

# Comparative evaluation of marginal fit and axial wall adaptability of copings fabricated by metal laser sintering and lost-wax technique: An *in vitro* study

Bhushan Satish Gaikwad, Girish Nazirkar<sup>1</sup>, Rajani Dable<sup>2</sup>, Shailendra Singh<sup>1</sup>

Department of Prosthodontics and Crown and Bridge, Sinhgad Dental College and Hospital, Pune, <sup>1</sup>Department of Prosthodontics and Crown and Bridge, SMBT Dental College and Hospital, Ahmednagar, Maharashtra, <sup>2</sup>Department of Prosthodontics and Crown and Bridge, Teerthanker Mahaveer Dental College and Research Centre, Moradabad, Uttar Pradesh, India

## Abstract

**Purpose:** The present study aims to compare and evaluate the marginal fit and axial wall adaptability of Co-Cr copings fabricated by metal laser sintering (MLS) and lost-wax (LW) techniques using a stereomicroscope.

**Materials and Methods:** A stainless steel master die assembly was fabricated simulating a prepared crown; 40 replicas of master die were fabricated in gypsum type IV and randomly divided in two equal groups. Group A coping was fabrication by LW technique and the Group B coping fabrication by MLS technique. The copings were seated on their respective gypsum dies and marginal fit was measured using stereomicroscope and image analysis software. For evaluation of axial wall adaptability, the coping and die assembly were embedded in autopolymerizing acrylic resin and sectioned vertically. The discrepancies between the dies and copings were measured along the axial wall on each halves. The data were subjected to statistical analysis using unpaired *t*-test.

**Results:** The mean values of marginal fit for copings in Group B (MLS) were lower (24.6  $\mu\text{m}$ ) than the copings in Group A (LW) (39.53  $\mu\text{m}$ ), and the difference was statistically significant ( $P < 0.05$ ). The mean axial wall discrepancy value was lower for Group B (31.03  $\mu\text{m}$ ) as compared with Group A (54.49  $\mu\text{m}$ ) and the difference was statistically significant ( $P < 0.05$ ).

**Conclusions:** The copings fabricated by MLS technique had better marginal fit and axial wall adaptability in comparison with copings fabricated by the LW technique. However, the values of marginal fit of copings fabricated that the two techniques were within the clinically acceptable limit ( $< 50 \mu\text{m}$ ).

**Keywords:** Axial fit, casting, computer-aided designing/computer aided manufacturing, internal fit, marginal fit, metal laser sintering

**Address for correspondence:** Dr. Bhushan Satish Gaikwad, E/602 Nancy Lake Homes Opposite Bharati Vidyapeeth Gate, Katraj, Pune - 411 046, Maharashtra, India.

E-mail: dr.bhushan.mds@gmail.com

**Received:** 16<sup>th</sup> October, 2017, **Accepted:** 23<sup>rd</sup> November, 2017

Access this article online	
Quick Response Code:	Website: www.j-ips.org
	DOI: 10.4103/jips.jips_271_17

This is an open access article distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as the author is credited and the new creations are licensed under the identical terms.

**For reprints contact:** reprints@medknow.com

**How to cite this article:** Gaikwad BS, Nazirkar G, Dable R, Singh S. Comparative evaluation of marginal fit and axial wall adaptability of copings fabricated by metal laser sintering and lost-wax technique: An *in vitro* study. J Indian Prosthodont Soc 2018;18:47-52.

## INTRODUCTION

The marginal fit is of paramount importance for a successful fixed dental prosthesis (FDP).<sup>[1-3]</sup> Literature is replete with clinical trials underlining the importance of marginal accuracy for clinical success.<sup>[1,4]</sup> The axial wall adaptation affects the seating of a prosthesis in turn affecting the marginal fit, rendering it equally important. Incomplete marginal fit has been associated with the dissolution of luting cement, development of secondary caries, adverse pulpal reactions, and periodontal inflammation. The marginal fit of castings relies on perceptive tooth preparation, accurate impressions, precision castings with careful finishing, and cementation procedures.<sup>[5]</sup>

