Marginal Accuracy and Internal Fit of Dental Copings Fabricated by Modern Additive and Subtractive Digital Technologies

Keywords

Casting
Direct Metal Laser Sintering
Internal Fit
Marginal Accuracy
Scanning Electron Microscope

Authors

Dr Neha Nelson ‡
(B.D.S (Bachelor of Dental Surgery), M.D.S. (Master of Dental Surgery))

Dr Jyothi K S ‡
(B.D.S (Bachelor of Dental Surgery), M.D.S. (Master of Dental Surgery))

Dr Kiran Sunny ‡
(B.D.S (Bachelor of Dental Surgery), Postgraduate student))

Address for Correspondence

Dr Jyothi K S ‡
Email: drjyothiksms@rediffmail.com

‡ *Coorg Institute of Dental Sciences, Virajpet, affiliated to Rajiv Gandhi University of Health Sciences, Bangalore*

Received: 05.09.2015
Accepted: 28.10.2016
doi: 10.1922/EJPRD_01611Nelson06

ABSTRACT

The margins of copings for crowns and retainers of fixed partial dentures affect the progress of microleakage and dental caries. Failures occur due to altered fit which is also influenced by the method of fabrication. An in-vitro study was conducted to determine among the cast base metal, copy milled zirconia, computer aided designing computer aided machining/manufacturing zirconia and direct metal laser sintered copings which showed best marginal accuracy and internal fit. Forty extracted maxillary premolars were mounted on an acrylic model and reduced occlusally using a milling machine up to a final tooth height of 4 mm from the cementoenamel junction. Axial reduction was accomplished on a surveyor and a chamfer finish line was given. The impressions and dies were made for fabrication of copings which were luted on the prepared teeth under standardized loading, embedded in self-cure acrylic resin, sectioned and observed using scanning electron microscope for internal gap and marginal accuracy. The copings fabricated using direct metal laser sintering technique exhibited best marginal accuracy and internal fit. Comparison of mean between the four groups by ANOVA and post-hoc Tukey HSD tests showed a statistically significant difference between all the groups ($p<0.05$). It was concluded that the copings fabricated using direct metal laser sintering technique exhibited best marginal accuracy and internal fit. Additive digital technologies such as direct metal laser sintering could be cost-effective for the clinician, minimize failures related to fit and increase longevity of teeth and prostheses.

INTRODUCTION

Fixed dental restorations aim to restore function and esthetics of lost intraoral structures without jeopardizing the oral or general health of patient. An ill-fitting restoration is potentially harmful for abutment and supporting periodontium.[1-5] The success of a complete coverage crown is dependent on the marginal adaptation, which can be influenced by finish line configuration, repeated ceramic firing cycles, and luting agents. An excellent marginal adaptation of metal ceramic and all-ceramic restorations minimizes plaque accumulation and reduces the chance for recurrent caries and periodontal disease.[6-8] Marginal discrepancies expose the luting material to the oral environment, thus leading to cement dissolution, microleakage, caries and failure of the prosthesis.[9] The internal gap is the perpendicular distance between the metal substructure and the abutment teeth that presents at the occlusal/incisal and axial surfaces. The values of mar-

ejprd.org - Published by Dennis Barber Journals

ginal gap/internal fit range from 50 to 200 μm in the literature, but 120 μm after cementation is considered clinically acceptable.[9] The long-established casting procedures i.e., lost wax (LW) technique requires the fabrication of wax patterns which involve exhaustive time consuming methods. Removal of a wax pattern from a die with a shoulder finish line causes an average of 35 μm opening of the margin before investing due to inherent limitations such as thermal sensitivity, elastic memory and a high coefficient of thermal expansion.[9] The high melting range and oxidation of base metal alloys during casting increases the technique sensitivity of such fabrication systems.[9-15]

