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In vitro Comparison of Marginal Fit of Cad-Cam Zirconia, SMLS Co-Cr, Pressable Lithium Disilicate, and Cast Ni-Cr Copings

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Abstract

Context: Clinically acceptable marginal fit of crowns has been the focus of various investigations. There is limited literature comparing marginal accuracy CAD-CAM zirconia, SMLS Co-Cr, Pressable Lithium Disilicate, and cast Ni-Cr copings.

Aim: Evaluate and compare marginal accuracy of CAD-CAM zirconia, SMLS Co-Cr, Pressable lithium Disilicate, and cast Ni-Cr copings.

Methods and Material: Forty copings were fabricated (Ten each in Group I - CAD- CAM zirconia, Group II - SMLS Co-Cr, Group III - lithium disilicate, and Group IV- cast Ni-Cr copings) on a standardized stainless steel model with long chamfer finish line. Four areas around the tooth surface namely mesial (M), distal (D), buccal (B) and lingual (L) surfaces were digitally analyzed for marginal fit under the stereomicroscope.

Stastical Analysis: Comparison between groups was done by using one-way ANOVA test followed by a Post Hoc Tukey-Kramer multiple comparisons test.

Results: The mean marginal gap (in µm) for Group I on lingual, buccal, mesial and distal surface was 37.05, 38.54, 37.61 and 36.09 respectively. The mean marginal gap (in µm) of Group II on lingual, buccal, mesial and distal surface was 48.48, 50.88, 50.12, and 49.5 respectively. The mean marginal gap (in µm) of Group III on lingual, buccal, mesial and distal surface was 63.04, 64.07, 64.97 and 65.81 respectively. The mean marginal gap (in µm) of Group IV on lingual, buccal, mesial and distal surface was 75.68, 74.75, 73.86, and 72.78 respectively.

Conclusion: The marginal fit of CAD-CAM zirconia copings is more accurate as compared to SMLS Co-Cr, pressable lithium disilicate and cast Ni-Cr alloy copings on a standardized metal model.

Keywords: Marginal Gap; Stereomicroscope; CAD – CAM; Metal Laser Sintering; Pressable Ceramic

Abbreviations: SMLS: Selective Metal Laser Sintering; Co-Cr: Cobalt-Chromium Alloy; CAD: Computer Aided Designing; CAM: Computer Aided Manufacturing; CNC: Computer Numerically Controlled (CNC); HIP: Hot Isostatic Pressing.

Introduction

The success of a dental restoration is determined by 3 main factors: esthetic value, resistance to fracture, and marginal adaptation [1-5]. Inadequate marginal fit leads to cement dissolution, plaque accumulation, which increases the risk of carious lesions & periodontal diseases [6-11].

Traditionally metal copings have been fabricated by the lost wax technique and casting method. Inaccurate marginal fit of copings fabricated by this technique may result from contraction of impression material, distortion of wax patterns, or irregularities in the cast metal. Newly developed selective metal laser sintering (SMLS) technique uses a high power laser to fuse the small particles of metal into a mass that has a desired 3-dimensional shape. The laser selectively fuses powdered material by scanning cross-sections generated from the 3-dimensional digital description of the part (for example, from a CAD file or scan data) on the surface of the powder bed. SMLS is a CAD/CAM based technique in which frameworks and metal copings can be designed and fabricated using cobalt-chromium alloy (Co-Cr). Co-Cr powdered alloy used in this technique has slight variations in composition. The molybdenum content in the alloy powder used in SMLS is comparatively less than the alloy which is used for conventional casting. After each cross section is scanned, the powder bed is lowered by one-layer thickness and a new layer of material is applied on top. The process is repeated until the part is completed. Advantage of SMLS system include easy fabrication of complicated shapes and short working time due to elimination of the procedures of fabricating a wax pattern, investing, burning and casting works [12].