Literature revealed that the clinically acceptable marginal discrepancy for a cast restoration ranges from 10 to 160  $\mu\text{m}$ .<sup>[5]</sup> However, most of the authors have considered marginal discrepancies exceeding 100  $\mu\text{m}$  as unacceptable.<sup>[6]</sup>

Various computer-aided designing/computer-aided manufacturing (CAD/CAM)-based systems are available for rapid production of FDP and are available in dental laboratories. One such technology is the metal laser sintering (MLS). The MLS is an additive technique, based on the 3-dimensional information received from the CAD and the prosthesis is fabricated in CAM machine. The main advantage of MLS technique is that it eliminates the drawbacks of the lost-wax (LW) technique. In addition, the MLS technique renders easy fabrication of prosthesis with complex design. The technology is automated and has shorter working time due to elimination of procedures involved in the LW technique, i.e., wax pattern, investment, wax burnout, and casting works.

To consider a technique clinically acceptable, the technique has to undergo comparative evaluation of critical parameters with a gold standard. Thus, purpose of the present study was to compare and evaluate the marginal fit and axial wall adaptability of Co-Cr coping fabricated by the LW and MLS techniques.

## MATERIALS AND METHODS

### Custom stainless steel master die

The stainless steel (SS) master die simulated a prepared crown with a  $6^\circ$  total axial wall taper. The axial height and occlusal diameter were 6 mm with a  $90^\circ$  shoulder finish line of 1 mm. Occlusal crosshairs were placed for precise reorientation of respective coping. A computer numerical control reference markings were scribed below the margin at 4 sites which were  $90^\circ$  apart ( $0^\circ$ ,  $90^\circ$ ,  $180^\circ$  and  $360^\circ$ ).

Base of the die had two cylindrical projections on two sides which helped in precise orientation of the counter die [Figure 1].

### FABRICATION OF STONE DIES

The SS die was duplicated in type IV die stone (Ultra rock, Kalabhai) [Figure 2] by polyvinylsiloxane impression material (3M ESPE, Germany). Forty die stone replicas were fabricated and checked for the fitting of SS counter die. The dies were randomly divided into two equal groups, i.e., Group A (LW) and Group B (MLS). All the dies were coated with die hardener (Heart-Man Dental Laboratory, Korea) to avoid loss of surface detail during coping fabrication.

### Fabrication of Co-Cr copings by lost-wax technique (Group A)

The stone dies in Group A were coated with two layers of die spacer corresponding 30  $\mu\text{m}$ . Wax separator



Figure 1: Stainless steel master die and counter

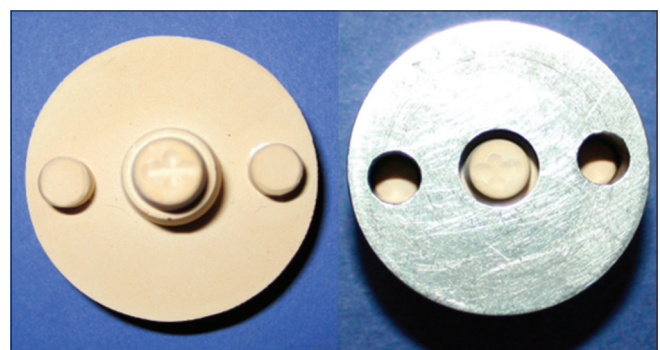


Figure 2: Stone die and fitting of counter die

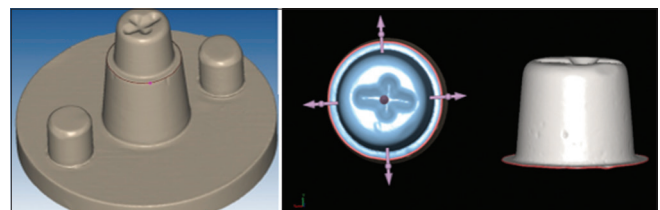


Figure 3: Scanned stone die and coping design



(Sigmament, India) was applied on the die as well as the counter die. Standardized wax patterns were made by flowing molten wax in the space between the stone die and counter die for all the samples. After the pattern wax completely solidified, counter die was removed carefully and wax pattern was inspected and carved to attain a uniform thickness of 0.5 mm; correction of defective pattern was done as well. Wax patterns were invested (Bellasan, BEGO, Germany) (Bego Sol, BEGO, Germany) individually following the manufacturers instruction implementing ringless casting technique<sup>[7]</sup> to obtain Co-Cr (Wirobond, BEGO, Germany) copings for Group A.

