471
Cergo Kiss	Deep chamfer Group IV	8	247.912	103.3	411.5	±96.995

Table 2: t-Test for quality of means and comparison of significance between the groups.

Compared Groups	df	t-value	p-value	Sig.
G I vs G III	14	2.358	0.03	S
G I vs G II	14	7.103	0.00	HS
G I vs G IV	14	15.553	0.00	HS
G III vs G II	14	4.269	0.00	HS
G III vs G IV	14	9.008	0.00	HS
G II vs G IV	14	2.940	0.01	S

Table 3: Modes of fracture of zolid groups.

zolid	Minim. Fracture n (%) (Crack)	Less than half of crown lost n (%)	More than half of crown lost n (%)	Severe fracture of tooth and/or crown n (%)	Total
90° Shoulder	8(100%)	0(0%)	0(0%)	0(0%)	8(100%)
Deep Chamfer	8(100%)	0(0%)	0(0%)	0(0%)	8(100%)

Table 4: Modes of fracture of Cergo Kiss groups.

Cergo Kiss	Minim. Fracture n (%) (or Crack)	Less than half of crown lost n (%)	More than half of crown lost n (%)	Severe fracture of tooth and/or crown n (%)	Total
90° Shoulder	3(37.5%)	2(25%)	2(25%)	1(12.5%)	8(100%)
Deep Chamfer	4(50%)	0(0%)	3(37.5%)	1(12.5%)	8(100%)

Figure 5(a). Failure type of a zolid crown after fracture test. (b) Optical microscope image of fractured surface of a zolid crown (x40 magnification).

Figure 6(a). Failure type of a Cergo Kiss crown after fracture test. (b) Optical microscope image of fractured surface of a Cergo Kiss crown (x40 magnification).

DISCUSSION

The supporting die structure has been reported to affect the fracture strength of all-ceramic restorations because of the influence of the elastic modulus of the supporting die. Using supporting die structures that have lower elastic moduli are suitable for fracture strength tests in order to accurately reflect clinical conditions.[27] According to that, natural freshly extracted teeth were chosen in this study to be prepared to receive the tested crowns instead of stainless, epoxy resin and composite resin dies which don't reproduce the real force distribution as that occurring on crowns cemented on natural human teeth.[28] On the other hand, dentin exhibits a lower modulus of elasticity than stainless steel and as a consequence, the inner crown surface shows a greater shear stress every time the tooth is subjected to deformation. [8, 16, 29]

A thin layer of condensation silicon was used in this study to resemble the periodontal ligament thus acting as a cushion to resemble the clinical condition and to avoid the external reinforcement of the root structure by the rigid acrylic resin.[30-32]

The parallel-A-Prep device was used to prepare the teeth since it could maintain the cutting axis exactly at the angle selected by controlling the taper precisely by the taper of the cutting bur used. This helped that all axial walls were maintained parallel thus preventing all undercuts and as a result all prepared teeth exhibited uniform and minimal tapers of 6 degrees.[8] Since a tapered bur imparts an inclination of 2-3 degrees to any tooth surface it cuts if the shank of the bur was held parallel to the intended path of insertion of preparation, then by using a protractor the degree of taper of 6 degrees was obtained by tilting the bur to a tapered angle of 3 degrees.[21]

The dual-cure resin cement was used as it has been widely indicated for luting crowns.[33-35] The polymerization reaction of dual-cure resin cement is chemically and photo-initiated which ensures higher conversion rate of curing, leading to better mechanical properties and such cements promoted more reliable micro-shear bond strength and micro-hardness values than the flowable resin for cementation of all ceramic restorations.[36] In order to evaluate the effects of water storage and thermo cycling on the fracture resistance of crown specimens, all specimens in this study were stored in distilled water for 7 days and were subjected to 500 cycles in water between 5°C and 55°C before testing their fracture resistance.[8,16] The use of 5 mm in diameter stainless steel ball was to simulate the contact pressure of the crown by opposing cusps as the contact pressure was influenced by the ratio of the elastic modulus of the dental porcelain to the elastic modulus of the loading ball, and by the radius of the loading ball. Placing a piece of rubber layer between the load applicator and tested crown was to act as stress breaker to prevent cone cracking, and to simulate the cushion effect of food between opposing teeth.[6,8,18,25)