Advances in dental ceramics such as zirconium oxide cores, use of computer aided designing and computer aided machining/manufacturing (CAD/CAM) and copy milling techniques have created new possibilities for all ceramic restorations. CAD/CAM fabrication of zirconia (Zr) copings involves the operation of a 3D design on the monitor, followed by mechanized production by a computer-controlled milling machine. Despite this, potential errors in the scanning process, software design, milling, and shrinkage effects could lead to poor restoration fit.[16-18] Copy-milling of zirconia ceramic is a low cost alternative to CAD/CAM fabrication. In contrast to CAD/CAM fabrication, where prostheses are designed virtually, copy-milling requires a resin pattern of the restoration. This is then scanned to proceed with copy-milling of the definitive restoration from pre-sintered zirconia ceramic. Copy-milling of zirconia ceramic can produce anatomically contoured restorations without additional steps of ceramic veneering by using available external stains.[19] Direct metal laser sintering (DMLS) system is an additive metal fabrication technology, based on information received from three dimensional CAD, in which metal powder is shot selectively using a data file and fused with a laser to coat approximately a 20 to 60 μm thick layer with each shooting to complete a metal structure. Advantages include easy fabrication of complicated contours, operation of an automatic system, with quick results due to elimination of procedures like wax pattern fabrication, investing, burning, and casting works.[20] Although vast literature data exists regarding the fit of copings fabricated by different methods, commonly, metal dies with multiple impressions of the same have been used. However, in this study extracted teeth have been used which bring more relevance to the results obtained. Also there is a paucity of literature that compares all the four techniques under a single study design.

Therefore the aims and objectives of this *in-vitro* study were

To evaluate, compare and determine among nickel chromium (Ni-Cr) cast coping, copy milled zirconia, CAD-CAM zirconia and cobalt chromium (Co-Cr) DMLS copings which exhibited best marginal accuracy and internal fit.

MATERIALS AND METHODS

For this *in-vitro* study, healthy maxillary first premolars extracted for orthodontic purpose were selected and carious, restored, root canal treated and fractured teeth were excluded from this study. A rubber based silicone mold was used to make autopolymerizing polymethyl methacrylate resin models (DPI RR Cold cure). Five holes were drilled in each of the eight acrylic models to contain five extracted teeth. Each tooth was marked at its cementoenamel junction in order to determine up to where the tooth would be submerged. Custom perforated trays were fabricated with three stops to ensure uniform seating on each acrylic model. Each tooth was marked at buccal, lingual, mesial and distal surfaces, 4 mm above the cementoenamel junction as measured and determined with a caliper. The model was stabilized in milling machine (Paraskop® M) and with the diamond disk (#911H-180, Dentsply) attached to handpiece (KaVo K9, KaVo Dental, GmbH) secured in the vertical arm of the milling machine uniform occlusal reduction of all teeth was done. A clamp was fabricated to hold the handpiece securely to the vertical arm of the surveyor (Marathon 103- Saeyang Microtech). The clamp had two arms. One arm held the vertical arm of the surveyor and the other arm held the high-speed handpiece (Pana-Max2 KV). The clamp was fabricated in such a way that the long axis of the medium coarse torpedo diamond (ISO 288/012, Mani® Dia-Burs®, Mani, Inc.) was parallel to the long axis of the mounted teeth. The acrylic blocks were held firmly in a surveyor base. Axial reduction was accomplished to a depth of 0.6 mm (i.e. torpedo diamond penetrated half of its diameter into the tooth). To control the depth of reduction a silicone index was fabricated and sectioned prior to tooth preparation and also verified after each axial surface reduction. An axial length of approximately 4 mm was maintained for each sample. Single step putty wash impressions were made using polyvinyl siloxane impression materials (Express™ VPS impression material) and poured with Type IV dental stone (Kalrock).

