Fitting accuracy of ceramic veneered Co-Cr crowns produced by different manufacturing processes

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PURPOSE. The purpose of this *in vitro* study was to evaluate the fitting accuracy of single crowns made from a novel presintered Co-Cr alloy prepared with a computer-aided design and computer-aided manufacturing (CAD/CAM) technique, as compared with crowns manufactured by other digital and the conventional casting technique. Additionally, the influence of oxide layer on the fitting accuracy of specimens was tested. **MATERIALS AND METHODS.** A total of 40 test specimens made from Co-Cr alloy were investigated according to the fitting accuracy using a replica technique. Four different methods processing different materials were used for the manufacture of the crown copings (milling of presintered (Ceramill Sintron-group_cer_sin) or rigid alloy (Tizian NEM-group_ti_nem), selective laser melting (Ceramill NPL-group_cer_npl), and casting (Girobond NB-group_gir_nb)). The specimens were adapted to a resin model and the outer surfaces were airborne-particle abraded with aluminum oxide. After the veneering process, the fitting accuracy (absolute marginal discrepancy and internal gap) was evaluated by the replica technique in 2 steps, before removing the oxide layer from the intaglio surface of the crowns, and after removing the layer with aluminum oxide airborne-particle abrasion. Statistical analysis was performed by multifactorial analysis of variance (ANOVA) (α=.05). **RESULTS.** Mean absolute marginal discrepancy ranged between 20 µm (group_cer_npl for specimens of Ceramill NPL) and 43 µm (group_cer_sin for crowns of Ceramill Sintron) with the oxide layer and between 19 µm and 28 µm without the oxide layer. The internal gap varied between 33 µm (group_ti_nem for test samples of Tizian NEM) and 75 µm (group_gir_nb for the base material Girobond NB) with the oxide layer and between 30 µm and 76 µm without the oxide layer. The absolute marginal discrepancy and the internal gap were significantly influenced by the fabrication method used (P<.05). **CONCLUSION.** Different manufacturing techniques had a significant influence on the fitting accuracy of single crowns made from Co-Cr alloys. However, all tested crowns showed a clinically acceptable absolute marginal discrepancy and internal gap with and without oxide layer and could be recommended under clinical considerations. Especially, the new system Ceramill Sintron showed acceptable values of fitting accuracy so it can be suggested in routine clinical work. ***[J Adv Prosthodont 2020;12:100-6]***

KEYWORDS: Crowns; Cobalt-chrome; Silicone replica; Computer-aided design and computer-aided manufacturing (CAD/CAM); Lost-wax casting

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INTRODUCTION

The accuracy, including marginal and internal fit of metal-ceramic restorations, plays a key role in their long-term success.[1,2] Microscopic openings at the margins can support the accumulation of bacteria, secondary caries, and periodontal inflammation.[3-5] If the internal fit of restorations is reduced, this can lead to an increase in cement gap size, which can influence mechanical stability.[6,7] For the use of resin cements, large cement gaps may result in higher water absorption, which can lead to hydrolytic degradation with a reduction in

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elastic modulus and mechanical stability.[8-10] The focus of restorations should be to obtain the smallest possible gaps, with studies reporting that a marginal gap of 25 to 120 μm was acceptable for dental restorations.[11,12] An optimal internal gap range of 20 to 100 μm has been reported.[13] Different factors can influence the marginal and internal gap including impression technique, luting material, and fabrication technique.[6,14]

Metal-based dental restorations have been reported to have excellent fitting accuracy. Accuracy problems have been increased by the use of non-noble alloy prostheses, as these have been increasingly popular in recent years because of their low cost, biocompatibility, and possibility of production with conventional techniques, or digitalized technology.[15-17] The traditional fabrication method by the lost-wax technique for base metal restorations contains extensive steps including tooth preparation and impression, cast production, waxing, investing, and casting. During this procedure, different errors can affect the precision of dental prostheses.