Development in ceramic materials such as lithium disilicate, and zirconium oxide cores, uses of hot press and CAD-CAM equipment have opened up new path for all ceramic restorations [13]. CAD-CAM not only provides reproducible results fulfilling certain standards but also reduces the errors arising from the technicians. However, it is associated with higher cost. When measuring the marginal gap after cementation, the same number of teeth or steel dies as that of restoration sample is needed to control the variables. On the other hand, only one tooth or steel die is needed if the measurement is done without a luting agent. Investigators have found a significant increase in the marginal discrepancy after cementation [14,15]. These results, however, varied according to the luting agent. The marginal fit was, therefore, measured without cementation for variable control in this study.

There is limited literature which compares marginal accuracy of CAD-CAM zirconia, SMLS Co-Cr, Pressable lithium disilicate, and cast Ni-Cr copings. So the present in vitro study was conducted to evaluate and compare the marginal accuracy of CAD-CAM zirconia, SMLS Co-Cr, Pressable lithium disilicate, and cast Ni-Cr copings.

Methods and Material

Fabrication of stainless steel master model

For fabricating a standardized master model, a typhodont mandibular first molar tooth was first scanned using three-dimensional (3-D) computer-aided designing (CAD) software. After scanning of the mandibular first molar tooth, a uniform chamfer finish line of 1.2 mm in width, 6-degrees occlusal convergence, 1.5 mm reduction on functional cusps with functional cusp bevel and 1 mm reduction on non-functional cusps simulating a prepared mandibular first molar was carried out on the CAD software. A rectangular platform measuring 4 cm in length, 3 cm in breadth and base of thickness 2 cm made of stainless steel material was chosen for the purpose of milling. To fabricate a standardized master model consisting of a metal die exactly in the centre of the rectangular platform, computer-aided manufacturing (CAM) was carried out using the data obtained from the CAD software which was then transferred to the computer numerically controlled (CNC) milling machine (LAVA CNC 500) and engraving was done. After engraving, finishing and polishing of the master model was carried out. The stainless steel metal master model was used to fabricate all the copings and also to serve as an abutment for the measurement of marginal discrepancy.

Fabrication of CAD-CAM zirconia copings

A dental CAD/CAM system, 3M LAVA CAD/CAM system (3M ESPE Dental Products St. Paul, MN U.S.A) was used to fabricate the 10 zirconia copings used in this study. Metal model of the abutment was scanned using 3M Scanner. Scanned data were then converted into CAD data. Copings for all-ceramic crowns were designed using the dental wings supported by 3M software. No cement space was included for the margin, and 45 µm was used for the axial and occlusal surfaces of the abutment. Thickness of the copings were designed to be 0.5 mm. Design data were converted into processing data and sent to the processing machine (CNC 500 LAVA 3M).The zirconia blocks were cut and milled, and then the milled blocks were finally sintered to make zirconia copings. The internal surfaces & margins of the copings after placing on die were examined using a binocular loupe (HEINE HR-C 2.5x, HEINE, Herrsching, Germany) to check the complete seating.

Fabrication of SMLS Co-Cr alloy copings

In order to fabricate the SMLS copings, the same virtual coping design technique was used as stated above with the CAD software program. Then the copings were fabricated using a SMLS machine (EOSINT M270; EOS GmbH, Krailling, Germany) by fusing Co-Cr powder (EOS Cobalt Chrome SP2; EOS GmbH, Krailling, Germany). The powder was sintered to a layer thickness of 20 µm at a building speed of 2-20 mm^3/s from the incisal edge to the margin at 1500^0C in an inert gas environment (nitrogen atmosphere). After sintered, the copings were cooled down to the room temperature in the furnace (decreasing at the rate of $9^0C/m$). The internal surfaces & margins of the copings after placing on die were examined using a binocular loupe (HEINE HR-C 2.5x, HEINE, Herrsching, Germany) to check the complete seating.