In this study, the superior mechanical properties of zolid full contour zirconia crowns can be explained to be due to the finer grain size and the tetragonal-monoclinic transformation toughening mechanism which leads to compressive stresses in the material and results in reduced crack propagation which contribute to the improved fracture resistance of the zirconia crowns. However, some studies reported that the combination of ageing and phase transformation has been detrimental for fatigue properties of Y-TZP.[37,38] The high fracture strength values exhibited by GI crowns can be referred to the occlusal forces borne by circumferential 90° shoulder and consequently less stress concentration occurring on the axial walls compared to other preparation designs.[14,25]

In this study, the variation in the statistical significance between the fracture resistance of the Cergo Kiss heat press ceramic and the zolid zirconia CAD/CAM systems can be attributed to the structural properties of this type of heat press leucite reinforced ceramic. It has been reported that an increase of crystalline content of a glass-ceramic is accompanied with an increase of the strength and fracture toughness due to the fine dispersion of crystals. The main difference between heat pressed leucite-based cores and the lithium-based core ceramics lies in that the leucite-based type has its crystals, which are dispersed in a glassy matrix of an amount and sizes enough to raise the magnitude of toughness to a greater level compared to the lithium-based core ceramics.[37] In the case of lithium disilicate containing pressable ceramics, the difference in mean grain length has no measurable effect on the strength and fracture toughness. Conversely, the minimal variations of the grain size shape and orientation in the glass-infiltrated alumina reinforced ceramics strongly affects the strength and fracture toughness of these ceramics. From a clinical standpoint, the alignment of elongated grains parallel to the surface is preferred over perpendicular or random alignment, as the greatest resistance to crack propagation through the core material is achieved.[6]

However, the techniques of fabrication of all-ceramic lithium disilicate restorations such as Empress2 (Ivoclar Vivadent AG, Schaan, Liechtenstein) and the In-Ceram Alumina, slip casting + dry pressing (VITA Zahnfabrik GmbH, Germany) don't seem to take into account such issue and the orientation of the crystals is most likely due to coincidental factors which led to a decrease in their fracture resistance when compared to the leucite-reinforced heat press ceramics, a reason that made manufacturers to enforce them with zirconium oxide.[6] This was supported by a study in which nearly all conventionally veneered crowns failed during chewing simulation;whereas crowns with CAD/CAM manufactured veneeres with Lithium disilicate ceramic (IPSemax CAD, Ivoclar Vivadent AG, Schaan, Liechtenstein) displayed ultimate loads to failure.[39]

Under the circumstances of this study, the following conclusions were drawn:

1. The highest fracture strength mean values were represented by the zirconia CAD/CAM full crowns cemented on teeth which received a 90º shoulder preparation.
2. Highly statistical significance was located between the zirconia CAD/CAM full crowns and the heat press full ceramic crowns regarding the 90º shoulder and the deep chamfer cervical margins.
3. The 90º shoulder and the deep chamfer preparations are considered suitable for the zirconia CAD/CAM full crowns in the premolar and molar regions.
4. The 90º shoulder preparation is considered more suitable for the heat press full ceramic crowns in the premolar region since the deep chamfer crowns exhibited lower fracture strength values than the average biting force in that region.
5. Both types of all-ceramic crowns can be considered as promising prosthodontic alternatives to metal-ceramic crowns and veneered all-ceramic crowns since dental technicians' errors can be surpassed in addition to their biocompatible and esthetic properties.

ACKNOWLEDGEMENT

The authors greatly thank Assist. Prof. Dr. Wisam Al-Rawi, College of Dentistry, University of Ann Arbor, USA for his efforts in providing the Parallel.A.Prep instrument.

