Comparison of accuracy of single crowns generated from digital and conventional impressions: an *in vivo* controlled trial

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ABSTRACT

Aim With the advances of digital technology, intraoral digital impression (DI) technique has become a major trend in prosthodontics with respect to traditional impression (TI) techniques; despite that, very few data are available concerning its accuracy. Thus, the purpose of this study was to compare the effectiveness of DI versus TI considering both marginal and internal gap (MG, IG, respectively) in cobalt-chromium (Co-Cr) single crowns manufactured by mean of computer-aided design and computer-aided manufacturing (CAD/CAM) technology.
Material and methods Thirty posterior teeth were considered for this study. For each abutment tooth, sixty and thirty copings were produced with the aid of TI and DI, respectively. Thirty of the sixty copings of the TI-group were then randomly selected to be veneered and cemented onto existing abutments. The space existing between the internal surface of the coping and the abutment tooth was evaluated onto an *in vitro* replica; the MG and IG were measured by Scanning Electron Microscope. The data were analysed by the Wilcoxon test (1-tailed).
Results The mean MG was 75.04 μm (SD = 13.12) and 55.01 μm (SD = 7.01) for the TI group and DI group, respectively. As regards the mean IGs, the values recorded were of 78.36 μm (SD = 19.66) for the TI-group and 59.20 μm (SD=3.33) for the DI-group. A statistically significant difference was found between the two groups (p-value = 0.001).
Conclusions Copings manufactured from DI showed better MGs and IGs with respect to copings produced from TI. However, both approaches produced clinically acceptable results.

KEY WORDS CAD/CAM; Dental impression; Digital impression; Intraoral scanner; Marginal fit.

INTRODUCTION

Dental impression is a negative imprint of an oral structure used to produce a positive replica, used as a permanent record or in the production of a dental restoration or prosthesis. Thus, accuracy in the development of the impression is a determining factor to assure a successful fabrication and survival of both fixed and implant-retained prosthesis (1,2). Conversely, inadequacy in impression-making technique and/ or in the manual steps of prosthesis fabrication may lead to several problems related to the misfit of the fixed dental prosthesis. These include luting agent dissolution (3), microleakage (4), caries hypersensitivity (5) and periodontal inflammation (6,7), but also issues concerning the retention of the crown which may affect prosthesis longevity (8).

Marginal and internal fitness (MG and IG, respectively) are important criteria for the success of fixed dental prostheses (FDPs). A high level of impression accuracy is important to assist the fabrication of a precise restoration (9).

According to the literature, the reported MG for the metal-ceramic crowns ranges for from 26 to 138 μm (10) or 50 to 100 μm (11), depending on whether these are fabricated by traditional impression (TI) (10) or digital workflow (DI) (11), respectively. In fact, to date, TI using different impression materials and DI using intraoral scanners, represent two approaches by which impressions of dental arches may be accomplished.

The implementation of the intraoral digital workflow has allowed the elimination of many procedures (12, 13). In comparison with TI, intraoral DI technique can save time and steps for both dentists and technicians. In particular, steps avoided at the dental office include tray selection, material dispensing/setting/ disinfection and impression packaging and shipping; steps eliminated at the lab are plaster pouring, die cutting, trimming, articulation, and extraoral scanning (8-11, 14). Moreover, simplification of the protocols also resulted in greater patient comfort depending on

time reduction in clinical treatments (15-17). However, different obstacles and deficiencies have to be addressed in intraoral impressions too; these are related to the digital workflow and include additional costs of purchasing an intraoral scanner, the learning curve and rate adjustment models and scanner displacement to assure scanning accuracy (15,16).

Several authors investigated different variables concerning the TI technique but few compared the accuracy of casts produced by TI versus DI techniques (18). Moreover, the results are discordant as some studies recorded better results from DI compared to TI (19,20,21), while others, considering the fit of single crowns, reported a comparable outcome for both techniques (22,23).

With the development of digital dentistry, more clinical investigations are needed to determine clinical accuracy of new DI techniques combined with CAD/CAM technology. According to our knowledge, only four studies evaluated the MG of crowns produced by means of TI versus DI techniques, with a replica *in vivo* (23-36); hence, the aim of this study was to compare the accuracy of the two approaches in realizing a single crown on natural tooth, measuring the MG through Scanning Electron Microscopy (SEM). The null hypothesis was that no significant differences would be found between TI and DI techniques.

