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A comparison of vertical marginal fit of three different types of all ceramic crown restorations (An *In vitro* study)

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Abstract

The objective of this in vitro study was to evaluate and compare the vertical marginal fit of crowns fabricated with three different techniques: ZrO2 CAD/CAM,ZO2; copy-milling machine and Lithium disilicate pressable ceramic, before and after porcelain firing cycles and after glaze cycles. An acrylic resin model of a left maxillary first molar was prepared and duplicated to have Nickel-Chromium master die. Thirty die stone dies were distributed randomly (10 dies for each group), group(I) system, copy milling (Amann Girrbach), group(II) heat pressable ceramic(Neytech system)and group(III) CAD/CAM (Amann Girrbach). Marginal gaps along vertical planes were measured at four indentations at the (mid mesial, mid distal, mid buccal, mid palatal) before (Time 0) and after porcelain firing cycles(Time 1) and after glaze cycles(Time 2) using a light microscope at a magnification of ×100. One way ANOVA LSD tests were performed to determine whether the mean and standard deviation of sub group Time 2 between the three systems. Results revealed that the mean values of the group(III) Time 0 were (6.77µm), Time 1(8.75µm) and Time 2(10.62 µm), group(I) Time 0 (151.95µm), Time 1(157.37µm) and Time 2(159.52 µm) , and group(II) Time 0 (55.35µm), Time 1(63.85µm) and Time 2(65.55 µm). One way ANOVA test revealed quantitative differences of the three groups. Comparing the mean values of marginal gap of the three tested groups at Time 2 revealed highly statistical significance(P<0.01).

Keywords: Vertical marginal fit, All ceramic restorations, CAD/CAM, and Zirconium oxide.

Introduction

With a growing awareness of esthetics and biocompatibility, patients increasingly request metal-free solutions (Reich *et al.,* 2005). Due to the successful use of all-ceramic crowns both in the anterior and posterior segments (Fradeani *et al.,* 2005), and with the introduction of advanced dental technology and high-strength ceramic materials, all-ceramic systems may become a viable treatment option even for extended fixed partial dentures (FPDs). Such restorative all-ceramic systems must fulfil biomechanical requirements and provide longevity similar to metal-ceramic restorations (Denry *et al.,* 1998) while providing enhanced esthetics (Raigrodski and Chiche, 2001).

Zirconia, which is a polycrystalline material without a glassy matrix and is partly stabilized by yttrium oxide (approximately3 mol%), is an alternative for multiunit frameworks. The use of zirconia ceramics for multiunit FPDs has been facilitated by the advent of computer aided design/computer aided manufacturing (CAD/CAM) systems (Raigrodski *et al.,* 2006). These all-ceramic restorations must meet requirements for strength, color stability, and precision of fit for clinical success (Schwartz *et al.,* 1970).

Due to the solubility of luting agents (Schwartz, 1986), minimizing marginal opening is paramount in decreasing prosthetic failure resulting from caries, plaque and food accumulation, and inflammation of the periodontal tissues (Bergenholtz *et al.,* 1982). McLean and Von Fraunhofer (1971) examined more than 1000 crowns after a 5-year period and concluded that a marginal opening of ≤120µm was clinically acceptable.

Copy milling and CAD-CAM systems have gained popularity due to their ease of fabrication, good mechanical properties, and decreased porosity (Gorman *et al.,* 2000).

The CAD-CAM technologies introduced to the dental profession in 1971 (Duret *et al.,* 1988). The most common method to fabricate a zirconia substructure is by CAD/CAM milling from a solid block. The fully sintered zirconia is milled at a 1:1 ratio, while the partially sintered zirconia is milled 20% to 25% larger than the desired final size due to shrinkage caused by the sintering process. The development of CAD/CAM technology has focused on precise and consistent manufacturing of zirconia ceramics. CAD/ CAM technology relies on exact dimensional predictions to compensate for sintering shrinkage, is an economical and reproducible method and in addition, has demonstrated improved marginal fit (Tinschert *et al.*, 2004).

Materials and Methods

Preparation of master die: A dentoform left maxillary first molar was prepared to receive all ceramic crown using a high speed hand piece with air-water coolant, that was adapted to the suspending arm of the modified surveyor in such a way so that the long axis of the bur was paralleled to the long axis of the ivorine tooth, the horizontal arm of the surveyor permitted vertical as well as rotational movement around the tooth.