REFERENCES

1. Tsitrou EA, Northeast SE, van Noort R. Evaluation of the marginal fit of three margin designs of resin composite crowns using CAD/CAM. J Dent 2007; 35:68-73.
2. Sjogren G, Sletten G, Dahl JE. Cytotoxicity of dental alloys, metals, and ceramics assessed by millipore filter, agar overlay, and MTT tests. J Prosthet Dent 2000; 84:229-36.
3. Siervo S, Pampalone A, Siervo P. Where is the gap? Machinable ceramic systems and conventional laboratory restorations at a glance. Quintesssence Int 1994; 25:773-9.
4. McLaren EA, Cao TP: Ceramics in Dentistry—Part I. Classes of Materials. Inside Dent 2009; 5:94-103.
5. Blatz M B. Long-term clinical success of all-ceramic posterior restorations. Quintessence Int 2002; 33:415-26.
6. Zahran M, El-Mowafy O, Philip AWLT, Finer Y. Fracture strength and fatigue resistance of all-ceramic molar crowns manufactured with CAD/CAM technology. J Prosthodont 2008; 17: 370-7.
7. Webber B, McDonald A, Knowles J. An in-vitro study of the compressive load at fracture of procera all ceramic crowns with varying thickness of veneer porcelain. J Prosthet Dent 2003; 89:154–60.
8. Kassem AS, Atta O, El-Mowafy O. Fatigue resistance and microleakage of CAD/CAM ceramic and composite molar crowns. J Prosthodont 2012; 21:28-32.
9. Otto T, De Nisco S. Computer aided direct ceramic restorations: a 10-year prospective study of Cerec CAD/CAM inlays and onlays. Int J Prosthodont 2002; 15:122-8.
10. Devaud V. Guidelines for success with zirconia ceramics: The changing standards. Pract Proced Aesthet Dent 2005; 17:508-10.
11. Roh H-S, Woo Y-H, Pae A. Full mouth rehabilitation with pressed ceramic technique using provisional restorations. Pressed ceramic technique. J Korean Academy Prosthodont 2013; 51:47-51.
12. Sadan A, Blatz MB, Lang B. Clinical consideration for densely sintered alumina and zirconia restorations: Part 1. Int J Periodon Rest Dent 2005; 25:213-9.
13. Cho L, Choi J, Yi YJ, Park CJ. Effect of finish line variants on marginal accuracy and fracture strength of ceramic optimized polymer / fiber-reinforced composite crowns. J Prosthet Dent 2004; 91:554-60.
14. Beuer F, Aggstaller H, Edelhoff D, Gernet W. Effect of preparation design on the fracture resistance of zirconia crown copings. Dent Mater J 2008; 27:362-7.
15. Goodis HE, Marshall GW Jr., White JM, Geel L, Hornberger B, Marshall SJ. Storage effects on dentin permeability and shear bond strengths. Dent Mater 1993; 9:79-84.
16. ElGuindy JF, Mostafa DH, ElAgroudi MA. Margin assessment and fracture resistance of adhesively luted ceramic crowns. J Amer Sc 2010; 6:264-73.
17. Soares PV, Santos-Filho PCF, Martins LRM, Soares CJ. Influence of restorative technique on the biomechanical behavior of endodontically treated maxillary premolars. Part I: Fracture resistance and fracture mode. J Prosthet Dent 2008; 99:30-7.
18. Aboushelib MA. Fatigue and fracture resistance of zirconia crowns prepared with different finish line designs. J Prosthdont 2012; 21: 22-7.
19. Pereira JR, Valle AL, Shiratori FK, Ghizoni JS, Melo MP. Influence of intraradicular post and crown ferrule on the fracture strength of endodontically treated teeth. Braz Dent J 2009; 20:297-302.
20. Rouse JS: Anterior ceramic crowns. In Summitt JB, Robbins JW, Schwartz RS (ed). Fundamentals of Operative Dentistry: A contemporary approach, 2nd ed, Chicago: Quintessence Pub Co, Inc; 2001. p.464.
21. AL-Makramani BMA, Razak AAA, Abu-Hassan M I. Comparison of the load at fracture of Turkom-Cera to Procera AllCeram and In-Ceram all-Ceramic restorations. J Prosthodont 2009; 18:484-8.
22. Adriana FQ, Oliveira F, Marco AB. Vertical marginal discrepancy of ceramic copings with different ceramic materials, finish lines, and luting agents: An in vitro evaluation. J Prosthet Dent 2004; 92:250-7.
23. Jalalian E, Rostami R, Atashkar B. Comparison of chamfer and deep chamfer preparation designs on the fracture resistance of zirconia core restorations. J Dent Res Dent Clin Dent Prospects 2011a; 5:41-5.
24. Jalalian E, Atashkar B, Rostami R. The effect of preparation design on the fracture resistance of zirconia crown copings (Computer Associated Design/Computer Associated Machine, CAD/CAM System). J Dent Tehran Univ Med Sc 2011b; 8:123-9.
25. Beuer F, Stimmelmayr M, Gueth JF, Edelhoff D, Naumann M. In vitro performance of full-contour zirconia single crowns. Dent Mater 2012; 28:449-56.
26. Burke FJT, Watts DC. Fracture resistance of teeth restored with dentine-bonded crowns. Quintessence Int. 1994; 25:335-40.
27. Yucel MT, Yondem I, Ayken F, Eraslan O. Evaluation of the supporting die structure on the fracture strength of all-ceramic materials. Clinical Oral Investigations 2012; 16:1105-10.
28. Jalalian E, Aletaha NS. The effect of two marginal designs (chamfer and shoulder) on the fracture resistance of all ceramic restorations, Inceram: An in vitro study. J Prosthodont Res 2011; 55:121-5
29. Potiket N, Chiche G, Finger IM. In vitro fracture strength of teeth restored with different all-ceramic crown systems. J Prosthet Dent 2004; 92:491-5.
30. Adanir N, Belli S. Evaluation of different post lengths effect on fracture resistance of a glass fiber post system. Eur J Dent 2008; 2:23-8.
31. Torabi K, Fattahi F. Fracture resistance of endo-dontically treated teeth restored by different FRC posts: An in vitro study. Indian J Dent Res 2009; 20:282-7.
32. Kumagae N, Komada W, Fukui Y, Okada D, Takahashi H, Yoshida K, Miura H. Influence of the flexural modulus of prefabricated and experimental posts on the fracture strength and failure mode of composite resin cores. Dent Mater J 2012; 31:113–9.
33. Oyagüe RC, Monticelli F, Toledano M, Osorio E, Fer-rari M, Osorio R. Influence of surface treatments and resin cement selection on bonding to densely-sintered zirconium-oxide ceramic. Dent Mater 2009a; 25:172-9.