MATERIALS AND METHODS

Patients enrollment

This study was performed in a private practice, in accordance with the Declaration of Helsinki and Good Clinical Practice (GCP).

A total of 30 adult patients were recruited from individuals who were previously considered for regular treatment with fixed prostheses. In particular, all patients needed single crowns in the posterior region.

As Good Clinical Research Practice (GCRP) requires, patients were always asked to give full and informed consent before inclusion within any protocol. Hence, informed consent was provided by each participant before being enrolled in the study.

Regarding the inclusion criteria, these were: over 18 years of age; good general health; no local inflammation; good oral hygiene; posterior teeth (premolar or molar) planned for regular treatment with single fixed crown and no requirement for additional endodontic treatment. On the other hand, the exclusion criteria included: pregnancy and advanced periodontal disease with teeth mobility.

Preparation technique

The treatment was performed by the same specialist in prosthodontics according to a standardized protocol; in particular, the teeth needing treatment were prepared

under local anaesthesia and providing a chamfer finish line (27). The chamfer finish line was carried out with a circumferential reduction of the tooth structure (range: 1.5-2 mm); all internal edges were rounded, and the preparation's convergence angle (approximately 6 degrees) was achieved through holding the chamfer tapered as straight as possible (24-27). Moreover, the margin was performed at the level of the gingiva and in any case without exceeding the subgingival depth beyond 1 mm (24-27). A provisional crown of polymethyl methacrylate acrylic (PMMA) (Luxatemp, DMG, Hamburg, Germany) was placed on the prepared tooth. Thereafter, the TI and the DI techniques were performed after a minimum waiting period of 4 weeks from the preparation to allow the healing of possible gingival injuries caused by the preparation procedure.

Impression protocols: TI versus DI technique

The provisional crowns were removed, and the abutment tooth was cleaned with pumice on a rotating brush. Double retraction cords (Ultrapak 000 and 00, Ultradent, South Jordan, USA) were plugged into the sulcus using the double cord technique; the same retraction cord technique was used for both the TI and DI. Sixty TI and 30 DI of the abutment tooth were realized. In particular, the DI was performed by using an intraoral digital scanner (Zfx Intrascan, Zfx GmbH, Zimmer Dental, Dachau, Germany) according to the manufacturer's protocol. No powder was applied and intraoral scanner was calibrated prior to scanning the abutment tooth. The stereolithographic interface (STL) files were then sent electronically by Zfx Dental-Net (Zfx GmbH, Zimmer Dental, Dachau, Germany) to dental laboratory. After finishing the intraoral scans, the TI technique was performed.

Perforated metal stock trays were used for the TI. The trays were varnished with an adhesive for polyvinyl siloxane (PVS) 5–10 minutes before impression (VPS Tray Adhesive, 3M ESPE, Seefeld, Germany). PVS materials were used as material impression for each conventional impression (Express 2 Penta Putty/Express 2 Light Body Quick, 3M ESPE, Seefeld, Germany). The dental antagonist was taken using dental alginate (Aroma Fine; GC Corp, Tokyo, Japan). The registration of the bite was performed by Imprint Bite (3M ESPE, Seefeld, Germany). The impressions were then poured with type IV dental plaster (Shera Hard Rock) and sent to the same dental laboratory. The model was scanned by means of a laboratory scanner Zfx Evolution (Zfx GmbH, Zimmer Dental, Dachau, Germany). The digitized data from the TI, as well as the DI, were transmitted to CAD software program (Exocad Dental CAD) which allowed for the design of the crowns using identical parameter settings for both; the STL files were then sent to centralized milling centre (Zfx, Gargazzone, Bolzano, Italy) for review and fabrication of Co-Cr copings. Three Co-Cr copings were fabricated for each

	Marginal Gap		Internal Gap	
	Traditional Impression	Digital Impression	Traditional Impression	Digital Impression
Mean	75.04 µm*	55.01 µm*	78.36 µm*	59.20 µm*
Standard Deviation	13.12 µm	7.01 µm	19.66 µm	3.33 µm
Min	53.17 µm	41.35 µm	46.43 µm	54.11 µm
Max	97.49 µm	66.41 µm	111.53 µm	66.55 µm
p-value*	0.001	0.001		
Level of statistical significance was set as $\alpha = 0.05$ and statistical power of 80%.				

TABLE 1. Results of marginal and internal gap.