#### Fabrication of Co-Cr copings by metal laser sintering technique (Group B)

The copings for Group B were fabricated using MLS technique in which individual dies were scanned (ESPE Lava scan ST scanner). Using the CAD software (Lave design software, 3M ESPE), coping design was made to be 0.5 mm in thickness and internal relief of 30 µm for each coping [Figure 3].

The coping data was transferred to CAM machine (EOSINT M 270) that processed a specially manufactured biocompatible Co-Cr alloy, i.e., EOS Cobalt-Chrome SP2 alloy (Co: 61.8–65.8 wt-%, Cr: 23.7–25.7 wt-%, Mo: 4.6–5.6 wt-%, W: 4.9–5.9 wt-%, Si: 0.8–1.2 wt-%, Fe: maximum 0.50 wt-%, Mn: Maximum 0.10 wt-%) which was developed for use in dental prostheses. The process was done by stacking the special alloy powder in vertical increments while a high-powered laser (Yb-fibre laser, 200 W) sintered the alloy particles, eventually forming the designed prosthesis.

#### Assessment of marginal fit

The copings obtained from Group A and Group B were seated on their respective dies and evaluated for marginal fit. To measure the marginal fit a stereomicroscope (Stereo Zoom S300) at ×40 magnification and image analysis software was used (Chroma Systems, India). The marginal fit was [Figures 4 and 5] determined as the maximum distance between the margin of the die and the most apical part of the casting margin in a plane parallel to the long axis of the die. The values were recorded at 0°, 90°, 180°, and 360° for each die, respectively, and mean marginal fit value was obtained in µm for all the specimens.<sup>[8]</sup>

#### Assessment of axial wall adaptation

Using modeling wax, boxing was done of the die-coping assembly to provide uniform and adequate space for autopolymerized acrylic resin tray material (Instant tray material, Asia special, India). Proportional mixture of

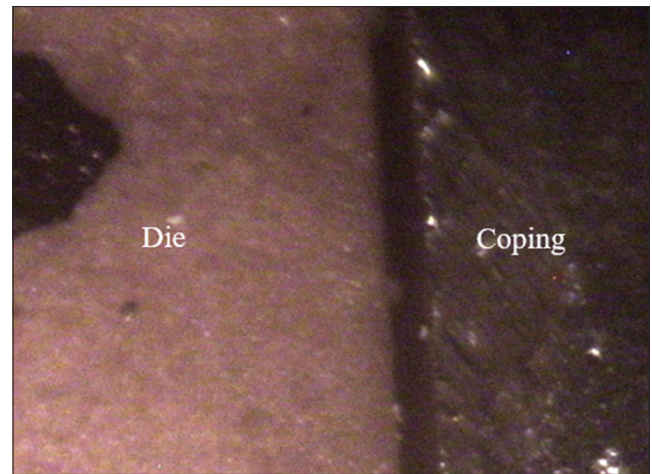


Figure 4: Marginal fit as observed at ×40 magnification for Group A

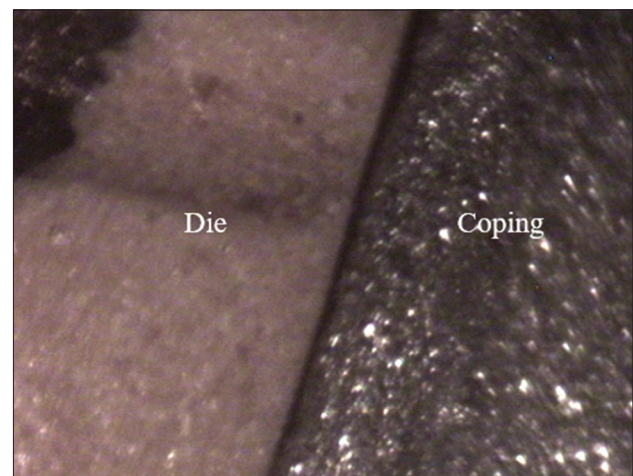


Figure 5: Marginal fit as observed at ×40 magnification for Group B



Figure 6: Sectioned coping-die assembly prepared to observe axial wall adaptation