The left maxillary first molar was prepared to receive a complete ceramic crown, with the following preparation features; a 90° radial shoulder finish line all around the tooth with (1 mm) depth determined by a digital vernier, a total circumferential axial reduction was about 1.5 mm, and axial taper of 6° using a diamond bur No.(G846R). This bur was selected because it provides a shoulder finishing line; occlusal reduction of about 2mm was performed using a diamond disk bur No.(G818) (Penwadee *et al.,* 2009). The prepared dentoform tooth was used as a pattern for construction of the metal master die. The dentoform tooth was then sprued, invested, burned out and casted using Nickel-Chromium alloy (Figure 1).

Figure (1): Steps of master die fabrication

A block of acrylic resin was then constructed to hold the master die in such a way so that the long axis of the master die lied vertical to the horizontal plane of the acrylic block, and a dental surveyor was used for this purpose. Four seating grooves (5mm depth and 3mm base) at each corner of the upper surface of the block were made to be used later as a guide and stopper for the special tray during Impression making. A surveyor was used to construct the special tray for the master die (Figure 2).

Figure (2): Finished master die with its acrylic base having seating groove at each corner

Impression procedures: A surveyor was used during the process of Impression taking, the master die was fixed to the horizontal table of the surveyor in such a way so that the long axis of the tooth was kept parallel to the long axis of the analyzing rod of the surveyor, the special tray was fixed to the suspending arm of the surveyor through the analyzing rod (previously attached to the tray during its construction) so that a standardized path of insertion and removal of the special tray was obtained (Figure 3).

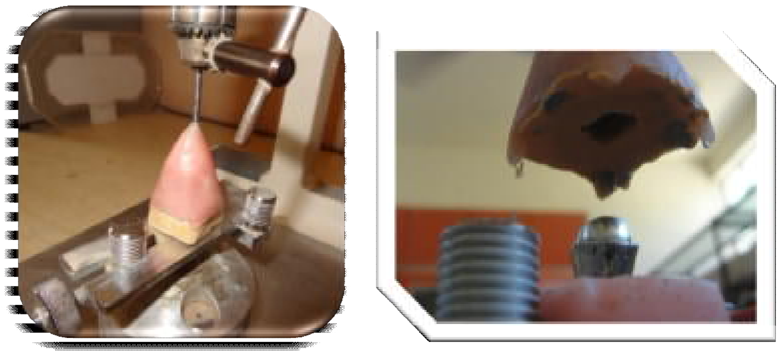

Figure (3): Construction of special tray

The special tray was coated with poly (Vinyl siloxane) adhesive for one hour prior to Impression making. The Impression was done using heavy and light viscosity poly vinyl siloxane. The special tray was used to obtain 30 Impressions. Both the heavy and light body Impression materials and catalysts were mixed using auto mixing gun. Type IV die stone was mixed in a vacuum auto mixer, the Impression was poured on the vibrator in accordance with the manufacturer's instructions, Thirty die stones were constructed from thirty Impressions. All laboratory procedures were performed by the same operator.

Samples grouping: The (30) stone dies were divided into three groups according to the technique of crown construction; group I (ZrO_2 copy-milling machine technique), group III (ZrO_2 CAD/CAM technique) and group III (pressable ceramic technique).

Copy-milling machine group (Group I): Ceramill system of copy-milling machine was used to fabricate the 10 zirconia crown restorations, In order to standardize the design and thickness of core copy milling framework a poly ethylene mould was constructed. A thickness of 1 mm core copy frame was constructed using the light cure Ceramill gel with Ceramill UV light, The copies frame was then seated in its position in the holding plate of the copy milling machine using Ceramill gel, The holding plate and Y-TZP block(zirconium block) were then attached to the clamping table of the copy milling machine, the milling procedure was then started, The copy was then coloured by immersing in the dye solution, and then sintering was carried out in the Ceramill Therm high-temperature furnace (1500°C for 9 hours) to complete sintering.

Empress group (Group II): In order to standardize the design of wax cores a polyvinyl siloxane mould for die stone was used to obtain 10 wax patterns for 10 die stones. The wax pattern was then sprued and invested into the ring, The investment ring and the plunger are preheated in the preheatening furnace at 700°C for 1h. After that, Investment ring and the plunger are removed from the furnace to be placed in the press furnace for heat press the ingot in to the ring, and then cooling the ring and finished the ceramic core and fitted in to the stone die (Figure 4).