FABRICATION OF COPINGS

For the LW technique (group C), ten dies prepared by Pindex System (Woody-SR 200-Drill Plaster Machine) were coated with die spacer (#19540600 Pico-Fit Silver and #19540500 Pico-Fit Gold, Renfert), and pattern was fabricated by using inlay wax (Type II Hindustan inlay wax) in a wax pot (LabMuse) by dipping method. A single pattern was first cast, finished and polished to obtain a coping thickness of 0.7±0.1 mm. This coping was then invested in a simple silicone matrix, removed and the space was filled with wax to obtain 10 patterns. The patterns were sprued (Sprue Wax, 10 gauge, MP Sai Enterprise Pvt. Ltd) and invested using phosphate bonded investment material (Bellavest® SH). The investment was heated in a furnace (IN FIRE SR 750 Cylinder furnace) to 900ºC for 30 minutes. Casting was done with a Ni-Cr alloy (Bellabond Plus) in a casting machine (Fornax® T). The castings were removed and the samples were trimmed with a handpiece (KaVo K9, KaVo Dental GmbH) and aluminum oxide stones (Lab series Coral, Shofu, Inc), finished with silicone carbide stones (Dura-Green Stone, Shofu, Inc) and air abraded with 250 μm aluminium oxide (Korox® 250) to obtain copings of uniform thickness of 0.6 mm. The second set of ten impressions was poured, the dies were scanned and the copings were designed using 3SHAPE Dental System™. After designing, copings were fabricated by additively layering Co-Cr powder (EOS CobaltChrome SP2) and laser sintered (EOSINT M 270 system). The finished DMLS copings (group A) were fully sintered; copings were retrieved and checked on the dies for the adequate fit. The third set of ten impressions was poured with scannable die material (Optic™ Scanning Stone). The dies were sectioned from the cast and scanned in CAD-CAM scanner (Dental Wings™). The scanner then gave command to the CAM machine (Computer Numerical Control milling machine- vhf CAM 450 Classic) to mill the zirconia copings from the pre-sintered zirconia blanks. The retrieved zirconia copings (group B) were sintered (Tizian Furnace HTS Speed sintering furnace) and evaluated for fit on the dies. For fabrication of zirconia copy milled copings (group D) on the fourth set of dies, resin patterns were made using light cure (Ceramill UV Lamp, Amann Girrbach) modeling gel (Ceramill gel, AmannGirrbach), patterns were retrieved and mounted on the mounting template, fixed on to the ceramill base and copy milling (Ceramill® motion 2) was completed. The pre-sintered zirconia (Ceramill® zirconia) copings were sintered (Ceramill® Therm 3, Amann Girrbach) for 8 hours, placed on the dies and checked for fit. For groups A, B and D the software was set to provide a uniform thickness of 0.6 mm throughout the coping. The cement space was set to 40 μm up to 1 mm from the margin. Also, post fabrication adjustments of copings were not required for these groups because the CAD systems ensured the uniformity of thickness.

TESTING OF SAMPLES

Forty copings obtained were cemented to the respective prepared extracted teeth using resin modified GIC luting cement (RelyX™ Luting 2) under uniform load of 5 kg. The samples were embedded in self-cure acrylic resin, cross-sectioned along the long axis using a diamond disk, then subjected for scanning and image analysis using scanning electron microscope (SEM) (Evo® ls 15). Electrons were bombarded with energy levels of up to 15 kV and specimens were observed in magnifications of ×1000. The internal gap and marginal discrepancies were measured with the software ScanPro. For measurement and analysis, points A and B were considered at the level axio-occlusal line angle, C and D were considered on buccoaxial and linguoaxial line angle to measure the internal fit. Points E and F were considered at the level of finish lines to measure the marginal discrepancy. The internal and marginal gap was measured from the tooth to the restoration and it included the cement thickness. One way analysis of variance (ANOVA) was used to compare means between the groups. Post-hoc Tukey Honestly Significant Difference (HSD) tests was done for multiple mean comparisons using software R version 3.1.1. and a P-value of <0.05 was considered statistically significant.