autopolymerizing acrylic resin was poured in the space while maintaining the position of coping over the dies. After the acrylic resin had polymerized, individual die-coping assembly was sectioned vertically through the

center by a diamond disc (DFS, Germany). Each section of individual die was finished by gently sliding over sandpaper which was laid on a flat surface to remove metal bur. Three markings were made on each axial wall, 1.5 mm above the axiomarginal line angle, and 1.5 mm below the occlusoaxial line angle. For each sample, there were in total of twelve points at which the values for axial wall adaptability were recorded in  $\mu\text{m}$ . Mean value was calculated for each prepared specimen [Figure 6].

### Statistical analysis

The acquired data were subjected to unpaired *t*-test for comparison of marginal fit and axial wall adaptability to test the level of significance between Group A and Group B.

### RESULTS

In view of the current study, the null hypothesis stated that there would be no statistically significant difference between Group A and Group B when compared for marginal fit and axial wall adaptability. The copings obtained from Group A and Group B exhibited clinically acceptable values of marginal fit ( $<50 \mu\text{m}$ ). Data from both the groups were subjected to comparative evaluation and showed a statistically significant difference ( $P < 0.05$ ) [Table 1]. The mean values for axial wall adaptability from Group A and Group B were  $54.49 \mu\text{m}$  and  $31.03 \mu\text{m}$ , respectively. On carrying out comparative evaluation, statistical data exhibited statistically significant difference between Group A with Group B ( $P < 0.05$ ) [Table 2].

### DISCUSSION

Marginal and internal fit are considered as important criteria for clinical success of crowns and FDP. Lack of adequate fit can be potentially detrimental because of the intraoral degradation of cements which invariably causes loss of marginal seal and promotes retention of plaque and food debris.<sup>[7,9]</sup>

Studies have showed that castability of Co-Cr alloy was within the range of Ni-Cr alloys and had better corrosion resistance.<sup>[10,11]</sup> In addition, Co-Cr alloys are less frequently associated with allergic reactions as compared to Ni-Cr alloys and are a common alternative for patients allergic to Nickel.<sup>[12,13]</sup> Considering these facts, in the present study, use of Co-Cr alloy can be justified and considered for crowns or FDP.<sup>[14]</sup>

It is a known fact that with increase in steps of a procedure, the technique becomes more susceptible to errors. The objective of any casting procedure is to provide a metallic duplication of missing tooth structure with as much

**Table 1: Statistical comparison of marginal fit between Group A and Group B in  $\mu\text{m}$**

Group	Mean	SD	SE of mean	Mean difference	<i>t</i>	<i>P</i>
Group A	39.53	$\pm 16.02$	1.79	14.93	6.738	$< 0.05$
Group B	24.6	$\pm 11.68$	1.30			

**Table 2: Statistical comparison between Group A and Group B for Axial Wall Adaptability (values in  $\mu\text{m}$ )**

Group	Mean	SD	SE of mean	Mean difference	<i>t</i>	<i>P</i>
Group A	54.49	$\pm 11.54$	1.83	23.46	8.1	$< 0.05$
Group B	31.03	$\pm 14.26$	2.25			

accuracy as possible.<sup>[15]</sup> A casting cannot be more accurate than the wax pattern from which it is made; thus, a flawless wax pattern should be accurately formed to have a precise casting.<sup>[16]</sup> The wax patterns can be developed either by additive technique, subtractive technique, or combination of both.<sup>[17]</sup> In the present study, the wax patterns for Group A samples were fabricated by flowing molten wax between the SS former and die followed by retrieval and carving to 0.5 mm thickness.

Ringless casting technique has proved to deliver better fitting copings when compared with conventional metal ring technique.<sup>[7]</sup> The ringless investment procedure ensured uniform expansion of the refractory mold by setting and thermal expansion.<sup>[15]</sup> Therefore, in the present study, ringless casting technique was implemented.