Fabrication of Pressable lithium disilicate copings

Ten copings were fabricated from lithium disilicate glass ceramics (IPS e.max Press, Ivoclar Vivadent AG) using a combination of the lost-wax and heat-press techniques. Die lubricant (Isocera, Bego, Germany) was applied to the metal die. Wax patterns were fabricated on the dies using dip wax technique to form wax copings. The patterns were contoured parallel to the emergence profile and margins were manually sealed under 1.5×magnification.The thickness of the copings was confirmed with a thickness gauge (POCO 2N; Kroeplin, Schluchtern, Germany) to be 0.5mm. Finally, to re-adapt the margin, the pattern was reflowed completely through the wax over a band approximately 1mm wide with a well heated instrument, PKT No.1. Wax was then added to fill the depression, and when the pattern had cooled, the marginal excess was carved and the margin was burnished. Patterns were invested in phosphate bonded investment (IPS Press VEST Speed, Ivoclar Vivadent AG). After wax elimination glass ceramic ingots (HO 2, Ivoclar Vivadent AG) were plasticized at 930^0C and vacuum pressed (EP 500 press furnace, Ivoclar Vivadent AG) into an investment mold. After a holding time of 25 min the pressed crowns were divested, separated and cleaned by applying 1% hydrofluoric acid (IPS e.max Press Invex Liquid, Ivoclar Vivadent AG) for 10 min. Internal surfaces were sandblasted with 100 µm aluminum oxide at 2 bar pressure. The internal surfaces of the copings were examined using a binocular loupe (HEINE HR-C 2.5x, HEINE, Herrsching, Germany) and any visible metal nodules were removed with water cooled diamond bur. To detect the invisible nodules or irregularities, the internal surfaces of the copings was checked on the master dies using vinyl poly-siloxane disclosing paste (Fit checker; GC Corporation). After removing the copings from the die, the contact spot, marked by

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the indicator on the inside of the copings was examined visually using a binocular loupe (HEINE HR-C 2.5x, HEINE, Herrsching, Germany), these marked spots were removed until no internal binding was occurred and a uniform thickness of disclosing paste achieved. Finally, the copings were fitted to metal die. All copings were manufactured under supervision by the same dental technician.

Fabrication of cast Ni-Cr alloy copings

For making nickel-chromium (Ni-Cr) alloy copings, wax patterns were fabricated in similar way as for Pressable lithium disilicate copings. The wax patterns were invested with a phosphate-bonded investment (Bellabond Plus, Bego, Germany) and cast with Ni-Cr (Bellasun, Bego, Germany) alloy using an induction casting machine (LC Cast – 60, Confident equipments). After casting, the ring was bench cooled to room temperature and divested. The copings were sandblasted with 50-µm Al_2O_3 at 0.2-MPa air pressure to remove the investment. The internal surfaces of the copings were examined using a binocular loupe (HEINE HR-C 2.5x, HEINE, Herrsching, Germany) and any visible metal nodules were removed with a tungsten carbide bur (No. H71EF; Brasseler GmbH and Go KG). To detect the invisible nodules or irregularities, the internal surfaces of the copings was checked on the master dies using vinyl poly-siloxane disclosing paste (Fit checker; GC Corporation). After removing the crown from the die, the contact spot, marked by the indicator on the inside of the copings was examined visually using a binocular loupe (HEINE HR-C 2.5x, HEINE, Herrsching, Germany), these marked spots were removed until no internal binding was occurred and a uniform thickness of disclosing paste achieved. Finally, the restorations were fitted to metal die. All copings were manufactured under supervision by the same dental technician.

Every finished coping was placed on the prepared metal die and checked for complete seating after which it is evaluated for the marginal fit accuracy using a stereomicroscope (Wuzhou New Found Instrument Co. Ltd., China, Model Xtl 3400 E). During stereomicroscope evaluation copings were secured to master die model using vice holder. Stereomicroscopic images were analyzed using image analysis system (Chroma Systems Pvt. Ltd. India) and measurements for marginal gap were taken on deepest portion of copings on lingual, buccal, mesial and distal. Total 160 measurements were recorded of 40 copings, 10 of each four study groups. The mean and standard deviation of marginal gap of four Groups on lingual, buccal, mesial and distal surface was calculated. Tukey-Kramer multiple comparison test was applied for comparative evaluation of marginal fit in different groups.