With the development of computer-aided design and computer-aided manufacturing (CAD/CAM) technology, it is possible to automatize several steps in the manufacturing process, which can eliminate sources of error. However, expensive milling tools, wear of system, and long processes are disadvantages of the digitalized methods. A new digitalized system (Ceramill Sintron; Amann Girrbach AG) may overcome these disadvantages. With this system, it is possible to produce dental prostheses with a dry millable Co-Cr sintered metal. The copings develop their final properties during the subsequent sintering process under a shielding gas atmosphere. The sintering process took place under an argon atmosphere at about 1300°C, during which the binders give the material its stability burn without residue. In the case of Ceramill Sintron, the volume shrinkage was approximately 11% lower than those of other ceramics and was considered before the CAD-construction. Few studies have investigated this new digital technology. Mai *et al.*[18] evaluated the fit of complete-arch bar frameworks of different presintered Co-Cr alloys after their sintering contraction. They reported that geometric discrepancies during the sintering process were significantly influenced by the presintered Co-Cr alloys used. Vojdani *et al.*[19] compared the fitting accuracy of 2 different CAD/CAM systems and concluded that copings of Ceramill Sintron had poorer marginal and internal fit than copings produced by a conventional CAD/CAM system. Kane *et al.*[20] analyzed the marginal and internal adaption of milled cobalt-chromium crowns made with the CAD/CAM technique and reported clinically acceptable marginal fit. In addition, Nesse *et al.*[17] examined different fabrication methods for Co-Cr restorations and evaluated the best results with the milled method compared with the selective laser melting technique and conventional lost-wax method. Different investigations have evaluated the fitting accuracy of dental restorations but the precision of fit produced with different techniques is unclear. Quante *et al.*[3] evaluated metal-ceramic crowns produced with a laser melting procedure and reported mean marginal discrepancies from 74 to 99 μm. These results are comparable with the study by Tamac *et al.*[21] who reported similar values of marginal fit for conventional cast metal-ceramic crowns (75.9 μm) and laser-sintered crowns (96.2 μm). Ucar *et al.*[22] compared the internal fit of laser-sintered and cast Co-Cr crowns, obtaining better internal fit for conventional cast crowns than for the laser-sintered ones. However, all of the studies evaluated acceptable fitting accuracies of crown produced by the laser-sintering technique. Overall, various authors investigated and compared the internal and marginal fit of CAD/CAM produced restorations with conventional fabricated prostheses, but these studies are difficult to compare because of variations in sample size, measurement method, and other parameters.

The purpose of the present *in vitro* study was to evaluate the absolute marginal discrepancy and the internal gap of metal-ceramic crowns made with the Ceramill Sintron system compared to other CAD/CAM techniques and the conventional lost-wax technique. The null hypothesis was that there is no significant difference between Ceramill Sintron fit accuracy and the established CAD/CAM techniques and the lost-wax method.

MATERIALS AND METHODS

The master model was molded with an addition-polymerized duplicating silicone (SILADENT Dr. Böhme & Schöps GmbH, Goslar, Germany) and was poured with polyurethane. By duplicating a master model, 40 working models were developed. 10 models per group were resulted. The name of groups were based on the material which was used: group_cer_sin for crowns of Ceramill Sintron, group_cer_npl for specimens of Ceramill NPL, group_gir_nb for the base material Girobond NB and group_ti_nem for test samples of Tizian NEM. These models of mandibular first molar (height: 5 mm, diameter 8 mm, circular plateau 1.5 mm) consisting of polyurethane (Biresin G24/25, SIKA GmbH, Stuttgart, Germany) were used. The molar was prepared for the intake of a ceramic veneered crown with a sloped shoulder of 120 degrees, a convergence angle of 6 degrees, and a loss of substance of 0.8 mm. To prevent rotation of the test specimens on the models, a bilateral milled groove (depth 1: 0.8 mm, depth 2: 1.3 mm) was prepared.

All models were scanned and the copings of crowns were digitally designed. For the veneering, the copings were dwindled to 1.2 mm. A thickness of 50 μm and 1.5 mm height from the finish line of tooth was defined for the cement space. The 50 μm thickness of groups of CAD/CAM techniques were achieved with the digital processing route. For specimens based on the conventional technique, the cement gap was created with die spacer. Copings of group_cer_sin (Ceramill Sintron) were produced by CAD/CAM technology. The presintered blanks were dry milled with the computerized-numerical-control-(CNC)-milling machine (Ceramill Motion 2 5X, Aman Girrbach AG,

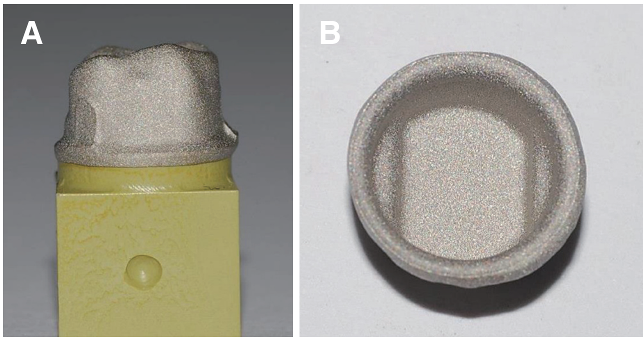

Fig. 1. Milled framework (Ceramill Sintron) after sintering without airbone-particle abrasion. (A) Outer surface, (B) Inner surface.