FIG. 1 Coping of the respective abutments tooth.
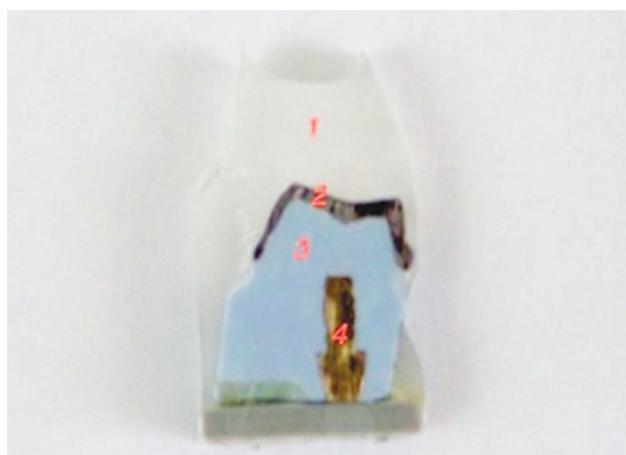
FIG. 2 Specimen blocks. Epoxy resin (1); coping (2); abutment tooth (3); metal post (4).

of the 30 teeth. A total of 90 Co-Cr copings showing the same design (cement gap: 80 µm; layer thickness: 700 µm; edge reinforcement: 250 µm) were fabricated. In particular, two copings were made using the TI techniques (n=60) and one coping by means of DI technique (n=30). Thereafter, one of the two copings prepared by TI technique was randomly examined for both the MG and IG while the other one was conserved to be veneered with porcelain and finally cemented to the patients. The cementation stage was performed after ensuring the correct seating of the crowns on the abutments tooth by a tray-in stage.

Fit analysis

To analyse the IG between the internal surface of the coping and the abutment tooth, replica technique was applied an *in vivo* (21,25). The copings were first filled with a low viscosity silicone (Xantropen VL, Heraeus Kulzer, Hanau, Germany) and then located on their corresponding abutment tooth. The copings were pressed in the correct position exerting maximum finger pressure in order to simulate the crown cementation. After 3 minutes, the copings were dragged off the

abutment tooth with a partial conventional impression (Express 2 Penta Putty/Express 2 Light Body Quick, 3M ESPE, Seefeld, Germany) which was poured with a resin Exakto-Form (Bredent, Senden, Germany) to obtain a stump mimicking the abutment tooth. All copings were cemented on the respective abutment tooth made of resin, using a resin-reinforced glass-ionomer cement (GC Fuji PLUS, GC Europe) (Fig. 1) before being embedded in an epoxy resin (Araldite 2000; Huntsman corporation, Ternate Varese, Italy). After 24 hours, the copings, cemented in abutment tooth incorporated in the resin, were cut in 2-mm thick slices using a precision cutter (Isomet LSS Buehler; ITW Company Lake Bluff). Thereafter, the sections were polished with a Labopol-35 (Struers s.a.r.l., Milano, Italy) and metalized by means of a high-vacuum carbon evaporator (Emitech K950X) prior to being analyzed by SEM (CamScan MX 3000) (29) (Fig. 2). One section for each coping was randomly selected and analyzed by SEM to identify the distance between the internal surface of the coping and the abutment tooth surface close to the preparation finish line (MG) (24,27,30) (Fig. 3); as well as the distance from the coping to the abutment at the lowest point
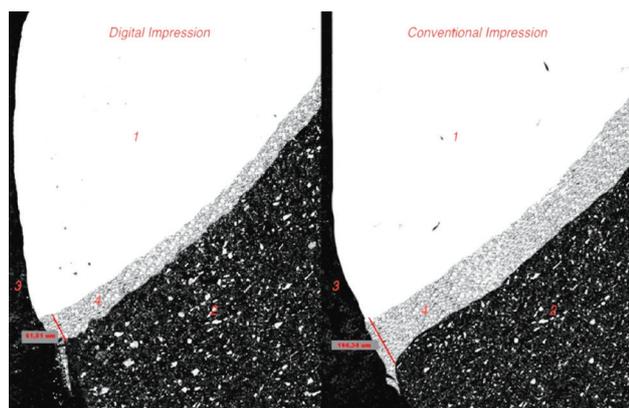
FIG. 3 SEM photographs. MG measurements. Coping (1); Abutment Tooth (2); Epoxy resin (3); Cement (4).
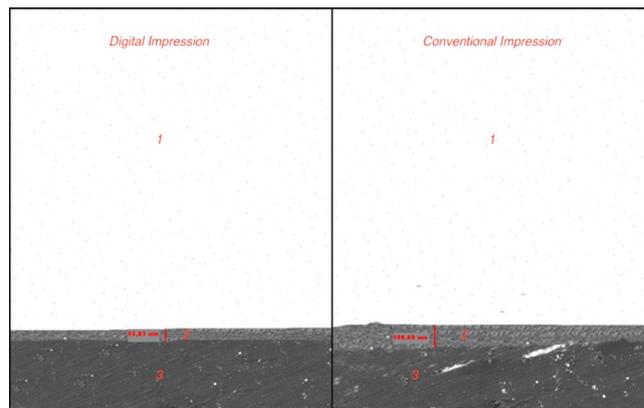
FIG. 4 SEM photographs. IG measurements. Coping (1); Abutment Tooth (2); Epoxy resin (3); Cement (4).