Problems with the fit of casting, either too large or small, can usually be traced to not following the instructions of investment manufacturer.<sup>[18]</sup> It is not possible to prescribe a single correct technique since many variables and environmental conditions are involved during the conventional LW procedure. To conclude, the casting procedure is partly empirical and a matter of routine procedure and routine procedure should be rigidly followed to achieve precise castings and consistent results.<sup>[15]</sup>

The MLS is a CAD/CAM-based technology in which designing of the prostheses is done in the software, after which the information is transferred to the MLS unit followed by fabrication of prostheses. The prosthesis is fabricated by incremental layering of the special Co-Cr alloy powder of approximately  $20 \mu\text{m}$  thick; the alloy particles are sintered by a high powered laser and the process is repeated till the entire prosthesis is formed.

Various studies have been conducted involving the new MLS procedure and have proved to be promising for dental applications when compared with the LW technique.<sup>[19-22]</sup>

The fit of a casting can be defined in terms of “misfit,” measured at various points between the casting surface and tooth. The perpendicular measurement from the internal surface of the casting to the axial wall of the preparation is called the internal gap, and the same measurement at the margin is called the “marginal gap.”<sup>[9]</sup> The vertical marginal misfit measured parallel to the path of withdrawal of the casting is called the vertical marginal discrepancy.<sup>[23]</sup>

The literature revealed that the range of clinically acceptable marginal discrepancy for cast restoration was from 10 to 160  $\mu\text{m}$ .<sup>[24]</sup> Previous studies concerning different materials and techniques resulted in a wide range of reported values of marginal and internal fit.<sup>[25-29]</sup> Various authors have evaluated the marginal accuracy of cast and CAD/CAM-fabricated crowns.<sup>[21,30,31]</sup> Most clinicians would be contended with marginal openings of 50  $\mu\text{m}$  or less and probably of 100  $\mu\text{m}$  clinically acceptable.<sup>[32]</sup> Others stated that marginal discrepancies in the range of 100  $\mu\text{m}$  seem to be clinically acceptable with regard to the longevity of the restorations.<sup>[33-37]</sup>

Data from the present study showed that copings from both groups had achieved the marginal fit well within 50  $\mu\text{m}$  (mean marginal discrepancy of copings in Group A was 40.79  $\mu\text{m}$  and that of Group B was 24.46  $\mu\text{m}$ ). The results were statistically significant between the two groups ( $P < 0.05$ ).

It is said that restorations need a theoretical luting cement film thickness of 20–40  $\mu\text{m}$ .<sup>[38]</sup> The cement space is critical as the luting agent will impart hydraulic pressure between the tooth and the restoration rendering incomplete seating with marginal discrepancy greater than before cementation. If the axial walls are not well relieved, there will be premature contact, further preventing the seating of coping.<sup>[39]</sup> In a study, it was observed that when the luting space was set to 10  $\mu\text{m}$ , the marginal gaps of the crowns were greater than when it was set to 30 or 50  $\mu\text{m}$ .<sup>[31,40]</sup> There are different ways to study and analyze the fit of dental restorations.<sup>[9,20,41,42]</sup> The die-coping assembly in the present study was embedded in autopolymerizing acrylic resin tray material and sectioned longitudinally followed by recording the observations. The intended area for observation was decided because when a die spacer is used, it is painted 1–1.5 mm above the marginal line angle. Thus, this area is more critical, i.e., vertical walls in the relief for internal fit. The results for axial wall adaptation were in accordance with previous studies for both the groups (mean axial wall adaptation for Group A 54.49  $\mu\text{m}$  and Group B 31.06  $\mu\text{m}$  respectively) and there was a statistically significant difference between the two groups ( $P < 0.05$ ). However,

currently, there is no consensus of the clinically acceptable cement film thickness in FDP.<sup>[43]</sup>

The present study was an *in vitro* study conducted under controlled conditions; thus, the results achieved in dental laboratory will vary. Within the limitations of the study, the copings fabricated by MLS technique were found to have less marginal discrepancy and consistent axial wall adaptability values as compared with copings fabricated by LW technique. However, further studies are needed to evaluate the parameters after the ceramic layering procedure. In the present study, copings were fabricated on standardize dies; therefore, there is also a need for addition investigations pertaining to a clinical situation.

## CONCLUSIONS

The results obtained in the present study assured that the MLS technique could be an alternative for conventional LW technique; however, the LW technique will still be considered as a gold standard for comparing the new techniques introduced in the field of dental laboratories to fabricate FPDs, as it has still stood the test of time and is widely practiced.