RESULTS

Each sample was observed using SEM *(Figure 1)* and the difference in mean internal gap for the four groups was found to be statistically significant by one-way ANOVA with a P-value of 0.0001 *(Table 1)*. Post-hoc Tukey HSD test done to know which group pair showed significant difference showed that there was significant difference (P<0.05) between all the pairs of groups *(Table 2)*. The marginal gap of the test samples were determined by observing each sample using SEM *(Figure 2)*. The difference in mean marginal gap for the four groups was found to be statistically significant by one-way ANOVA with a P-value of 0.0001 *(Table 3)*. Post-hoc Tukey HSD test done to know which group pair showed significant difference showed that, there was significant difference (P<0.05) between all the pairs of groups *(Table 4)*.

Table 1. One-way ANOVA for internal gap

Groups	Mean (SD) (μm)	F value	P-value
A	37.0 (4.5)	87.04	0.0001 S
B	79.8 (3.9)		
C	143.3 (29.3)		
D	101.6 (2.4)		

Group A = DMLS copings, Group B = Zr CAD-CAM copings, Group C = Cast Ni-Cr copings and Group D = Zr Copy Milled copings. SD = Standard deviation of the Mean. S = statistically significant.

Table 2. Post-hoc Tukey HSD test for internal gap

Groups	A	B	C
B	0.0001* S		
C	0.0001* S	0.0001* S	
D	0.0001* S	0.0126* S	0.0001* S

Group A = DMLS copings, Group B = Zr CAD-CAM copings, Group C = Cast Ni-Cr copings and Group D = Zr Copy Milled copings. * = P-value. S = statistically significant.

Table 3. One-way ANOVA for marginal gap

Groups	Mean (SD) (μm)	F value	P-value
A	59.5 (2.8)	161.1	0.0001 S
B	118.4 (4.7)		
C	199.7 (27.5)		
D	139.9 (6.7)		

Group A = DMLS copings, Group B = Zr CAD-CAM copings, Group C = Cast Ni-Cr copings and Group D = Zr Copy Milled copings. SD = Standard deviation of the Mean. S = statistically significant.

Table 4. Post-hoc Tukey HSD test for marginal gap

Groups	A	B	C
B	0.0001* S		
C	0.0001* S	0.0001* S	
D	0.0001* S	0.0097* S	0.0001* S

Group A = DMLS copings, Group B = Zr CAD-CAM copings, Group C = Cast Ni-Cr copings and Group D = Zr Copy Milled copings. * = P-value. S = statistically significant.

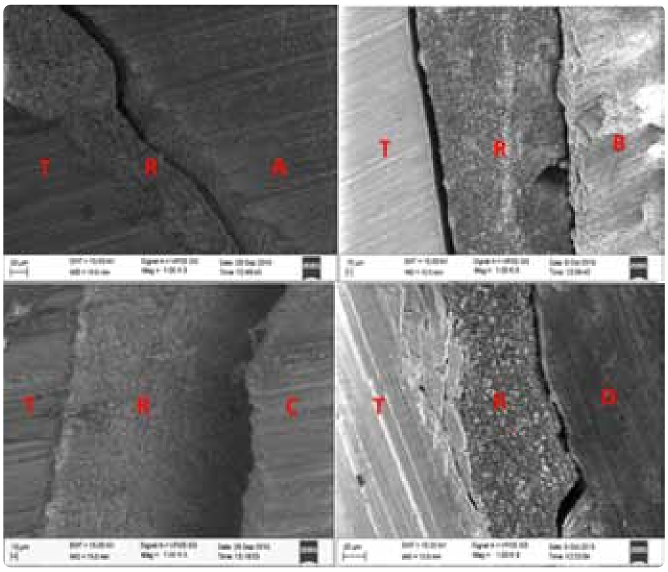

Figure 1: Representative SEM images showing internal gap for a specimen of Group A = DMLS copings, Group B = Zr CAD-CAM copings, Group C = Cast Ni-Cr copings and Group D = Zr Copy Milled copings. T = tooth, R = resin cement.