Figure (4): Steps of empress crown fabrication

Zirconia core manufacturing by CAD/CAM system (Group III): Scanning of the die: Scannable liquid (compatible with the scanning device of Ceramill In Lab), was applied to the die stone to obtain precise scanning picture. The optical scanner scanned the die models with the help of the Ceramill 3D InLab Software; Three-dimensional images were displayed on the computer monitor, so that all the surfaces and finishing lines were shown clearly.

Core design: Core designing procedure through the software was done with the following features, a minimum wall thickness of the core (1mm), and cement gap should have (0.05mm) thickness, starting at (0.25mm) from the margin (Penwadee *et al.,* 2009). The copy seen in the final design in the monitor (Figure 5).

Figure (5): Completing the core design.

The Y-TZP blank (zirconium block) was placed in the blank holder and fixed with the screws by the` screw key, and the milling process was then started.

Colouring and sintering: The copy was given its individual colour by immersing it in the dye solution. Sintering was carried out in the Ceramill Therm high-temperature furnace 1500°C for 9hrs to complete sintering.

Porcelain veneering cycling: For all three groups, the closing margins were made with a core structure. The veneer started (0.5mm) thickness at the margin, occlusally 1mm and at middle third about 0.75mm.

Measurement of the marginal gap: Marginal gaps along vertical planes were measured at four indentations on the margin at the midpoint of mesial, distal, buccal and palatal surfaces of the die using a light microscope.

The measurements were done at three interval times:

1-(Time 0): Before porcelain firing.

2-(Time 1): After porcelain firing.

3-(Time 2): After glazing cycle.

A screw loaded holding device following Thiab and Zakaria (2007) was used during measurements in order to maintain a seating pressure of (13.4N)(Subhy and Zakaria, 2005) between the all-ceramic crown and the master metal die during measurements calculation for this purpose.

The microscope was calibrated to 0.001mm (1μm) at magnification 100x. and the measurements were done by placing the sample on the microscope stage (Figures 2-34), which was adjusted until the image of the marginal area was display clearly on the computer monitor, and the digital image of the gaps were then captured. The image was treated with program (Image J) which was used to measure the vertical marginal gap between the copy and master die, the program (Image J) was used to measure the value in a pixels mark by drawing a line between the finishing line on the die and the copy margin line (Figure 6). All digital readings were recorded and converted to

(μm) by a magnification factor.

Figure (6): Digital images were captured during the measurement

Results and Discussion

A total of 1440 measurements from three groups were recorded at three intervals, Time 0 (Before)and Time 1 (After) porcelain firing cycles and Time 2 (After glaze cycles) with 16 measurements per crown at each interval time. On the other hand comparing the results recorded in Table (1) showed that the lowest mean value was recorded in group III (CAD-CAM group) at three interval times: 6.775 μm (Time 0), 8.750 μm (Time 1), and 10.625 μm(time 2), followed by group II (Empress group) at three interval times was recorded: (55.35 μm (Time 0), 63.85 μm (Time 1), and 63.85 μm (Time 2) and with height vertical marginal gap value recorded to group I (Copy milling group) at three interval times: 151.950 μm (Time 0), 157.365 μm (Time 1) and 159.525 μm (Time 1). Copy milling group (A1) Time (0), (A2) Time (1) and (A3) Time (2). Empress group (B1) Time (0), (B2) Time (1) (B3) and Time (2) CAD/CAM group (C1) Time (0), (C2) Time (1) and (C3) Time (2).

In Table (2) and (3), it was shown that the difference in marginal gap mean values for copy milling machine (group I) and Empress (group II) were statistically non-significant.

On the other hand, ANOVA test results for group III (CAD/CAM) showed highly significant differences among the different time subgroups (as shown in Table 4).

LSD test results showed that there is highly significant difference between time (0) and time (2), while there is no any significant difference between time (0) and time (1), and between time (1) and time (2) (as shown in Table 5).

According to these results the marginal gap value at time (2) was selected to be the base line data for comparing among the three groups to see whether the difference in the marginal gap value at time (2) among the three groups, the ANOVA test was applied in Table (6), which showed that the difference was highly significant (P=0.002).

This LSD test showed highly significant differences in the marginal gap values between the three groups, and this was clearly shown in Table (7).

Table (1): Descriptive statistics of the three groups for three times.

