Evaluation of the Internal and Marginal Discrepancies of Co-Cr Metal Copings Prepared via CAD/CAM and Conventional Casting

Keywords

Computer-Aided Design
Alloys
Computer-Aided Manufacture
Marginal Discrepancy
Internal Discrepancy

Authors

Dr. Suleyman Cagatay Dayan[§]
(DDS, PhD)

Dr. Burim Kiseri[^]
(DDS, PhD)

Dr. Burc Gencel[§]
(DDS, PhD)

Dr. Aysegul Kurt*
(DDS, PhD)

Address for Correspondence

Dr. Aysegul Kurt*

Email: kurt.aysegul@gmail.com

* *Trakya University, Faculty of Dentistry, Department of Prosthodontics, Edirne, Turkey*

§ *Program of Dental Technicians, Istanbul University, Istanbul, Turkey*

^ *Department of Prosthodontics, UBT College, Faculty of Dentistry, Pristina, Kosovo*

Received: 15.09.2018
Accepted: 05.12.2018

doi: 10.1922/EJPRD_01865Dayan06

ABSTRACT

The aim of this study was to assess the internal and marginal discrepancies of chromium-cobalt (Co/Cr) copings fabricated using different techniques. A typodont molar tooth was prepared and replicated in die stone and scanned. Forty Co-Cr alloy copings were produced using four different production techniques: conventional casting (C-group), direct metal laser sintering (DMLS-group), micro-stereolithography/casting combination (µSLA-group), and computer-aided milling (M-group) (n = 10). The internal and marginal discrepancies at various reference points were determined via digital microscopy. Analysis of variance (ANOVA) and Tukey's multiple comparisons tests were used for statistical analysis (p=0.05). The marginal and cervical discrepancies of the C-group were similar to those of the M-group (p>0.05) and better than those of the µSLA-group (p<0.05). The marginal and internal discrepancies of all groups were within clinically acceptable limits, but further improvements in the µSLA and DMLS techniques may be required prior to clinical implementation.

INTRODUCTION

Conventional metal ceramic restorations have been used to prepare fixed prostheses for several decades and afford satisfactory clinical outcomes;[1,2] thus, they remain the primary treatment choice in most cases. Basically, a ceramic material is fused to a metal substructure prepared either via casting or digitally enhanced metal-ceramic restoration.

The basic procedure for conventional casting is as follows: the invested wax pattern of the substructure is burnt out to create a heat-resistant chamber receiving a melted alloy to complete the casting.[3] This method is accurate only when high-quality hardware and carefully matched materials are available for use by experienced operators; furthermore, this is a time-consuming multistep procedure.[4] Advances in digital technology, including computer-aided design/computer-aided manufacturing (CAD/CAM), have revolutionised dental laboratories. CAD affords rapid high-precision modelling, simple and rapid design modification, and repeated use of the same design.[5,6] CAM involves two production methods: subtractive and additive. Subtractive CAM requires precise milling of blocks of material.[7] Metal copings may be made via subtractive manufacturing using soft metal blocks; this method aims to deal with stress formation in milling equipment during hard-metal block milling.[8] However, both subtractive methods produce significant amounts of excess material.[9] Alternatively, additive manufacturing transforms a 3-D digital design into physical form by creating layers of material.[7] Micro-stereolithography (μSLA) is an additive method using layered wax or resin to produce the desired pattern. In this method, the traditional lost-wax step remains and is used to obtain metal copings from the pattern.[10,11] Another additive method, direct metal-laser sintering (DMLS), has been introduced as a new metal-coping technique. Metal powder is directly irradiated with a laser to obtain layers of solidified material; the metal coping is thus completely formed.[12]

The success of dental restoration depends on the cohesive properties and health of residual tissues, which are influenced by the coping technique employed.[7,13-15] A poor internal fit may trigger loss of retention[13,14] and inappropriate marginal adaptation causes caries of exposed dentin, inflammation of gingival tissues, and periodontal disease.[13,15] A marginal gap of 25–200 μm is clinically acceptable,[13,16-19] but there is no standardized internal fit criterion.[20,21] While different methods have been used to compare marginal and internal fits,[11,12,17,22-27] no method is accepted as the standard.[28] Although all values lay within clinically acceptable limits, some studies reported lower marginal-internal discrepancies when conventional coping rather than CAM techniques were employed;[17,22,24] other studies using CAM to fabricate metal copings reported better marginal/internal discrepancies than those of conventional coping techniques.[24,25,29] The optimal production technique for dental restoration remains unclear.