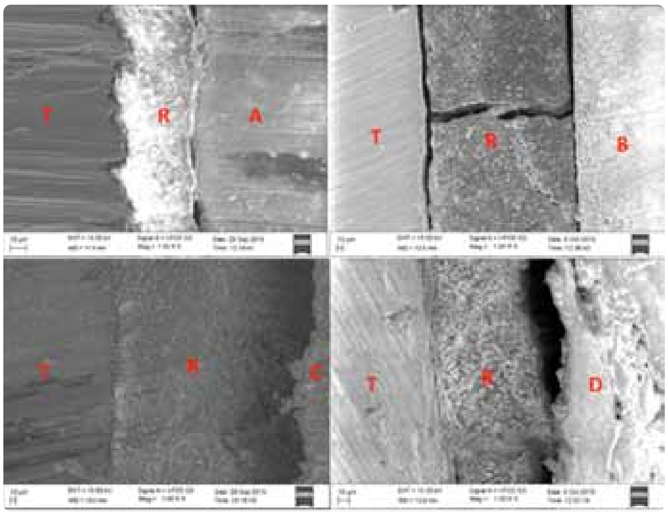

Figure 2: Representative SEM images showing marginal gap for a specimen of Group A = DMLS copings, Group B = Zr CAD-CAM copings, Group C = Cast Ni-Cr copings and Group D = Zr Copy Milled copings. T = tooth, R = resin cement.

DISCUSSION

The current study assessed and compared the internal fit and marginal accuracy of copings fabricated by four methods. Lofstrom and Barakat found that, as the enamel was thin near the margins of the restorations, microscopic cracks were present in the enamel of the teeth with complete crowns.[21] In the present study, the use of extracted teeth, far from ideal and uniform dies, could explain the larger values obtained in comparison with other *in vitro* studies.[24] During fabrication of metal copings by the LW method, making impressions cause discomfort for patients and inaccurate marginal fit may result from contraction of set impression material, warping of wax patterns, or irregularities in the cast metal.[20] Quante K *et al.*, observed that the alteration in marginal and internal fit was due to different alloy composition and coefficient of thermal expansion.[8] The solidification shrinkage of base metal alloys is high, which represents a challenge to obtain acceptable-fitting base metal casting. Also the fabrication of crowns using conventional technique may have numerous errors by the operator from making of the wax pattern to casting of the alloy.[15]

The DMLS technology fuses metal powder into a solid part by melting it locally using a focused Yb-fiber laser beam. Hence the copings were fabricated layer by layer, where each layer was sintered by laser before the next layer was applied. This could be the reason for the least marginal gap and internal gap in the copings made by DMLS system. Advantages of the DMLS system included easy fabrication of complicated shapes, operation of a computerized system which minimized working time due to elimination of procedures such as fabricating of wax patterns, investing, burning, and casting works. While the LW method wasted metal in spruing, the DMLS system reduced metal waste by selectively shooting the required amount.[20] Past studies have shown there is no significant difference between LW and DMLS techniques of fabrication.[8,15] However a study by Kim KB *et al.*, showed marginal fit of DMLS system was inferior to those of lost wax group.[20] In general, CAD/CAM fabrication has been shown to result in more precise restorations than conventional fabrication methods,[19,25] which is in agreement with the current study. Most of the CAD/CAM systems operate based on an optical scan data that allow internal gap distances to be adjusted directly through the luting space setting on the computer prior to milling of copings for crowns.[23] The CAD/CAM system can virtually design the coping on the scanned die as done in the present study, or based on a double scan technique in which both the pattern and die are scanned. Information regarding the die and wax is digitized by scanning, and the data are transmitted to a decentralized production center. The external contour and finish line are milled, and final sintering is performed in the manufacturing center.[24] According to Kunii J *et al.* the excellent fit obtained was attributed to the laser scanning system, which accurately measured the margin line of the stone model and the shrinkage adjustment of milled zirconia blanks during CAD process was satisfactory.[22]