## Financial support and sponsorship

Nil.

## Conflicts of interest

There are no conflicts of interest.

## REFERENCES

1. Karlsson S. The fit of procera titanium crowns. An *in vitro* and clinical study. Acta Odontol Scand 1993;51:129-34.
2. Odén A, Andersson M, Krystek-Ondracek I, Magnusson D. Five-year clinical evaluation of Procera AllCeram crowns. J Prosthet Dent 1998;80:450-6.
3. Besimo C, Jeger C, Guggenheim R. Marginal adaptation of titanium frameworks produced by CAD/CAM techniques. Int J Prosthodont 1997;10:541-6.
4. May KB, Russell MM, Razoog ME, Lang BR. Precision of fit: The Procera AllCeram crown. J Prosthet Dent 1998;80:394-404.
5. Ushiwata O, de Moraes JV, Bottino MA, da Silva EG. Marginal fit of nickel-chromium copings before and after internal adjustments with duplicated stone dies and disclosing agent. J Prosthet Dent 2000;83:634-43.
6. Hunter AJ, Hunter AR. Gingival margins for crowns: A review and discussion. Part II: Discrepancies and configurations. J Prosthet Dent 1990;64:636-42.
7. Lombardas P, Carbunaru A, McAlarney ME, Toothaker RW. Dimensional accuracy of castings produced with ringless and metal ring investment systems. J Prosthet Dent 2000;84:27-31.
8. Sorensen JA. A standardized method for determination of crown margin fidelity. J Prosthet Dent 1990;64:18-24.
9. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent 1989;62:405-8.
10. O'Connor RP, Mackert JR Jr., Myers ML, Parry EE. Castability, opaque