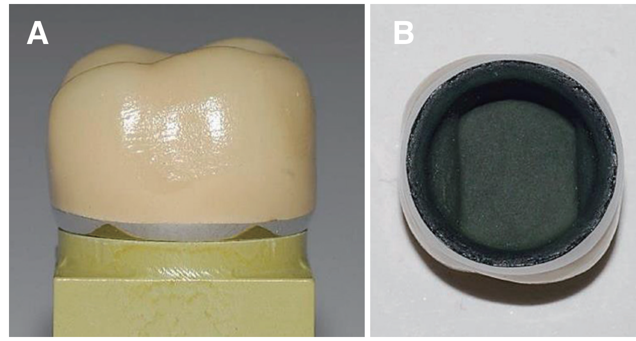

Fig. 2. Completed test specimen. (A) Outer surface, (B) Inner surface.

Pforzheim, Germany) for the manufacturing process. Then, the copings were sintered under argon atmosphere with 1300°C in furnace (Ceramill Argotherm, Amann Girrbach AG, Pforzheim, Germany) (Fig. 1). The copings of Ceramill NPL (group_cer_npl) were manufactured by using the selective laser sintering (SLS) as an additive manufacturing technique. Test specimens were constructed by controlled melting of metallic powder (Ceramill NPL, Co-Cr SP2-Pulver, Amann Girrbach AG, Pforzheim, Germany) with an ytterbium-fibre-laser (Sinteranlage EOSINT M270, EOS, München, Germany). The design of specimens of group_cer_sin was transferred with an occlusal jig. Copings of group_ti_nem were manufactured from the alloy casting Tizian NEM with the 5-axis computerized-numerical-control-(CNC)-milling machine (Tizian Cut 5 smart plus, Schütz Dental GmbH, Rosbach vor der Höhe, Germany) with a water cooling system. Test specimens consisting of the alloy casting of Girobond NB (group_gir_nb) were produced with the typical lost-wax-method in a vacuum pressure casting machine (Heracast IQ, Heraeus Kulzer GmbH, Hanau, Germany) according to the manufacturers' recommendations.

After the production process, all 40 copings were controlled of deformity and debris and steam cleaned. Next, the copings were adapted to the models until the best possible fit was achieved. The adaptation was conducted, under 4 x magnification, by an experienced technician. Inner areas of the copings that needed correction were marked using a permanent marker. The marks were applied to the teeth of the master model and the copings were placed on the die without force. If necessary, the colored spots inside the retainers were removed using a fine bur with a grit size of 46 µm (Brasseler, GmbH&Co.KG, Lemgo, Germany), and using water cooling and light pressure. This procedure was repeated until the copings achieved a uniform contact with the model teeth. Then, the outer surfaces were airborne-particle abraded with aluminum oxide (110 to 250 µm, 2-4 bar, Basis Quattro, Renfert, Hilzingen, Germany) and veneered with ceramic (bonder, opaquer and dentin material) with the aid of a jig according to the manufacturer's recommendations (Creation CC, D-A3, Willi Geller International GmbH, Breckerfeld, Germany). The veneering of specimens embraced the whole specimens with the exception of the 1 mm of the edge of framework (Fig. 2). After the veneering process, an oxide layer remained in the inner surfaces of crowns for the first measurements.

The silicon replica technique was used for determining marginal fit of Co-Cr crowns. For this procedure, the lumens of crowns were filled up with light body addition silicone (Aqium 3D Light, Müller Omikron, Lindhar, Germany), then the copings were placed onto the prepared teeth of the models and loaded with a force of 50 N in the occlusal direction. After the curing time of silicone specimens were removed from models and the silicone layer remained in the lumens of crowns. The thin silicone film represented the space between the model and the crown. Using another light body (Dublisil 20, Dreve Dentamid GmbH, Unna, Germany) and a heavy-body silicone (giroform, putty, Amann Girrbach AG, Pforzheim, Germany), silicone films of crowns were then stabilized using a jig. The replicas were segmented with a razor blade in mesio-distal and oro-vestibular direction and resulted in four measuring locations. The quartered replicas were investigated using a light-optical microscope (Leica Z16 APO, Leica GmbH, Wetzlar, Germany) connected with a digital camera (Leica DFC 320, Leica GmbH, Wetzlar, Germany) with a magnification of ×30. Overall two different measurements per measuring location were made. The microphotographs of all replicas were analyzed according to the distance measurements with the computer software. According to Holmes *et al.*,[23] absolute marginal discrepancy and the internal gap were analyzed.[24] The absolute marginal accuracy was defined as the direct distance between the outermost point of finish line of tooth and the coping margin. The internal gap is defined as the perpendicular measurement from the surface of the abutment to the inner surface of the crown at the end of the circular arc shaped preparation chamfer. In our study, all test specimens were first analyzed with the oxide layer. Oxide layers were then removed with aluminum oxide airbone-particle abrasion (110 µm, 3 bar, Basis Quattro, Renfert, Hitzlingen, Germany). With a special jig, a defined distance between the airbone-particle abrasion spray and specimen could be reached. Then, all crowns were investigated, with the replica technique as already described.