Sub group	N	Minimum	Maximum	Mean	Std. Deviation
A1	10	116.25	206.75	151.950	30.013
A2	10	128.00	181.75	157.365	16.541
A3	10	126.25	215.50	159.525	30.682
B1	10	45.00	72,00	55.35	10.3321
B2	10	53.75	77.25	63.85	8.6972
B3	10	47.50	82.25	65.55	12.2473
C1	10	4.25	10.75	6.775	1.8388
C2	10	6.25	11.75	8.750	1.9257
C3	10	7.25	14.25	10.625	2.6621

Table (2): One way- ANOVA for copy milling machine group (Time 0, Time 1 and Time 2)

	Sum of Squares	Mean Square	F	Sig.
BetweenGroups	304.779	152.390	0.216	0.807 N.S.
Within Groups	19042.563	705.280		
Total	19347.342			

N.S.:P>0.05(Non-Significant)

Table (3): One way- ANOVA for empress group at (Time 0, Time 1 and Time 2)

	Sum of Squares	Mean Square	F	Sig.
BetweenGroups	597.267	298.633	2.695	0.807 N.S.
Within Groups	2991.525	110.797		
Total	3588.792			

N.S.:P>0.05(Non-Significant)

Table (4): One way- ANOVA for CAD-CAM group (Time 0, Time 1 and Time 2)

	Sum of Squares	Mean Square	F	Sig.
BetweenGroups	74.129	37.065	7.844	0.002
Within Groups	127.588	4.725		H.S.
Total	201.717			

HS:P<0.01(highly significant)

Table (5): LSD test between the time subgroups of the CAD-CAM group(III).

(I) VAR0000	(J) VAR0000	Mean Difference (I-J)	Std. Error	Sig.
Time (0)	Time (1)	-1.90000-	.97032	.061
Time (0)	Time (2)	-3.82500-*	.97032	.001
Time (1)	Time (2)	-1.92500-	.97032	.058

Table (6): One Way-ANOVA for Empress group (Time 2), copy milling group(Time 2) and CAD-CAM group (Time 2).

	Sum of Squares	Mean Square	F	Sig.
Between Groups	113397.55	56698.777	154.843	0.002
Within Groups	9886.563	366.169		H.S.
Total	123284.113			

HS:P<0.01(highly significante)

Table (7): LSD test at time(2) for copy milling group(I), Empress group(II) and CAD-CAM group(III).

(1) Define		Mean Difference (I-J)	Std. Error	Sig.
1	2	93.97500	8.55767	0.000
1	3	148.90000	8.55767	0.000
2	3	54.92500	8.55767	0.000

1= Copy milling (group I) time (2).
2= Empress (group II) time (2).
3= CAD/CAM (group III) time (2).

In this in vitro study, the zirconium oxide-based ceramic CAD/CAM systems mean marginal gap (10.62µm) was followed by the Empress system mean marginal gap (65.55 µm) which both demonstrated acceptable marginal gaps, the copy milling system (159.52 µm) produced unacceptable marginal gap according to Christensen (1966); McLean and von Fraunhofer (1971); Suarez *et al.* (2003); Wolfart *et al.* (2003); Quintas *et al.* (2004); Bindl and Mörmann (2005); Sailer *et al.* (2007); Iwai *et al.* (2008) who suggested that 120 µm should be the highest limit for clinically acceptable marginal discrepancies.

Effect of porcelain veneering: In the present study, the results revealed that the veneering and glazing for group (I) and (II) had non-significant effect on the vertical marginal gap, which could be due to:

1-The thermal compatibility between core and veneering material.

2-Core rigidity coming from rigidity of core material and increase in the thickness of the core.

This came in agreement with Pera *et al.* (1994); Probster *et al.* (1996); Shearer *et al.* (1996); Song *et al.* (2004); Vigolo and Fonzi *et al.* (2008). For the CAD/CAM group, the results showed that glazing produced greater marginal gap differences that is statistically highly significant. These results are in agreement with the results of Balkaya *et al.* (2005) and Pak *et al.* (2010).

Effect of the fabrication procedure: The three systems showed a large variation in marginal gap values among them due to difference in their: procedure, materials and equipment during crown construction; therefore the standardized fabrication technique could not be obtained.