This study aimed to compare the internal and marginal discrepancies of chromium-cobalt (Co-Cr) copings fabricated using four different techniques: 1. conventional casting (C); 2. direct metal laser sintering (DMLS); 3. a micro-stereolithography/casting combination (μSLA); and, 4. computer-aided milling (M). The null hypothesis was that no significant difference in the internal and marginal discrepancies of the Co-Cr copings would be evident among the four production methods.

MATERIALS AND METHODS

The first molar mandibular tooth of a typodont (AG-3; Frasaco, Tettnang, Germany) was prepared using a dental milling machine (Bredent GmbH & Co. KG, Bremen, Germany), adhering to the preparation guidelines for metal ceramic restorations.[30] A taper of 6° and a circumferential chamfer of 1.0 mm were created using a 3° round-ended burr (Bredent GmbH & Co. KG). The occlusal schema was reduced by 1.5 mm using a cutback burr (Jota AG, Rüthi, Switzerland), Sweden) and other routinely used burrs (Jota AG). Sharp edges were smoothed with fine-grit burrs (Jota AG) and the final impression surfaces were polished with a fibre brush disc (Kettenbach GmbH & Co. KG, Eschenburg, Germany) (*Figure 1*). Forty impressions were made with the aid of a vinyl polyether silicone impression material (EXAlence 370 monophase; GC America Inc., Alsip, IL, USA) and poured into type IV dental stone (Fujirock OptiXscan; GC, Leuven, Belgium), yielding 40 working models that were assigned random numbers using an Excel random number generator (Microsoft Corp., Redmond, WA, USA); the models were divided into four groups (*Table 1*) according to the production method (n = 10/group).

Figure 1: Typodont master model (A taper of 6° and a circumferential chamfer of 1.0 mm were created on a maxillary right first molar).

The C group's dyes were painted with a die spacer (Aqua Fit; Renfert GmbH, Hilzingen, Germany) to 0.5 mm from the cervical margin, affording a 30-μm gap for the luting cement. Casting wax 0.5-mm-thick (Dipping Wax; Bego, Bremen, Germany) was then placed over the dye.[8,11] Wax thickness was controlled using a dental calliper (Calipretto S; Renfert GmbH, Hilzingen, Germany). Standard sprues were attached and a surface-wetting agent (Aurofilm; Bego) was applied to the waxed patterns

Table 1. Testing Groups

Technique	Alloy Manufacturer	Alloy Composition
Conventional Casting Technique	Bego Wirobond C, Bremen, Germany	Co:63.3, Cr:24.8, W:5.3, Mo:5.1, Si,Fe,Ce:<1.0
Direct Metal Laser Sintering	Dentaurum Remanium star CL, Pforzheim, Germany	Co: 60,5%,Cr: 28 %,W: 9%,Si: 1,5%,Other elements <1%: Mn, N,Nb, Fe
Micro-Stereolithograph / Casting Combination	Bego Wirobond C, Bremen, Germany	Co:63.3, Cr:24.8, W:5.3, Mo:5.1, Si,Fe,Ce:<1.0
Cad-Cam Milling	Amann Girrbach Ceramill sintron system, Pforzheim, Germany	Co: 66,Cr: 28,Mo:5, Si: < 1,Fe: < 1,Mn: <1,Further elements (C) <0.1

before placement in phosphate-based investment material (Bellavest-SH; Bego). After setting of the investment material, the flask was placed in a burn-out furnace (Midtherm 200 MP; Bego) and heated from room temperature to 250°C at 5°C/min, and then to 900°C at 7°C/min. To ensure complete burn-out, the flask was held at 900°C for 60 min. Casting of the Co-Cr alloy (Wirobond C; Bego) was performed in an automatic induction vacuum pressure casting machine (Nautilus CC Plus; Bego). The investment and sprues were removed via low-speed carbide disk abrasion.