Results

The mean ± SD marginal gap of Group I on lingual, buccal, mesial and distal surface was 37.05 ± 4.19, 38.54 ± 3.68, 37.61 ± 4.05 and 36.09 ± 4.18 respectively. The mean ± SD marginal gap of Group II on lingual, buccal, mesial and distal surface was 48.48 ± 5.99, 50.88 ± 6.0, 50.12 ± 5.91 and 49.5 ± 5.67 respectively. The mean ± SD marginal gap of Group III on lingual, buccal, mesial and distal surface was 63.04 ± 4.21, 64.07 ± 4.26, 64.97 ± 4.41 and 65.81 ± 4.49 respectively. The mean ± SD marginal gap of Group IV on lingual, buccal, mesial and distal surface was 75.68 ± 10.38, 74.75 ± 10.68, 73.86 ± 10.71 and 72.78 ± 10.61 respectively.

Table 1: Multiple comparisons using Tukey-Kramer multiple comparison test for evaluation of marginal fit on four areas around tooth structure, namely Lingual (L); Buccal (B); Mesial (M) and Distal (D) in different four study groups.

Marginal fit	(I) Group	(J) Group	Mean difference (I-J)	p-value	Remarks
Lingual	CAD/CAM zirconia	SMLS	11.43	P<0.01	Significant
		Pressable lithium disilicate	25.99	P<0.001	Significant
		Cast Ni-Cr alloy	38.63	P<0.001	Significant
	SMLS	Pressable lithium disilicate	14.56	P<0.001	Significant
		Cast Ni-Cr alloy	27.20	P<0.001	Significant
	Pressable lithium disilicate	Cast Ni-Cr alloy	12.64	P<0.001	Significant
Buccal	CAD/CAM zirconia	SMLS	12.34	P<0.01	Significant
		Pressable lithium disilicate	25.53	P<0.001	Significant
		Cast Ni-Cr alloy	36.21	P<0.001	Significant
	SMLS	Pressable lithium disilicate	13.19	P<0.001	Significant
		Cast Ni-Cr alloy	23.87	P<0.001	Significant
	Pressable lithium disilicate	Cast Ni-Cr alloy	10.68	P<0.01	Significant
Mesial	CAD/CAM zirconia	SMLS	12.51	P<0.01	Significant
		Pressable lithium disilicate	27.36	P<0.001	Significant
		Cast Ni-Cr alloy	36.25	P<0.001	Significant
	SMLS	Pressable lithium disilicate	14.85	P<0.001	Significant
		Cast Ni-Cr alloy	23.74	P<0.001	Significant
	Pressable lithium disilicate	Cast Ni-Cr alloy	8.89	P<0.05	Significant

Distal	CAD/CAM zirconia	SMLS	13.41	$P<0.001$	Significant
		Pressable lithium disilicate	29.72	$P<0.001$	Significant
		Cast Ni-Cr alloy	36.69	$P<0.001$	Significant
	SMLS	Pressable lithium disilicate	16.31	$P<0.001$	Significant
		Cast Ni-Cr alloy	23.28	$P<0.001$	Significant
	Pressable lithium disilicate	Cast Ni-Cr alloy	6.97	$P>0.05$	Not Significant

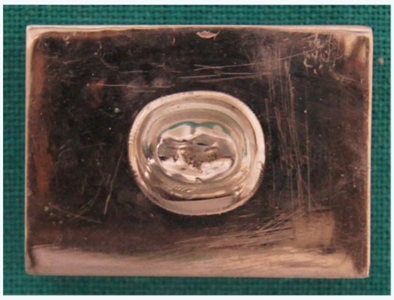

Figure 1: Stainless steel metal model die.

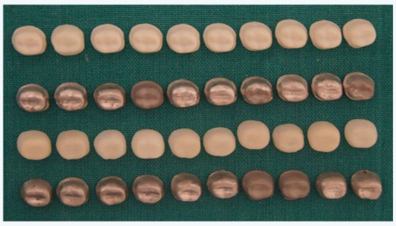

Figure 2: Copings used in study.

Figure 3: Measurement of marginal gap under stereomicroscope.

Tukey-Kramer multiple comparison tests was applied for comparative evaluation of marginal fit in different groups. The marginal fit of Group I on lingual, buccal, mesial, and distal surfaces as compared to Group II, Group III and Group IV was found to be statistically significant ($p<0.001$) (Table 1) & (Figures 1-3). The marginal fit of Group II on lingual, buccal, mesial, and distal surfaces as compared to Group III and Group IV was found to be statistically significant ($p<0.001$).The marginal fit of Group III on lingual, buccal, and mesial surfaces as compared to Group IV was found to be statistically significant ($p<0.001$).The marginal fit of Group III on distal surface as compared to Group IV was found to be statistically not significant ($p>0.05$).