of the abutment tooth (24) (IG) (Fig. 4). All laboratory preparations (embedding, slicing and polishing) were performed by an experienced technician of the University of Padua.

Statistical analysis

Preliminarily, a pilot study was conducted to generate data on the expected effect size and standard deviation to allow for power calculations. The number of samples provided for the calculation was 12 copings, 6 per group. The level of statistical significance was set as $\alpha = 0.05$ and statistical power of 80%. The test group average was 67.85 μm (SD 7.39) while the control group average was 61.1 μm (SD 5.78). Null hypothesis for difference between averages was supposed to be 4.84 μm. Twenty copings per group were then estimated after power calculation. The sample size was set to 30 copings per group since a 35% bias (10 copings per group) was expected. The Wilcoxon matched-pairs signed-ranks test (1-tailed) was used to compare groups. Statistical analysis was performed using statistical software SPSS 16.0 (SPSS Inc., Chicago, Illinois, USA) (31).

RESULTS

Mean MG was 75.04 μm (SD=13.12; Min = 53.17 μm; Max = 97.49 μm) for the group of the TI technique and 55.01 μm (SD=7.01; Min = 41.35 μm; Max = 66.41 μm) for the DI-group. A statistically significant difference was present between two groups (p value= 0.001). Mean IG was 78.36 μm (SD=19.66; Min = 46.43 μm; Max = 111.53 μm) for the TI-group and 59.20 μm (SD=3.33; Min = 54.11 μm; Max = 66.55 μm) for the DI-group (Table 1). A statistically significant difference was present between two groups (p-value= 0.001). The results of the Wilcoxon matched-pairs signed-ranks test (1-tailed) showed that the copings of the DI group fit better than the ones of the TI.

DISCUSSION

Fixed dental prostheses are routinely manufactured. CAD/CAM methods are used more often, allowing to overcome the limitations of the lost-wax technique which is time-intensive and also yields inconsistent results (32). A typical fixed restoration, manufactured using a dental CAD/CAM system needs a dental impression. Since the accuracy of the impression affects the accuracy of the definitive cast, an accurate impression is essential to fabricate a prosthesis with a good fit. Conversely, an inaccurate impression may result in failure to restore tooth anatomy leading to prosthesis misfit, and occurrence of mechanical and/ or biological complications such as disturbed occlusal function and painful muscles (33).

As dental impressions represent an important step in all restorative treatments, to date, significant progress has been made in procedures for making impressions for fixed prosthodontics. Beside the TI techniques, DI techniques stands out. Hence, the aim of this study was to assess the accuracy of copy denture templates produced using DI versus TI techniques for fabricating cobalt-chromium copings veneered with porcelain.

According to our data, a statistically significant difference was found between conventional impression group and digital impression group (p-value = 0.001). Specifically, the comparative statistical analysis showed that the copings of DI-group had a better fit than the copings of the TI- group.