Thirty working models of the other three groups were scanned (D 700 3D Scanner; 3-Shape Dental System, Copenhagen, Denmark) using dedicated software (3-Shape CAD Design Software; 3-Shape A/S) to generate stereolithography (STL) files. The copings of the DMLS and μSLA groups were 0.5-mm in thickness over a simulated 30μm cement gap 0.5mm distant from the cervical margins, similar to the wax patterns of the C group. Ten STL files were sent for laser-sintering (Concept Laser GmbH, Lichtenfels, Germany) to obtain DMLS copings. A carbon-free, laser-melting Co-Cr alloy powder that did not require oxide firing after sintering was used (Remanium Star CL; Dentaurum, Pforzheim, Germany). The layer density ranged from 2–10 cm^3/h depending on the material. The thickness of the sintered layer was 0.02–0.08 mm. Another set of STL files was processed on a 3D-printer (Solidscape D76+; Solidscape, Merrimack, NH, USA), to yield printed wax copings for the μSLA group. The printed copings were subjected to procedures identical to those for the wax patterns of the C group.

The copings for the M group were created using the virtual design technique described above. Then, the copings were fabricated using a computer-aided milling unit (Ceramill Sintron system; Amann Girrbach, Pforzheim, Germany). Milled copings from Co-Cr blocks were subjected to sintering at 1,300°C for 1 h in a Sintron (Ceramill Argotherm).

All procedures were performed by a single experienced, certified dental technician following the manufacturers' instructions. All copings were cleaned with 125-μm Al_2O_3 particles delivered with an airborne particle abrasion unit (Basic Master; Renfert, Hilzingen, Germany) at a pressure of 0.2 MPa; the nozzle was 5 cm distant from the copings.[14]

To evaluate the marginal discrepancies between copings and the master models, we used the direct-view technique.[1] Twenty-four spots were marked and numbered on the typodont master models (measuring points) *(Figure 2)*. Stereomicroscope images (SMZ800N; Nikon Instruments Inc., Tokyo, Japan) were captured from coping-model assemblies at standardized positions (dictated by the reference points) using a digital camera (H550S; Nikon) and magnified 100-fold. Marginal discrepancies were evaluated using photo-editing software (Photoshop CS4; Adobe Systems Software, San Jose, CA, USA); we measured the distances from the edges of copings to the finish lines of working models and the values were recorded in micrometers. Internal discrepancies were measured using a silicone replica method.[31,32] Copings were fixed onto working models using silicone (Honigum Light Body; DMG, Hamburg, Germany) under finger pressure for 2 min to simulate clinical conditions.[20] After the impression material set, the copings were removed and another silicone layer (Honigum Medium Body; DMG) was applied over the first silicone film to stabilize the first layer prior to measurement. The silicone replicas were inspected for any defects and re-made if necessary. The replicas were then sectioned twice (in both the buccolingual and mesio-distal directions) with a surgical blade, revealing the thicknesses of the light body silicone layers (which represented the internal gaps). Measurements were made from the mesial, distal, buccal, and palatal aspects of the mid-regions of the axial, cervical, and occlusal walls on digital images captured by the stereomicroscope at 100× magnification *(Figure 3)*. Data were collected from single occlusal, axial, and cervical points for each image. Thus, four occlusal, axial, and cervical measurements were made for each coping. All measurements were performed by the same operator, and were repeated three times in a non-consecutive manner. Thus, for each coping, occlusal, axial, and cervical discrepancies were measured 12 times and the averages calculated.

In this study, SPSS software (ver. 20.0; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. In addition to descriptive statistical methods, Tukey's multiple comparisons test and ANOVA applied to analyse differences among groups at the $p<0.05$ significance level. Intra-class correlation coefficients (ICCs) were calculated to assess the reliability of repeated measurements.

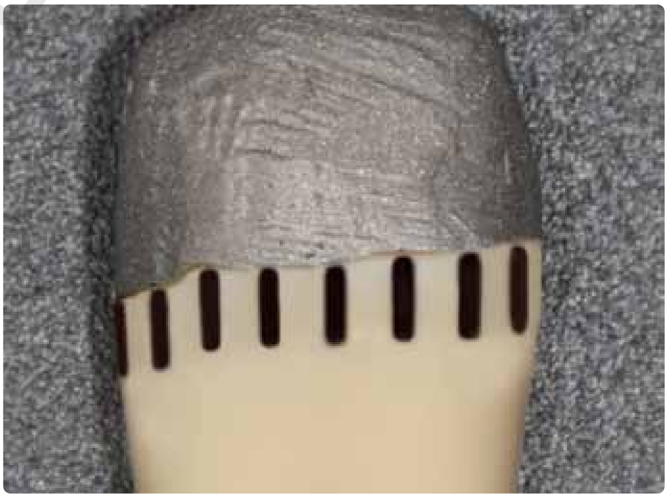

Figure 2: For marginal gap measurement, predefined measuring points on typodont master model with representative metal coping