In the present study copings fabricated by CAD/CAM process exhibited superior marginal and internal fit compared to copy milling procedures. The difference may originate from the die spacer thickness and the reference used for the coping manufacturing. The CAD/CAM system manufactures the coping based on a die, while the Ceramill system manufactures the coping on the basis of the intaglio of the epoxy resin pattern. Furthermore, the intaglio of Ceramill coping is manufactured by milling, while the coping intaglio is not milled for CAD/CAM system.[24] However, the fit of CAD/CAM copings were inferior when compared to copings fabricated by DMLS system due to possible shrinkage. Another source of error is the wear of milling instruments over time. During the milling procedure diamond grains are dulled or lost, changing the dimensions of the instruments and reducing milling precision.[16] Pre-sintered zirconia blanks which were used for fabrication of copings for both CAD/CAM and copy milling system, are advantageous for easy machining without damaging tools and causing chip formation. However, owing to the large sintering shrinkage that occurs during post-machining heat treatments, it is necessary to compensate these changes in framework dimensions.[22] The difference between the copings fabricated by DMLS system and by CAD/CAM and copy milling systems could be attributed to the anisotropic shrinkage of zirconia blanks subjected to post-machining sintering.[22]

There has been substantial disagreement about the acceptable marginal gap for fixed dental prostheses. Ucar Y *et al.*, stated that a gap of 100 µm is tolerable, and that marginal discrepancies of less than 80 µm are difficult to detect under clinical conditions.[15] Bindl and Mormann evaluated both the marginal and internal gap width of all-ceramic CAD/CAM copings on chamfer preparations, and reported marginal gap width varying from 17 µm to 43 µm and internal gap width from 81 µm to 136 µm.[14] Past literature also suggests values of 100 µm for marginal misfit as good and values of 200–300 µm as acceptable.[9] Therefore, the marginal accuracies measured in the present study, could be rated as good for DMLS group and CAD-CAM group, and acceptable for copy milling and conventional group. Also, natural human teeth were used in the present study for marginal and internal fit evaluation of copings to provide clinical significance with respect to finish line designs and cementation methods. There are some limitations in this study. Sizeable differences within each group between marginal and internal gap could be attributed to differences in the techniques, limitations of scanning systems which result in rounded edges and internal accuracies[9] and also the measured areas may not specifically represent the precision of fit of the whole specimen. Though the copings were standardized in fabrication, the natural tooth posed a challenge for accurate preparation. This was due to partial dehydration of tooth specimens, possible enamel cracking and chipping at the margins similar to clinical situations. Also, the operator skill to handle the cement accurately each time may be influenced by ambient temperature and experience. Marginal fit and the internal fit of copings before cementation and fatigue testing by thermal cycling which is responsible for long term success of marginal fit of crowns were not determined. Also, all copings were produced and tested in laboratories, which may not replicate clinical use.

CONCLUSIONS

Within the limitations of this *in-vitro* study, the following conclusions were drawn:

1. Co-Cr copings fabricated using DMLS technique exhibited best marginal accuracy followed by zirconia CAD/CAM coping, zirconia copy milled copings and Cast Ni-Cr copings.
2. Among all the four copings, DMLS Co-Cr copings exhibited best internal fit. Zirconia CAD/CAM copings showed slighter internal fit followed by zirconia copy milled copings. Cast Ni-Cr exhibited least internal fit.