Revising the literature, there are few studies evaluating the accuracy of single crowns produced through the support of intraoral scanners (23,24,34); at first, we considered the MG (μm), but as *in vivo* measurement of the MG is not achievable, we used a replica technique (14,17,24,30,34); the purpose was to assess the misfit between the crown and the abutment tooth. In the literature, few studies measured the MG of crowns produced by means of intraoral scanning versus

conventional impressions, taking advantage of a replica (23-26). Among these, Boeddinghaus et al. (23) analyzed the marginal fit of dental crowns realized from three different intraoral digital impressions and one from conventional impression. The recorded mean values of MG were 88 μm (range: 68 – 136 μm), 112 μm (range: 94 – 149 μm) and 149 μm (range: 114 – 218 μm) for True Definition (3M ESPE, Seefeld, Germany), Cara Trios (3Shape, Copenhagen, Denmark) and OCam (Sirona, Bensheim, Germany), respectively. As regards the conventional impression technique, the recorded MG value was 113 μm (range: 81 – 157 μm). Zarauz et al. (24) analyzed the marginal fit of dental crowns based on one intraoral digital system (Caredet-iTero, Align Technology, San Jose, USA) and one conventional impression. Mean IG and mean MG were 111.40 μm (SD=54.04)/80.29 μm (SD=26.24), respectively for the crowns of the intraoral DI group and 173.00 μm (SD=92.65)/133.51 μm (SD=48.78) for the TI group. Syrec et al. (25) found a MG of 49 μm for the DI group (Lava Cos, 3M ESPE, Seefeld, Germany) and 71 μm for the TI-group. Brawek et al. (26) measured the misfit of crowns generated by two intraoral digital scanners, without considering any conventional impression technique. The mean MGs for Lava Cos (3M ESPE, Seefeld, Germany) and CEREC AC (Sirona Dental Systems, Long Island City, NY) were 51 μm and 83 μm, respectively.

After comparing the results reported by other authors with the ones recorded by our analysis, it emerges that the mean MG we identified was slightly smaller than the results of Boeddinghaus et al. (23) and Zarauz et al. (24); conversely, it was similar to the values reported by Syrec et al. (25), Brawek et al. (26) and Scotti et al. (34). As Syrec et al. (25), we fabricated only copings, while Boeddinghaus et al. (230) and Zarauz et al. (24) veneered the crowns with porcelain. Thus, the addition of aesthetic ceramic might have some influence in the marginal fit (35).

To date, there is not a consensus on what is clinically acceptable in terms of maximum marginal gap width. However, according to the first study in literature (36), the reported value which can be considered as clinically acceptable is <120 μm. Noteworthy, all intraoral impression systems in the few published clinical studies reported a MG <100 μm.

CONCLUSION

Despite the limitations of this study, it can be concluded that the copings fabricated from the DI, produced MG and IG adaptation results overall better than copings fabricated from TI. However, both techniques assure the obtainment of clinically acceptable results. The technology of intraoral DI enables the clinician to produce accurate restorations without the unpleasant aspects of traditional impression materials and techniques.

REFERENCE

1. White SN, Ingles S, Kipnis V. Influence of marginal opening on microleakage of cemented artificial crowns. J Prosthet Dent 1994;71:257–264.
2. Di Fiore A, Meneghello R, Savio G, Sivolella S, Katsoulis J, Stellini E. In vitro implant impression accuracy using a new photopolymerizing SDR splinting material. Clin Implant Dent Relat Res 2015; 17 Supple2 :721-9.
3. Jacobs MS, Windeler AS. An investigation of dental luting cement solubility as a function of the marginal gap. J Prosthet Dent 1991;65: 436–442.
4. Zoellner A, Bragger U, Fellmann V, Gaengler P. Correlation between clinical scoring of secondary caries at crown margins and histologically assessed extent of the lesions. Int J Prosthodont 2000;13:453–459.
5. Gardner FM. Margins of complete crowns--Literature review. J Prosthet Dent 1982;48:396–400.
6. Reeves WG. Restorative margin placement and periodontal health. J Prosthet Dent 1991;66:733–736.
7. Bader JD, Rozier RG, McFall WTJ, Ramsey DL. Effect of crown margins on periodontal conditions in regularly attending patients. J Prosthet Dent 1991;65:75–79.
8. Felton DA, Kanoy BE, Bayne SC, Wirthman GP. Effect of in vivo crown margin discrepancies on periodontal health. J Prosthet Dent 1991;65:357–364.
9. Ting-Shu S, Jian S. Intraoral digital impression technique: a review. J Prosthodont 2015;24:313–321.
10. Fransson B, Oilo G, Gjeitanger R. The fit of metal-ceramic crowns, a clinical study. Dent Mater 1985;1:197–199.
11. 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.
12. Di Fiore A, Vigolo P, Graiff L, Stellini E. Digital vs Conventional Workflow for Screw-Retained Single-Implant Crowns: A Comparison of Key Considerations. Int J Prosthodont 2018 Nov/Dec;31(6):577-579.
13. Joda T, Ferrari M. Chairside protocol for posterior single-unit implant restorations in a complete digital workflow. J Osseointegr 2018;10(2):33-36.
14. 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;102:253–259.
15. Christensen GJ. Impressions are changing: deciding on conventional, digital or digital plus in-office milling. J Am Dent Assoc 2009;140:1301–1304.
16. Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J Prosthet Dent 2013;109:121–128.
17. Anadioti E, Aquilino SA, Gratton DG, Holloway JA, Denry I, Thomas GW, Qian F. 3D and 2D marginal fit of pressed and CAD/CAM lithium disilicate crowns made from digital and conventional impressions. J Prosthodont 2014;23:610–617.
18. Henkel GL. A comparison of fixed prostheses generated from conventional vs digitally scanned dental impressions. Compend Contin Educ Dent 2007;28:422-431.
19. Bindl A, Mormann WH. Clinical and SEM evaluation of all-ceramic chair-side CAD/CAM-generated partial crowns. Eur J Oral Sci 2003;111:163–169.
20. Wittneben J-G, Wright RF, Weber H-P, Gallucci GO. A systematic review of the clinical performance of CAD/CAM single-tooth restorations. Int J Prosthodont 2009;22:466–471.
21. Biagioni A, Pecciarini M, Ferrari M. A systematic review about randomized clinical trials on digital impressions on sound teeth. J Osseointegr 2019;11(2): 2-6.
22. Cho SH, Schaefer O, Thompson GA, Guentsch A. Comparison of accuracy and reproducibility of casts made by digital and conventional methods. J Prosthet Dent 2015;113:310–315.