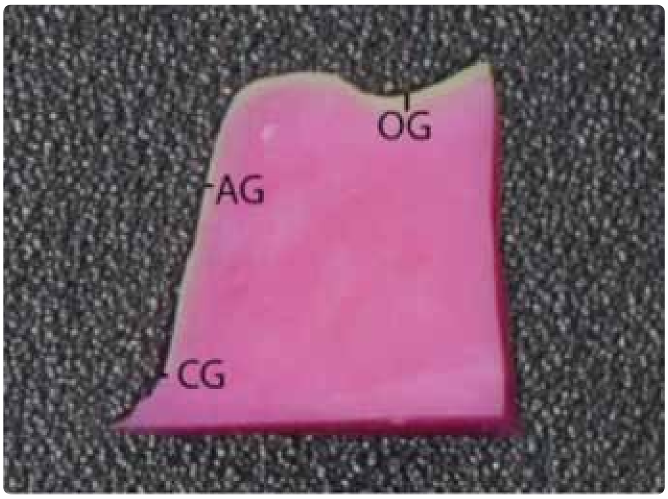

Figure 3: Predefined measuring points on each slice of internal gap replica. OG, occlusal gap; AG, axial gap; CG, cervical gap.

RESULTS

The discrepancy of copings was evaluated on four aspects as marginal, axial, occlusal, and cervical. The ICCs were 0.97–0.99, indicating near-perfect intra-rater reliability. The mean marginal, axial, occlusal, and cervical gaps, and the standard deviations, are listed in Table 2.

The C group exhibited the lowest marginal discrepancy, significantly less than those of the DMLS and μSLA groups (P<0.05). The DMSL group exhibited the greatest marginal discrepancy, thus significantly greater than those of the C and M groups (P<0.05). The axial gaps did not differ significantly among the groups (P>0.05). The occlusal gap was significantly smaller in the C group (P<0.05). The largest occlusal gap was that of the DMLS group, but did not differ significantly from that of the μSLA group (P>0.05). The C group had the smallest cervical gap, significantly less than that of the μSLA group (P<0.05).

DISCUSSION

Recently, CAD/CAM has been extensively applied to create dental prostheses. Rapid prototyping technologies are used to create metal copings, wax patterns, facial prostheses, surgical models, stents, and titanium implants for fixed restorations. Technologies that use additive rather than subtractive methods are particularly valuable.[5-11] This study was conducted to compare the marginal and internal discrepancies of Co-Cr copings made using the latest CAD methods (additive methods: DMLS and μSLA; subtractive method: M) and the conventional method (C). The null hypothesis that no differences in marginal or internal discrepancies would be evident between the four production methods, was rejected. Copings produced by the conventional method exhibited lower discrepancies than those produced by the other methods (*Table 2*), in line with the findings of earlier studies.[11,17,22,23]

However, our findings disagree with those of some previous studies.[24-27] Harish *et al.*[24] and Gunsoy *et al.*[25] used a cross-sectioning technique to explore the marginal and internal discrepancies of Co-Cr crowns and found that DMLS was associated with lower discrepancies than the conventional method. Ullattuthodi *et al.*[26] found no significant differences between the conventional method and DMSL using the direct view technique for marginal discrepancy measurement. The cited authors found that the conventional method afforded a better internal fit than the DMSL method, using a cross-sectioning technique. Kocaağaoğlu *et al.*[27] found that the conventional technique yielded higher marginal discrepancies than hard metal-milled, DMSL, and soft metal- milled techniques, using silicon replica measurements. Kim *et al.*[12] used the same measurement technique as Kocaağaoğlu *et al.*[27] but found that the conventional and soft metal-milled techniques were associated with lower marginal discrepancies than the DMSL and μSLA techniques. The contradictory results may reflect variations in measurement methods and crown production techniques.