- masking, and porcelain bonding of 17 porcelain-fused-to-metal alloys. *J Prosthet Dent* 1996;75:367-74.
11. Sarkar NK, Greener EH. *In vitro* corrosion resistance of new dental alloys. *Biomater Med Devices Artif Organs* 1973;1:121-9.
  12. Wiltshire W, Ferriera MR, Ligthelm AJ. Allergies to dental materials. *Quintessence Int* 1996;27:513-20.
  13. Wataha JC, Messer RL. Casting alloys. *Dent Clin North Am* 2004;48:vii-viii, 499-512.
  14. Roach M. Base metal alloys used for dental restorations and implants. *Dent Clin North Am* 2007;51:603-27, vi.
  15. Anusavice KJ. *Phillips' Science of Dental Materials*. 11<sup>th</sup> ed. Philadelphia: W. B. Saunders; 2003. p. 295-350.
  16. Eissmann HF. Marginal adaptation to die. In: Rhoads JE, Rudd KD, Morrow RM, editors. *Dental Laboratory Procedures, Fixed Partial Dentures*. 2<sup>nd</sup> ed., Vol. 2. Princeton: The C. V. Mosby Company; 2014. p. 191-3.
  17. Troendle GR. Waxing to a functional core. In: Rhoads JE, Rudd KD, Morrow RM, editors. *Dental Laboratory Procedures, Fixed Partial Dentures*. 2<sup>nd</sup> ed., Vol. 2. Princeton: The C. V. Mosby Company; 2014. p. 175-84.
  18. Jenderson MD, Stocks CL. Investing. In: Rhoads JE, Rudd KD, Morrow RM, editors. *Dental Laboratory Procedures, Fixed Partial Dentures*. 2<sup>nd</sup> ed., Vol. 2. Princeton: The C. V. Mosby Company; 2014. p. 213-9.
  19. Akova T, Ucar Y, Tukay A, Balkaya MC, Brantley WA. Comparison of the bond strength of laser-sintered and cast base metal dental alloys to porcelain. *Dent Mater* 2008;24:1400-4.
  20. Quante K, Ludwig K, Kern M. Marginal and internal fit of metal-ceramic crowns fabricated with a new laser melting technology. *Dent Mater* 2008;24:1311-5.
  21. Örtorp A, Jönsson D, Mouhsen A, Vult von Steyern P. The fit of cobalt-chromium three-unit fixed dental prostheses fabricated with four different techniques: A comparative *in vitro* study. *Dent Mater* 2011;27:356-63.
  22. Xiang N, Xin XZ, Chen J, Wei B. Metal-ceramic bond strength of Co-Cr alloy fabricated by selective laser melting. *J Dent* 2012;40:453-7.
  23. Groten M, Axmann D, Pröbster L, Weber H. Determination of the minimum number of marginal gap measurements required for practical *in-vitro* testing. *J Prosthet Dent* 2000;83:40-9.
  24. Schwartz IS. A review of methods and techniques to improve the fit of cast restorations. *J Prosthet Dent* 1986;56:279-83.
  25. Belser UC, MacEntee MI, Richter WA. Fit of three porcelain-fused-to-metal marginal designs *in vivo*: A scanning electron microscope study. *J Prosthet Dent* 1985;53:24-9.
  26. Al Wazzan KA, Al-Nazzawi AA. Marginal and internal adaptation of commercially pure titanium and titanium-aluminum-vanadium alloy cast restorations. *J Contemp Dent Pract* 2007;8:19-26.
  27. Witkowski S, Komine F, Gerds T. Marginal accuracy of titanium copings fabricated by casting and CAD/CAM techniques. *J Prosthet Dent* 2006;96:47-52.
  28. Jesús Suárez M, Lozano JF, Paz Salido M, Martínez F. Marginal fit of titanium metal-ceramic crowns. *Int J Prosthodont* 2005;18:390-1.
  29. Valderrama S, Van Roekel N, Andersson M, Goodacre CJ, Munoz CA. A comparison of the marginal and internal adaptation of titanium and gold-platinum-palladium metal ceramic crowns. *Int J Prosthodont* 1995;8:29-37.
  30. Bindl A, Mörmann WH. Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations. *J Oral Rehabil* 2005;32:441-7.
  31. Nakamura T, Dei N, Kojima T, Wakabayashi K. Marginal and internal fit of Cerec 3 CAD/CAM all-ceramic crowns. *Int J Prosthodont* 2003;16:244-8.
  32. Holmes JR, Sulik WD, Holland GA, Bayne SC. Marginal fit of castable ceramic crowns. *J Prosthet Dent* 1992;67:594-9.
  33. Fransson B, Oilo G, Gjeitanger R. The fit of metal-ceramic crowns, a clinical study. *Dent Mater* 1985;1:197-9.
  34. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an *in vivo* technique. *Br Dent J* 1971;131:107-11.
  35. Blackman R, Baez R, Barghi N. Marginal accuracy and geometry of cast titanium copings. *J Prosthet Dent* 1992;67:435-40.
  36. Wu Y, Moser JB, Jameson LM, Malone WF. The effect of oxidation heat treatment of porcelain bond strength in selected base metal alloys. *J Prosthet Dent* 1991;66:439-44.
  37. Lautenschlager EP, Monaghan P. Titanium and titanium alloys as dental materials. *Int Dent J* 1993;43:245-53.
  38. Levine WA. An evaluation of the film thickness of resin luting agents. *J Prosthet Dent* 1989;62:175-8.
  39. Oruç S, Tulunoğlu Y. Fit of titanium and a base metal alloy metal-ceramic crown. *J Prosthet Dent* 2000;83:314-8.
  40. Campagni WV, Preston JD, Reisbick MH. Measurement of paint-on die spacers used for casting relief. *J Prosthet Dent* 1982;47:606-11.
  41. Milan FM, Consani S, Correr Sobrinho L, Sinhoreti MA, Sousa-Neto MD, Knowles JC, *et al.* Influence of casting methods on marginal and internal discrepancies of complete cast crowns. *Braz Dent J* 2004;15:127-32.
  42. Jahangiri L, Wahlers C, Hittelman E, Matheson P. Assessment of sensitivity and specificity of clinical evaluation of cast restoration marginal accuracy compared to stereomicroscopy. *J Prosthet Dent* 2005;93:138-42.
  43. Ucar Y, Akova T, Akyil MS, Brantley WA. Internal fit evaluation of crowns prepared using a new dental crown fabrication technique: Laser-sintered Co-Cr crowns. *J Prosthet Dent* 2009;102:253-9.