MANUFACTURER DETAILS

- DPI RR Cold cure; Dental Products of India, Mumbai, India
- Paraskop® M, BEGO, GmbH, Germany
- #911H-180, DENTSPLY, Canada Ltd.
- KaVo K9, KaVo Dental, GmbH, Biberach
- Marathon 103- Saeyang Microtech, 348, Seongseo-ro, Dalseo-gu, Daegu, Korea
- Pana-max2 KV, Nakanishi Inc. Japan
- ISO 288/012, Mani® Dia-Burs®, Mani, Inc. Tochigi, Japan
- Express™ VPS impression material, 3M ESPE, India
- Kalrock, Kalabhai Karson Private Limited, Mumbai, India
- Woody-SR 200-Drill Plaster Machine, Sirio Dental Division, Italy
- #19540600 Pico-Fit Silver, Renfert, GmbH, Germany
- #19540500 Pico-Fit Gold, Renfert, GmbH, Germany
- Type II Hindustan inlay wax, Hindustan Dental Products, Hyderabad, India
- LabMuse, Russia
- Sprue Wax, 10 gauge, MP Sai Enterprise Private Limited, Thane, Maharashtra
- Bellavest® SH, BEGO, GmbH, Germany
- IN FIRE SR 750 Cylinder furnace, Sirio Dental Division, Italy
- Bellabond Plus, BEGO, Germany
- Fornax® T, BEGO, GmbH, Germany
- Lab series Coral, Shofu, Inc. Kyoto, Japan
- Dura-Green Stone, Shofu, Inc. Kyoto, Japan
- Korox® 250, BEGO, GmbH, Germany
- EOS CobaltChrome SP2, EOS Gmbh, Germany
- EOSINT M 270 system; EOS Gmbh, Germany
- Optic™ Scanning Stone, ETI Empire Direct, Anaheim, USA
- Dental Wings™, GmbH, Dusseldorf, Germany

- Computer Numerical Control (CNC) milling machine- vhf CAM 450 Classic, vhf camfacture AG, Germany
- Tizian Furnace HTS Speed sintering furnace, Schutz Dental GmbH, Germany
- Ceramill UV Lamp, Amann Girrbach, GmbH, Germany
- Ceramill gel, Amann Girrbach, AG, USA
- Ceramill® zirconia, Amann Girrbach, GmbH, Germany
- Ceramill® motion 2, Amann Girrbach, GmbH, Germany
- Ceramill® Therm 3, Amann Girrbach, AG, USA
- RelyX™ Luting 2, 3M ESPE, India
- Evo® ls 15, Zeiss, Germany