Statistical analysis was performed using SPSS for Windows, version 23.0 (SPSS Software, Ehningen, Germany). The normal distribution of data and homogeneity of variance were checked using the Kolmogorov-Smirnov and Levene tests, respectively. In order to detect whether different processing routes had a significant influence on the absolute marginal discrepancy and internal gap, multifactorial analysis of variance was used, with a level of significance set at 0.05. Differences between groups were checked for significance with the post hoc Scheffé test or, alternatively, the post hoc Tamhane test, if variances were not homogeneous.

RESULTS

Table 1 and Table 2 show detailed results for each measurement with the different processing techniques. Multifactorial analysis reveals that the processing route used has a statistically significant influence on each measurement ($P < .001$). The hypothesis that the fitting accuracy of tested crowns depends on the fabrication technique used could be confirmed. Test specimens of the group Ceramill NPL, produced by selective laser sintering, showed the lowest mean values for absolute marginal discrepancy with and without oxide layer. For the measurement of internal gap, crowns consisting of Tizian NEM achieved the lowest value with and without oxide layer.

Usually oxide layers were removed before inserting crowns. In this study, the influence of oxide layer was evaluated using the replica technique before and after removing this layer. The internal gap of test groups _cer_sin, _cer_npl, and _gir_nb decreased after removing the oxide layer. Values of absolute marginal discrepancy of groups _cer_sin, _cer_npl, and _ti_nem also decreased without the oxide layer. Statistical differences were only analyzed for the group of Tizian NEM ($P = .035$). The multifactorial analysis showed that the oxide layer has no influence on the absolute marginal discrepancy ($P = .161$) and the internal gap ($P = .279$) of crowns. Only the comparison within the individual groups exhibited an influence of the oxide layer on the milled crowns for the absolute marginal discrepancy.

DISCUSSION

In the literature, different studies were found for the investigation of fitting accuracy of ceramic and metal-based crowns produced by several techniques. However, there is a lack of published studies evaluating presintered Co-Cr alloys compared to other fabrication methods. Therefore, this study provided a comparison between three CAD/CAM techniques and a conventional technique according to the production of Co-Cr crowns. The results of the present

Table 1. Results for absolute marginal discrepancy of Co-Cr crowns by different processing routes

Group	With oxide layer			Without oxide layer			*P*
	MD	MV	SD	MD	MV	SD	
cer_sin (n = 10)	31.5	42.7[b]	5.3	20.8	27.8[b]	2.8	.050
cer_npl (n = 10)	18.6	19.8[a]	1.9	18.6	19.0[a]	1.7	.786
ti_nem (n = 10)	20.8	22.8[a]	2.1	18.6	27.7[a]	3.4	.035
gir_nb (n = 10)	18.6	21.8[a]	2.0	18.6	20.7[a]	2.0	.976

Values denoted by same index in column do not differ with statistical significance; MD median, MV mean value, SD standard deviation.
Significance level was set at 0.05.

Table 2. Results for internal gap of Co-Cr crowns of different processing routes

Group	With oxide layer			Without oxide layer			*P*
	MD	MV	SD	MD	MV	SD	
cer_sin (n = 10)	46.5	51.5[b]	3.6	47.4	49.9[b]	4.1	.647
cer_npl (n = 10)	74.9	71.9[c]	3.2	65.7	63.9[c]	3.2	.755
ti_nem (n = 10)	29.4	33.3[a]	2.4	27.9	29.7[a]	2.8	.716
gir_nb (n = 10)	61.9	75.0[c]	6.4	67.6	75.6[c]	5.5	.936

Values denoted by same index in column do not differ with statistical significance; MD median, MV mean value, SD standard deviation.
Significance level was set at 0.05.