Table 2. Mean (±standard deviation) of marginal, axial, occlusal and cervical gap values (μm) in groups

Group	Marginal Gap	Axial Gap	Occlusal Gap	Cervical Gap
Conventional Casting	70.32 (±21.98)[a]	81.98 (±25.08)[a]	91.68 (±21.11)[a]	75.36 (±24.94)[a]
Direct Metal Laser Sintering	114.06 (±9.73)[c]	79.89 (±7.31)[a]	166.47 (±14.56)[b]	91.54 (±8.93)[a,b]
Micro-Stereolithography	101.91 (±26.54)[b,c]	91.68 (±21.11)[a]	148.31 (±28.75)[b,c]	103.59 (±22.01)[b]
Computer-aided Milling	89.80 (±12.07)[a,b]	84.28 (±8.65)[a]	123.92 (±15.39)[c]	93.68 (±4.12)[a,b]

Values in the same column followed by the same letter are not significantly different (P>.05).

In the present study, the direct view technique was used to measure marginal discrepancies of metal copings on a working model and the silicon replica technique employed to measure internal discrepancies. The direct view technique does not require sectioning of the coping-die assembly or replication of the cement space prior to measuring discrepancies. The technique is non-invasive and yields reproducible results.[9,28] The silicon replica technique is a highly reliable method for measurement of internal discrepancies, accurately reflecting post-cementation status.[31,32] However, care must be taken to not damage the silicone.[33]

According to present study, marginal discrepancies of Co-Cr copings in the C, M, μSLA, and DMLS groups were, respectively, 70.32, 89.80, 101.91, and 114.06 μm. In terms of the marginal discrepancies of dental prostheses, the American National Standards Institute/American Dental Association specifications[16] state that the 'clinical acceptance of bonded prosthesis' should be less than 25 μm. In practice, however, such small gaps are relatively difficult to attain.[17] Gassino *et al*. indicated that the maximum clinically acceptable gap of metal ceramic restorations should be 100 μm.[18] To ensure a good long-term prognosis, McLean stated that the clinically approved marginal gap should be 120 μm;[13] Björn *et al*.[19] stated that the maximum marginal gap should be less than 200 μm. Thus, the marginal values obtained in the current study were within acceptable limits for all groups; there is no standardised internal discrepancy criterion for Co-Cr metal crowns.[20,21] The internal discrepancies of Co-Cr metal copings fabricated via DMLS by Kocaağaoğlu *et al*.[27] and Ucar *et al*.[20] were, on average, 89.8–208.3 μm and 62.6 μm, respectively. Kim *et al*.[12] and Farjood *et al*.[11] found that the internal discrepancies of Co-Cr metal copings fabricated via μSLA were, on average, 72.4–258 μm and 95.9 μm, respectively. In the present study, the maximum internal discrepancies measured at the occlusal area were 91.68, 166.47, 148.31, and 123.92 μm for C, DMSL, μ-SLA, and M copings, respectively. These findings indicate that the technology must improve to reduce internal discrepancies in Co-Cr metal copings, especially DMLS- and SLA-prepared copings. In addition, Kim *et al*.[12] recently reported results similar to those of the present study; axial discrepancies were less than occlusal discrepancies when different coping production techniques were compared. The smaller gaps in axial areas indicate that metal copings are not perfectly attached, creating larger gaps in the occlusal surfaces. Large occlusal gaps are commonly observed when using dental CAD/CAM systems.[33]

In-vivo and *in-vitro* studies on marginal and internal fits are ongoing. Standardisation is not possible using the present in vivo methods. Additionally, in vivo studies are more difficult to perform than *in vitro* studies. The marginal and internal discrepancies obtained *in vitro* do not accurately reflect the in vivo values, but nonetheless provide valuable information for clinical applications. In this *in vitro* study, the marginal discrepancies of all the Co-Cr copings fabricated by DMLS, M, μSLA and conventional techniques were found to be within the range of clinical acceptance (<120 μm), but further improvements in the μSLA and DMLS techniques may be required prior to clinical implementation.

The potential reasons for the marginal and internal discrepancies of Co-Cr copings are the presence of multiple and sensitive manufacturing steps, even when new production techniques are used.[17] Overall, the quantitative data revealed fewer discrepancies in the conventional casting group, but not all inter-group comparisons were significant. However, the digital production techniques were associated with smaller standard deviations independent of the degree of discrepancy, and were thus more reproducible. It seems that the hardware used for digital production cannot yet exactly replicate the CAD, but all end-products from a specific design were highly similar. It is likely that ongoing efforts to improve calibration between the CAD and CAM units will soon resolve the design/product differences.