REFERENCES

1. Nawafleh, N.A., Mack, F., Evans, J., Mackay, J. and Hatamleh, M.M. Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: A literature review. *J. Prosthodont.*, 2013; **22**: 419-428.
2. Weaver, J.D., Johnson, G.H. and Bales, D.J. Marginal adaptation of castable ceramic crowns. *J. Prosthet. Dent.*, 1991; **66**: 747-753.
3. Nakamura, T., Dei, N., Kojima, T. and Wakabayashi, K. Marginal and internal fit of Cerec 3 CAD/CAM all-ceramic crowns. *Int. J. Prosthodont.*, 2003; **16**: 244-248.
4. Gonzalo, E., Suárez, M.J., Serrano, B. and Lozano, J.F.L. Marginal fit of zirconia posterior fixed partial dentures. *Int. J. Prosthodont.*, 2008; **21**: 398-399.
5. Beuer, F., Neumeier, P. and Naumann, M. Marginal fit of 14-unit zirconia fixed dental prosthesis retainers. *J. Oral. Rehabil.*, 2009; **36**: 142-149.
6. Euan, R., Figueras-Alvarez, O., Cabratosa-Termes, J., Brufau-de Barbera, M. and Gomes-Azevedo, S. Comparison of the marginal adaptation of zirconium dioxide crowns in preparations with two different finish lines. *J. Prosthodont.*, 2012; **21**: 291-295.
7. Limkangwalmongkol, P., Chiche, G.J. and Blatz, M.B. Precision of fit of two margin designs for metal-ceramic crowns. *J. Prosthodont.*, 2007; **16**: 233-237.
8. Quante, K., Ludwig, K. and Kern, M. Marginal and internal fit of metal-ceramic crowns fabricated with a new laser melting technology. *Dent. Mater.*, 2008; **24**: 1311-1315.
9. Vojdani, M., Torabi, K., Farjood, E. and Khaledi, A.A.R. Comparison the marginal and internal fit of metal copings cast from wax patterns fabricated by CAD/CAM and conventional wax up techniques. *J. Dent. Shiraz. Univ. Med. Sci.*, 2013; **14**: 118-129.
10. Belser, U.C., MacEntee, M.I. and Richter, W.A. Fit of three porcelain-fused-to metal marginal designs in vivo: a scanning electron microscopic study. *J. Prosthet. Dent.*, 1985; **53**: 24-29.
11. Holmes, J.R., Bayne, S.C., Holland, G.A. and Sulik, W.D. Considerations in measurement of marginal fit. *J. Prosthet. Dent.*, 1989; **62**: 405-408.
12. Valderrama, S., Van Roekel, N., Andersson, M., Goodacre, C.J. and Munoz, C.A. A comparison of the marginal and internal adaptation of titanium and gold-platinum-palladium metal ceramic crowns. *Int. J. Prosthodont.*, 1995; **8**: 29-37.
13. Kokubo, Y., Ohkubo, C., Tsumita, M., Miyashita, A., Vult von Steyern, P. and Fukushima, S. Clinical marginal and internal gaps of Procera All-Ceram crowns. *J. Oral. Rehabil.*, 2005; **32**: 526-530.
14. Bindl, A. and Mormann, W.H. Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations. *J. Oral. Rehabil.*, 2005; **32**: 441-447.
15. Ucar, Y., Akova, T., Akyil, M.S. and Brantley, W.A. Internal fit evaluation of crowns prepared using a new dental crown fabrication technique: Laser sintered Co-Cr crowns. *J. Prosthet. Dent.*, 2009; **102**: 253-259.
16. TorabiArdekani, K., Ahangari, A.H. and Farahi, L. Marginal and internal fit of CAD/CAM and slip-cast made zirconia copings. J. *Dent. Res. Dent. Clin. Dent. Prospect.*, 2012; **6**: 42-48.
17. Karatasli, O., Kursoglu, P., Capa, N. and Kazazoglu, E. Comparison of the marginal fit of different coping materials and designs produced by computer aided manufacturing systems. *Dent. Mater. J.*, 2011; **30**: 97-102.
18. Rinke, S., Fornefett, D., Gersdorff, N., Lange, K. and Roediger, M. Multifactorial analysis of the impact of different manufacturing processes on the marginal fit of zirconia copings. *Dent. Mater. J.*, 2012; **31**: 601-609.
19. Karl, M., Graef, F., Wichmann, M. and Krafft, T. Passivity of fit of CAD/CAM and copy milled frameworks, and anatomically contoured, zirconia ceramic, implant supported fixed prosthesis. *J. Prosthet. Dent.*, 2012; **107**: 232-238.
20. Kim, K.B., Kim, W.C., Kim, H.Y. and Kim, J.H. An evaluation of marginal fit of three-unit fixed dental prostheses fabricated by direct metal laser sintering system. *Dent. Mater.*, 2013; **29**: e91-96.
21. Lofstrom, L.H. and Barakat, M.M. Scanning electron microscopic evaluation of clinically cemented cast gold restorations. *J. Prosthet. Dent.*, 1989; **61**: 664-669.
22. Kunii, J., Hotta, Y., Tamaki, Y., *et al.* Effect of sintering on the marginal and internal fit of CAD/CAM- fabricated zirconia frameworks. *Dent. Mater. J.*, 2007; **26**: 820-826.
23. Baig, M.R., Tan, K.B. and Nicholls, J.I. Evaluation of the marginal fit of a zirconia ceramic computer-aided machined (CAM) crown system. *J. Prosthet. Dent.*, 2010; **104**: 216-227.
24. Grenade, C., Mainjot, A. and Vanheusden, A. Fit of single tooth zirconia copings comparison between various manufacturing processes. *J. Prosthet. Dent.*, 2011; **105**: 249-255.
25. Biscaro, L., Bonfiglioli, R., Soattin, M. and Vigolo, P. An in vivo evaluation of fit of zirconium-oxide based ceramic single crowns, generated with two CAD/CAM systems, in comparison to metal ceramic single crowns. *J. Prosthodont.*, 2013; **22**: 36-41.