study investigated that the tested techniques for fabrication of metal-based crowns showed statistically significant differences according the fitting accuracy at the marginal and internal positions. Therefore, the null hypothesis was rejected, as there were noticeable differences in the fitting accuracy between CAD/CAM produced and lost-wax technique fabricated restorations. The crucial point of measurement methodology is that different techniques can lead to different results according to the fitting accuracy of restorations.[25] No guidelines are available for the analysis of fitting accuracy.[26] In the present investigation, the approved replica technique was used. Different authors have used this method for investigation of marginal and internal fit of crowns.[27-29] The replica technique offers the advantage of not destroying the restorations during the analysis.[30] However, the replica technique as a 2D measurement technique is limited by the number of cross-sections regarding the fit of the whole restoration and the possibility of removal the complete elastometric film.[31,32] However, numerous authors evaluated the replica technique as a method with high reliability and validity.[33,34] In the current study, all measured values of absolute marginal discrepancy were investigated according to Holmes.[35] The absolute marginal discrepancy described the distance between the crown copings´ margin and the finish line of tooth. This section of measurements is regarded as the standard for the analysis of marginal fit of crowns because it considers the vertical and horizontal section.[26]

The marginal fit of dental restorations is one of the most important aspects for clinical long-term success.[36] Marginal gaps can lead to biological, functional, and mechanical complications like endodontic inflammation, periodontitis, marginal bone resorption and loss of retention.[37] In the literature, different *in vitro* and *in vivo* studies investigated the fitting accuracy of crowns and evaluated a marginal gap between 10 and 190 µm as an acceptable clinical range.[4,38] For example, Bhaskaran *et al.*[38] investigated a clinically acceptable gap between 10 and 160 µm for the marginal gap and 81 and 136 µm for the internal gap. Vojdani *et al.*[19] also investigated the new system Ceramill Sintron with presintered Co-Cr restorations and showed 195 µm for the mean marginal discrepancy. Vojdani *et al.* also concluded that the specimens of this new system could not showed poorer marginal and internal fit than specimens produced by conventional technique. In contrast to Vojdani *et al.*, the results of our study showed lower values of marginal fitting accuracy of metal crowns. The results of the absolute marginal discrepancy ranged between 19.8 (group_cer_npl) and 42.7 µm (group _cer_sin) with oxide layer and 19.0 (group_cer_sin) and 27.8 µm (group_cer_npl) without oxide layer. These measured values of absolute marginal discrepancy were clearly in the range of defined guiding margin so that all four processing techniques of crowns had clinically acceptable marginal fit.

The other investigated measurement variable in the present study was the internal gap, which is also an important criterion for the analysis of clinical acceptability of restorations. Large internal discrepancies can reduce the strength of crown-cement system.[39] In the literature, values regarding the maximum of clinically acceptable cement gap for an optimal retention of crowns were described as 100 µm, 120 µm and 170 µm.[12,40,41] In the current study, independent of the used manufacturing technique, all values of gap size under 100 µm with and without oxide layer could be rated as good and acceptable for dental prostheses. It has been shown that the absolute marginal discrepancy and the internal fit are significantly dependent on the type of manufacturing system. Test specimens consisting of Girobond NB showed best fitting accuracy, which can be possibly explained by the manual fitting of each specimen. The results indicate that both the digitization and computerized manufacturing process have their limitations.[40] Subtractive working systems used for test specimens of group_cer_sin and _cer_npl can cause milling inaccuracies. The precision depends on the size of the tools used during the manufacturing process. If preparation of teeth is smaller than the smallest diameter milling tools used, larger joint gaps can be possible.[42] The specimens of the selective laser sintering of group_ti_nem were made without any milling tools. Tamac *et al.*[21] evaluated insufficient fitting accuracy with laser sintering systems due to technical limitations of the laser. In this study, the influence of oxide layer of the fitting accuracy was investigated. It was shown that the fitting accuracy increased after the removing of oxide layer. The reason could be inhomogeneity in the occlusal area caused by the oxide layer. The lowest deviation after removing the oxide layer was shown for the specimens consisting of Tizian NEM.

The results of the current study showed that the new Ceramill Sintron System can be an alternative technique for the production of metal-ceramic crowns. More studies are necessary to evaluate different restorations by different production methods.

CONCLUSION

Within the limitations of the present study, it has been concluded that the Ceramill Sintron system can reach comparable results with approved manufacturing techniques according to the marginal and internal fit of Co-Cr crowns. All evaluated manufacturing techniques showed clinically acceptable values of fitting accuracy.

Further research should be carried out to obtain more detailed information about the new Ceramill Sintron system.

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