34. Oyagüe RC, Monticelli F, Toledano M, Osorio E, Ferrari M, Oso-rio R. Effect of water aging on microtensile bond strength of dual-cured resin cements to pre- treated sintered zirconium-oxide ceramics. Dent Mater 2009b; 25:392-9.
35. Schmitter M, Mueller D, Rues S**.** Chipping behavior of all-ceramic crowns with zirconia frame work and CAD/CAM manufactured veneer. J Dent 2012; 40:154-62.
36. Prieto LT, Souza EJ, Araujoc TP, Lima AF, dos Santos CT, Paulillo LAMS:. Knoop hardness and effectiveness of dual- cured luting systems and flowable resin to bond leucite- reinforced ceramic to enamel. J Prosthodont 2013; 22:54-8.
37. Chevalier J, Grémillard L, Virkar AV, Clarke DR. The tetragonal-monoclinic transformation in zirconia: Lessons learned and future trends. J Am Ceram Soc 2009; 92:1901–20.
38. Kirsten A, Begand S, Oberbach T, Telle R, Fischer H. Subcritical crack growth behavior of dispersion oxide ceramics. J Biomed Mater Res Braz Appl Biomater 2010; 95:202-6.
39. Della Bona A, Mecholsky JJ Jr., Anusavice KJ. Fracture behavior of Lithia disilicate and leucite based crowns. Dent Mater 2004; 20:956-62.