CONCLUSION

Within the limitations of this study, the following conclusions may be drawn:

1. The marginal and cervical discrepancies of the C group were similar to those of the M group and better than those of the μSLA group.
2. The axial discrepancies did not differ significantly among the groups.
3. Compared to the C technique, the DMLS, M, and μSLA techniques exhibited larger occlusal discrepancies.
4. The marginal and internal discrepancies of all groups were within clinically acceptable limits, but further improvements in the new techniques may be required prior to clinical implementation.

ACKNOWLEDGMENTS

The authors thank 'Independent Statistician Hande Kartal' for performing statistical analyses of the results.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest: The authors declare that they have no conflict of interest.

REFERENCES

1. Petteno, D., Schierano, G., Bassi, F., Bresciano, M.E., Carossa, S. Comparison of marginal fit of 3 different metal-ceramic systems: an in vitro study. *Int. J. Prosthodont.*, 2000;**13**:405-408.
2. Zarone, F., Russo, S., Sorrentino, R. From porcelain fused-to-metal to zirconia: clinical and experimental considerations. *Dent. Mater.*, 2011;**27**:83-96.
3. Wohlwend, A., Strub, J.R., Schärer, P. Metal ceramic and all-Porcelain restorations: Current considerations. *Int. J. Prosthodont.*, 1989;**2**:13-26.