Discussion

The ultimate goal of successful fixed partial denture (FPD) prosthesis can be achieved only when an accurate and precise marginal fit is produced. Microleakage and marginal openings are important causes of fixed restoration failures. One of the reasons for high microleakage is the amount of marginal gap, the increase of which causes greater microleakage, because the amount of cement exposed to oral fluids depend on the extent of the marginal gap [16].

Marginal discrepancies in the range of 40-120 μm have been reported to be clinically acceptable with regard to longevity of a restoration [17]. All the copings tested in this study are in the range of 35-80 μm, which is within acceptable limits. The different materials and applied techniques in the manufacturing of crown systems have significant effects on the strength of the final restoration as well as the marginal fit. Imperfect restoration margins offer recesses for adherence of oral bacteria, which may cause secondary caries and traumatic gingival irritation [18]. This in vitro study examined the marginal adaptation of four types of copings, consisting of frameworks fabricated using CAD/CAM zirconia, selective metal laser sintering (SMLS), pressable lithium disilicate and cast nickel-chromium (Ni-Cr) alloy. The marginal discrepancies of group CAD/CAM zirconia were significantly smaller compared to those of the other three study groups.

A stainless steel die was used for making copings and served as the abutment for the measurement of marginal discrepancy for all the copings made in this study. The advantages of the stainless steel die are standardized preparation and avoidance of wear of the die during the coping fabrication and measurements. The deep chamfer finish line preparation was selected because it meets the requirements for all the four study groups used in this study [19]. The majority of marginal discrepancy is known to develop during the oxidation cycle for metal copings [20]. This is often

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attributed to the release of residual stresses incurred during casting, grinding or polishing phases of the procedure. As the prostheses cools from the firing temperature, the difference in thermal contraction between the metal coping and the porcelain may result in additional marginal discrepancy [21].

The mean marginal gap widths of the CAD/CAM zirconia fabricated superstructures were significantly smaller than those of the selective metal laser sintered frameworks. This finding can be attributed to advancements in scanning technology, restoration-designing software with improved margin detection and precision milling technologies. The vertical marginal gap values obtained were within the range of clinical acceptance i.e. 40 μm to 120 μm. The CAD/CAM zirconia system mills the framework with the final dimensions out of a densely sintered Y-TZP (Yittria stabilized Tetragonal Zirconia Polycrystals) blank which is fabricated with the 'Hot Isostatic Pressing (HIP)' technology. This technology involves sintering partially sintered zirconia material at a high temperature in a high density, homogenous zirconia material with improved mechanical properties [22]. For CAD/CAM ceramic crowns, marginal gaps of 17 μm to 118 μm have been reported by various authors [23]. Similar results were obtained in the present study.

However, a higher accuracy was achieved with the soft, partially sintered Y-TZP ceramics compared with the hot isostatic pressed (HIP) Y-TZP blocks. This finding can be attributed to the ease of machining and the precisely controlled sintering cycle in a specially designed sintering oven which aided in achieving a consistently accurate fit. The lesser accuracy of hard HIP-YTZP ceramics can be attributed to their extreme hardness and higher flexural strength (> 1,200 MPa), which can cause greater wear of the milling burs and a reduction in the efficiency of the milling unit consequently leading to lesser accuracy of fit. The Post Hoc comparison of both hard and soft types of ceramics showed no statistical significance, indicating that either form of Y-TZP ceramic produces clinically acceptable restorations. The comparable mechanical properties and the relative ease and speed of soft Y-TZP blank milling may explain why more operators choose this method to fabricate zirconia restorations, whereas only a small number prefer the hard Y-TZP blanks [24].