Empress group: The finding of Empress group could be explained by the fact that it was fabricated through a combination of the lost-wax and heat-pressed techniques, and may undergo dimensional changes caused by the use of a separating medium before waxing of the core, the shrinkage occurring during solidification of the wax, and the dimensional changes occurring in the investment. Finally the dimensional changes in glass-ceramic ingot when plasticized and pressed into an investment mould caused by the shrinkage after casting of the ingot could be related to the high fusing temperature which will cause greater fit discrepancy, and the expansion of the investment may be inadequate to compensate for the casting shrinkage and in turn obtaining a good fit (Duncan, 1982).

The other cause of marginal gap on the Empress group could be attributed to different degree of surface roughness produced in the casting which was invested by investment material. Surface roughness will increase when using high mould temperatures (Schnell *et al.* 1963; Coony and Caputo, 1981; Lacy *et al.* 1985).

Copy milling group: The finding of copy milling group at time (2) was in coincidence with Hjerppe *et al.* (2008). The large marginal gap of the copy milling group in a crown fabrication could be explained:

1- The marginal gap might be influenced by the separating medium that was used during the fabricating of composite core and polymerization shrinkage that occurred after polymerization of the composite material of the core.

2- The milling bur (carbide burs) at its tip is not small enough to mill the small cavities and grooves on the inner surface of the preparation in copy milling group, therefore the milling procedure is unable to create a supra fine details on the inner surface as the CAD-CAM system.

3- The enlarged machining of the pre sintered Y-TZP blank may be inadequate to compensate for the shrinkage occurring after sintering of the Y-TZP blank milling procedure such as the accuracy in the CAD-CAM system.

CAD-CAM group: In this group, all steps that might have caused the dimensional changes in the Empress system and copy milling system are not found in the CAD-CAM system procedures. The creating of an enlarged during designing of the framework before sintering Y-TZP blank and milling, to compensate the account shrinkage that associated with sintering to achieve the definitive fit of restoration with its final strength (Strub *et al.*, 2006).

The presintered Y-TZP blank have a number that was set in the software during designing of the core that represent the volume of sintering shrinkage, so that the balance between the enlarged machining of the pre sintered Y-TZP block and the shrinkage occurring during the sintering process is highly precise, thus creating frameworks with an overall improved marginal gap and high significantly smaller than other system.

Marginal gap values reported in the present study for CAD-CAM Ceramill system (10.62μm) were in agreement with those of Gonzalo *et al.* (2009) who reported that the CAD-CAM Zirconia restoration showed the lowest marginal gap (9- 12 μm).

The other causes of lowest marginal gap of the CAD-CAM Ceramill system is the supra fine milling of the inner surface that will improve the seating of the coping to the die.

Effect of die spacer: Some authors (Grajower and Lewinstein, 1983; Hunter and Hunter, 1990; Adriana *et al.*, 2004) stated that “adequate die spacing is a more important factor than margin configuration for the accuracy of crown margins”. The greater the internal relief, the less time interval is required for definitive seating, leading to less force required and potentially less strain to all-ceramic margins (Wilson *et al.,* 1990).

The lowest marginal gap of the CAD-CAM Ceramill system was contributed to fewer laboratory steps and predetermined die spacer designed in the software (50μm thickness) According to some studies, if die spacer was applied to the entire prepared surface except a region of 0.25 μm above the finish line might cause improved marginal fitting of the core (Campagni *et al.,* 1982; Campbell, 1990; Adriana *et al.,* 2004).

This explanation was clearly shown in our results, since in the Empress and copy milling groups, 3 layers of die spacer was painted to get a thickness of about 45μm of internal relief (Adriana *et al.,* 2004).

However, the standardizing of the definitive thickness of die spacers is a problem related to die spacing, even for the same number of layers with different brands of die spacers (Campagni *et al.,* 1982). These layers of die spacer will be affected with the gypsum material of the die, on the other hand, the painting of the die spacer to the die never gets definitive thickness and length such as that was designed in CAD-CAM system.

Conclusions

Within the limitations of this study, it was concluded that the group(II) and group(III) demonstrated acceptable marginal fit; however, group(I) produced larger gap measurements and thus were unacceptable. The porcelain firing and the glaze firing cycles did not affect the marginal gap of group(I) and group(II) crowns; however, the porcelain firing and the glaze firing cycles affected the marginal gap of group(III) crowns. In general, the glazing cycle(time2) affected the marginal gaps of the three tested groups statistically a highly significant.

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