4. Miyazaki, T., Hotta, Y., Kunii, J., Kuriyama, S., Tamaki, Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. *Dent. Mater. J.*, 2009;**28**:44-56.
5. Koutsoukis, T., Zinelis, S., Eliades, G., Al-Wazzan, K., Rifaiy, M.A., Al Jabbari, Y.S. Selective Laser Melting Technique of Co-Cr Dental Alloys: A Review of Structure and Properties and Comparative Analysis with Other Available Techniques. *J. Prosthodont.*, 2015;**24**:303-332.
6. Abdulhameed, N., Roulet, J.F., Chen, C., Hussein, H. A Measurement Protocol for the Marginal and Internal Fit of All-Ceramic Crowns. *Eur. J. Prosthodont. Restor. Dent.*, 2017;**25**:193-200.
7. Van Noort, R. The future of dental devices is digital. *Dent. Mater.*, 2012;**28**:3-12.
8. Kim, K.B., Kim, J.H., Kim, W.C., Kim, J.H. Three-dimensional evaluation of gaps associated with fixed dental prostheses fabricated with new technologies. *J. Prosthet. Dent.*, 2014;**112**:1432-1436.
9. Nesse, H., Ulstein, D.M., Vaage, M.M., Øilo, M. Internal and marginal discrepancy of cobalt-chromium fixed dental prostheses fabricated with 3 different techniques. *J. Prosthet. Dent.*, 2015;**114**:686-692.
10. Bhaskaran, E., Azhagarasan, N.S., Miglani, S., Ilango, T., Krishna, G.P., Gajapathi, B. Comparative Evaluation of Marginal and Internal Gap of Co–Cr Copings Fabricated from Conventional Wax Pattern, 3D Printed Resin Pattern and DMLS Tech: An In Vitro Study. *J. Indian. Prosthodont. Soc.*, 2013;**13**:189-195.
11. Farjood, E., Vojdani, M., Torabi, K., Khaledi, A.A. Marginal and internal discrepancy of metal copings fabricated with rapid prototyping and conventional waxing. *J. Prosthet. Dent.*, 2017;**117**:164-170.
12. Kim, D.Y., Kim, J.H., Kim, H.Y., Kim, W.C. Comparison and evaluation of marginal and internal gaps in cobalt–chromium alloy copings fabricated using subtractive and additive manufacturing. *J. Prosthodont.* Res., 2018;**62**:56-64.
13. McLean, J.W., von Fraunhofer, J.A. The estimation of cement film thickness by an in vivo technique. *Br. Dent. J.*, 1971;**131**:107-111.
14. Lövgren, N., Roxner, R., Klemendz, S., Larsson, C. Effect of production method on surface roughness, marginal and internal fit, and retention of cobalt-chromium single crowns. *J. Prosthet. Dent.*, 2017;**118**:95-101.
15. Hunter, A.J., Hunter, A.R. Gingival margins for crowns: a review and discussion. Part II: Discrepancies and configurations. *J. Prosthet. Dent.*, 1990;**64**:636-642.
16. Council on Dental Materials and Devices. Revised American National Standards Instititute/American Dental Association Specification No. 8 for Zinc Phosphate Cement. *J. Am. Dent. Assoc.*, 1978;**96**:121-123.
17. Park, J.K., Lee, W.S., Kim, H.Y., Kim, W.C., Kim, J.H. Accuracy evaluation of metal copings fabricated by computer-aided milling and direct metal laser sintering systems. *J. Adv. Prosthodont.*, 2015;**7**:122-128.
18. Gassino, G., Barone Monfrin, S., Scanu, M., Spina, G., Preti, G. Marginal adaptation of fixed prosthodontics: Anew in vitro 360- degree external examination procedure. *Int. J. Prosthodont.*, 2004;**17**:218-223.
19. Björn, A.L., Björn, H., Grkovic, B. Marginal discrepancy of restorations and its relation to periodontal bone level II. crowns. *Odontol. Revy.*, 1970;**21**:337-346.
20. Ucar, Y., Akova, T., Akyil, M.S., Brantley, W.A. Internal discrepancyevaluation of crowns prepared using a new dental crown fabrication technique: laser-sintered Co-Cr crowns. *J. Prosthet. Dent.*, 2009;**102**:253-259.
21. Örtorp, A., Jönsson, D., Mouhsen, A., von Steyern, P.V. The discrepancy of cobalt–chromium three-unit fixed dental prostheses fabricated with four different techniques: a comparative in vitro study. *Dent. Mater.*, 2011;**27**:356-363.
22. Kim, K.B., Kim, J.H., Kim, W.C., Kim, H.Y., Kim, J.H. Evaluation of the marginal and internal gap of metal-ceramic crown fabricated with a selective laser sintering technology: two-and three-dimensional replica techniques. *J. Adv. Prosthodont.*, 2013;**5**:179-186.
23. Vojdani, M., Torabi, K., Farjood, E., Khaledi, A.A. Comparison the marginal and internal discrepancy of metal copings cast from wax patterns fabricated by CAD/CAM and conventional wax up techniques. *J. Dent.*, 2013;**14**:118-129.
24. Harish, V., Mohamed Ali, S.A., Jagadesan, N., Mohamed Ifthikar, S.S., Debasish Basak, F.H. Evaluation of internal and marginal discrepancyof two metal ceramic system–In vitro study. *J. Clin. Diagn. Res.*, 2014;**8**:ZC53.
25. Gunsoy, S., Ulusoy, M. Evaluation of marginal/internal discrepancy of chrome-cobalt crowns: Direct laser metal sintering versus computer-aided design and computer-aided manufacturing. Niger. *J. Clin. Pract.*, 2016;**19**:636-644.
26. Ullattuthodi, S., Cherian, K.P., Anandkumar, R., Nambiar, M.S. Marginal and internal discrepancyof cobalt-chromium copings fabricated using the conventional and the direct metal laser sintering techniques: A comparative in vitro study. *J. Indian. Prosthodont. Soc.*, 2017;**17**:373-380.
27. Kocaağaoğlu, H., Kılınç, H.İ., Albayrak, H., Kara, M. In vitro evaluation of marginal, axial, and occlusal discrepancies in metal ceramic restorations produced with new technologies. *J. Prosthet. Dent.*, 2016;**116**:368-374.
28. Nawafleh, N.A., Mack, F., Evans, J., Mackay, J., 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.
29. Huang, Z., Zhang, L., Zhu, J., Zhang, X. Clinical marginal and internal discrepancy of metal ceramic crowns fabricated with a selective laser melting technology. *J. Prosthet. Dent.*, 2015;**113**:623-627.
30. Podhorsky, A., Rehmann, P., Wöstmann, B. Tooth preparation for full-coverage restorations—a literature review. *Clin. Oral. Investig.*, 2015;**19**:959-968.
31. Laurent, M., Scheer, P., Dejou, J., Laborde, G. Clinical evaluation of the marginal discrepancy of cast crowns–validation of the silicone replica method. *J. Oral. Rehabil.*, 2008;**35**:116-122.
32. Rahme, H.Y., Tehini, G.E., Adib, S.M., Ardo, A.S., Rifai, K.T. In vitro evaluation of the “replica technique” in the measurement of the discrepancy of Procera crowns. *J. Contemp. Dent. Pract.*, 2008;**9**:25-32.
33. Kokubo, Y., Tsumita, M., Kano, T., Sakurai, S., Fukushima, S. Clinical marginal and internal gaps of zirconia all-ceramic crowns. *J. Prosthodont. Res.*, 2011;**55**:40-43.