The results of the present study suggest that the new zirconia ceramic systems fabricated with CAD/CAM technology presents better marginal fit as compared to selective metal laser sintered copings. These results were in accordance with a study conducted by Ece Tamac et al. [25]. The results of this study shows that selective metal laser sintered copings shows better marginal fit than pressable lithium disilicate and cast Ni-Cr alloy copings. This finding can be attributed to the fact that additive manufacturing is used during selective metal laser sintered copings fabrication and this technique uses a high power laser to fuse small particles of metal into a mass that has a desired 3-dimensional shape. The laser selectively fuses powdered material by scanning cross-sections generated from a 3-dimensional digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one-layer thickness, a new layer of material is applied on top and the process is repeated until the part is completed. These results are in accordance with Montero J. et al who concluded that selective metal laser sintering may be an alternative to vacuum-casting of base metals to obtain passive-fitting implant-supported crown copings [26].

Glass-ceramics have superior stability, biocompatibility, esthetics, and chemical inertness, making them a viable alternative restorative material. Leucite-reinforced glass-ceramics were originally designed for CAD/CAM restorations because of their high durability and ability to be milled accurately. These ceramics are reinforced by the incorporation of leucite crystals into their structure, giving them improved toughness and strength [27]. In the present study, the leucite-reinforced glass-ceramic superstructures showed higher accuracy of marginal fit compared with the cast Ni-Cr superstructures.

IPS Empress Copings show less marginal gap than the conventionally casted Ni-Cr alloy copings. IPS Empress 2 (Ivoclar Vivadent, Schaan, Liechtenstein) is a lithium-disilicate glass ceramic (SiO2-Li2O) that is fabricated through a combination of the lost-wax and heat-pressed techniques. A glass-ceramic ingot of the desired shade is plasticized at 920°C and pressed into an investment mold under vacuum and pressure. Its predecessor, IPS Empress (Ivoclar Vivadent) is a leucite-reinforced glass ceramic (SiO_2-Al_2O_3-K_2O) which, due to its strength is limited in use to single unit complete-coverage restorations in the anterior segment. IPS Empress 2 has improved flexural strength by a factor of 3 over IPS Empress, can be used for 3-unit fixed partial dentures in the anterior area and can extend to the second premolar. The framework is veneered with fluoroapatite-based veneering porcelain (IPS Eris; Ivoclar Vivadent), resulting in a semi translucent restoration with enhanced light transmission. IPS e.max press (Ivoclar Vivadent) was introduced in 2005 as an improved press-ceramic material compared to IPS Empress 2. It also consists of a lithium-disilicate pressed glass ceramic, but its physical properties and translucency are improved through a different firing process [28]. Yeo IS et al. [29] concluded that the IPS Empress 2 systems showed the smallest and most homogeneous gap dimension, whereas the conventional In-Ceram system presented the largest and more variable gap dimensions compared with the metal ceramic restorations.

The conventionally casted Ni-Cr superstructures show more marginal gap when compared with the CAD/CAM superstructures. This finding can be attributed to the expansion and contraction associated with the impression materials, gypsum, wax pattern distortion during removal and the spruing process are other factors that may affect the accuracy of superstructures fabricated using the lost-wax process [30]. These results are in accordance with a study conducted by Tamer E. Shokry et al. [31] who concluded that titanium copings fabricated by CAD/CAM demonstrated the least marginal discrepancy among all groups, while the base metal (Ni-Cr) groups exhibited the most discrepancy of all groups tested.

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It is difficult to interpret the statistical results of the previous studies because of variations in sample size, the measurement per specimen and the measurement methods used. There is no standardized method to measure the marginal fit. The most common methods are ‘direct viewing, sectioning, probing and explorative and visual examinations’ [32]. In the current study, the direct viewing of the crown on a die is used to measure the marginal fit of all the copings. Direct viewing has the advantage of being nondestructive and therefore applicable to clinical practice. The vertical cervical marginal gap measurement was selected as the most frequently used to quantify the accuracy of fit of a restoration [33].

Conclusion

Within the limitations of the present study, following conclusions can be drawn:

1. The marginal fit of CAD/CAM zirconia copings is more accurate as compared to selective metal laser sintered (SMLS), pressable lithium disilicate and cast Ni-Cr alloy copings on a standardized metal master model.
2. Base metal alloy (Ni-Cr) exhibited a discrepancy that was significantly higher than the rest of the groups.
3. The marginal discrepancies of all the copings were within the clinically acceptable range of 80-120 μm.

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