23. Boeddinghaus M, Breloer ES, Rehmann P, Wostmann B. Accuracy of single-tooth restorations based on intraoral digital and conventional impressions in patients. Clin Oral Investig 2015;19:2027–2034.

24. Zarauz C, Valverde A, Martinez-Rus F, Hassan B, Pradies G. Clinical evaluation comparing the fit of all-ceramic crowns obtained from silicone and digital intraoral impressions. Clin Oral Investig 2016;20:799–806.

25. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J. Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent 2010;38:553–559.

26. Brawek PK, Wolfart S, Endres L, Kirsten A, Reich S. The clinical accuracy of single crowns exclusively fabricated by digital workflow--the comparison of two systems. Clin Oral Investig 2013;17:2119–2125.

27. Monaco C, Caldari M, Scotti R. Clinical evaluation of 1,132 zirconia-based single crowns: a retrospective cohort study from the AIOP Clinical research group. Int J Prosthodont 2013;26:435–442.

28. Tsitrou EA, Northeast SE, van Noort R. Evaluation of the marginal fit of three margin designs of resin composite crowns using CAD/CAM. J Dent 2007;35:68–73.

29. Marchionni S, Baldissara P, Monaco C, Scotti R. A Systematic method for predetermined scanning electron microscope analysis in dental science. Scanning 2010;32:97–103.

30. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent 1989;62:405–408.

31. Bressan E, Tessarolo F, Sbricoli L, Caola I, Nollo G,Di Fiore A. Effect of chlorhexidine in preventing plaque biofilm on healing abutment: a crossover controlled study. Implant Dent 2014;23:64–68.

32. Kim DY, Kim JH, Kim HY, Kim WC. Comparison and evaluation of marginal and internal gaps in cobalt-chromium alloy copings fabricated using subtractive and additive manufacturing. J Prosthodont Res 2018 Jan;62(1):56-64.

33. Lee H, So JS, Hochstedler JL, Ercoli C. The accuracy of implant impressions: a systematic review. J Prosthet Dent 2008;100:285–291.

34. Scotti R, Cardelli P, Baldissara P, Monaco C. WITHDRAWN. Clinical fitting of CAD/CAM zirconia single crowns generated from digital intraoral impressions based on active wavefront sampling. J Dent 2011 Oct 17 [Epub ahead of print].

35. Pak HS, Han JS, Lee, JB, Kim SH, Yang JH. Influence of porcelain veneering on the marginal fit of Digident and Lava CAD/CAM zirconia ceramic crowns. J Adv Prosthodont 2010;2:33–38.

36. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J 1971:131, 107–111.