Original papers

Comparison of the marginal discrepancy of PFM crowns in the CAD/CAM and lost-wax fabrication techniques by triple scanning

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Abstract

Background. Computer-aided design/computer-aided manufacturing (CAD/CAM) systems are widely used for the fabrication of porcelain-fused-to-metal (PFM) crowns.

Objectives. This study was conducted to compare PFM crowns through triple scanning in terms of marginal discrepancy between the CAD/CAM and lost-wax fabrication techniques.

Material and methods. Twenty uniform resin dies of a prepared maxillary first molar were randomly divided into 2 groups: conventional lost-wax; and milling. Marginal discrepancy was evaluated at the framework and porcelain steps through triple scanning and direct visualization under a stereomicroscope. Then, the crowns were cemented to the related die and the marginal gap was measured with triple scanning, direct visualization under a stereomicroscope and scanning electron microscopy (SEM). The data was analyzed using the independent *t* test and the one-way analysis of variance (ANOVA). The significance level was set at 0.05.

Results. Differences in the mean marginal gap were measured by the various evaluation methods. Triple scanning and stereomicroscopy identified increasing discrepancy during the fabrication process. According to the results of the independent *t* test, stereomicroscopy showed no difference after cementation between the CAD/CAM and lost-wax groups ($p > 0.05$), triple scanning showed higher fitness in the CAD/CAM group ($p < 0.05$), and SEM showed better adaptation in the lost-wax group ($p < 0.05$); however, there was a positive correlation between the findings of stereomicroscopy and SEM ($p < 0.05$).

Conclusions. The cobalt-chromium crowns had clinically acceptable marginal fitness from both the CAD/CAM and lost-wax techniques; however, the lost-wax group showed lower marginal discrepancy after cementation according to SEM.

Key words: computer-aided design, crown, dental marginal adaptation, metal-ceramic alloys

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Introduction

The clinical durability of porcelain-fused-to-metal (PFM) restorations stems from their exact adaptation to the abutment teeth.[1] In the case of a misfit, some complications would occur, such as dental caries,[1] periodontal disease,[2–5] dental pulpitis,[3] reduced long-term success of the PFM crown,[3] and cement loss.[4]

Nickel-chromium and cobalt-chromium are popular alloys in PFM restorations. Due to nickel allergy and the toxicity of beryllium, cobalt-chromium alloys are considered the better alternative.[4] They have some characteristics, such as a relatively low cost,[5,6] stability in biological environments, corrosion resistance,[4–6] and the ease of use in computerized milling methods.[5] Cobalt-chromium alloys are used in the lost-wax and computer-aided design/computer-aided manufacturing (CAD/CAM) methods.[4–6]

Metal frameworks are conventionally fabricated using the lost-wax and casting technique, in which certain drawbacks – such as the large number of laboratory steps[2,5] and the lack of a standard cement thickness – can increase the technical sensitivity and the number of errors. Digital methods and CAD/CAM systems have become popular, as they reduce the number of laboratory steps, have a simple fabrication procedure[1] and are cost-effective.[6] It seems that the CAD/CAM method, with its fewer steps and less human interference, could lower the number of errors and enhance the fitness of restorations.

A marginal gap of less than 120 μ is clinically acceptable for long-term durability and restoration success according to a study by McLean and von Fraunhofer.[7] An increased gap size exposes the cement and bonding materials in the oral cavity, which gradually dissolve, producing a space for tiny microorganisms to penetrate, and even larger ones over time. This process results in restoration loss and tooth caries. Moreover, plaque accumulation increases and gingival health is endangered.[8–10]

The methods of evaluating the marginal gap could be categorized as either destructive or non-destructive. Restorations cannot be used after applying destructive methods like sectioning and scanning electron microscopy (SEM).[11] Non-destructive methods are commonly used and are classified into two-dimensional (2D) (like direct visualization under a stereomicroscope, profilometry and the replica technique)[12] and three-dimensional (3D) (like micro-computed tomography (micro-CT)[13] and triple scanning[14]) methods.

Several studies have compared marginal adaptation between 2 techniques of fabrication of PFM restorations – lost-wax and CAD/CAM – using different evaluation methods[1–6]; however, the results are controversial and there is no consensus. The purpose of the present study was to evaluate the marginal adaptation of cobalt-chromium PFM crowns fabricated with the lost-wax and CAD/CAM techniques through direct visualization under a stereomicroscope and triple scanning at the framework and porcelain stages as well as after cementation. After cementation, all of the samples were evaluated using SEM as the gold standard.

The null hypotheses were as follows:
- the marginal adaptation of PFM crowns is similar in both fabrication methods (lost-wax and CAD/CAM);
- the marginal adaptation of PFM crowns is similar at all fabrication steps (framework, porcelain and after cementation).

Material and methods

Preparation of the samples

In this in vitro experiment, 20 uniform resin models of a maxillary first molar were milled from a single scan of a prepared tooth for metal-ceramic restorations with the following features: a 1.5-millimeter radial shoulder finish line, an axial convergence of 6°, and an occlusal reduction of 1.5 mm in the non-functional cusp and of 2 mm in the functional cusp at a level of 45°. In each model, some notches were prepared in the base part and outside of the finish line as reference points.

Impressions were made from all samples with the one-stage putty and light-bodied wash technique using polyvinylsiloxane (Panasil®; Kettenbach, Eschenburg, Germany), then poured with type IV stone. The stone dies were randomly divided into 2 groups: conventional lost-wax; and CAD/CAM.

Framework fabrication

In the 1st group, a 30-micron spacer (Renfert® die:master system; Renfert, Hilzingen, Germany) was uniformly applied to the stone dies up to 1 mm from the finish line. The frameworks were waxed with 0.5-millimeter uniform wax (Renfert) with a lingual shoulder position 1 mm wide and 2 mm high. The wax patterns were then cylindered with an investment material (the Z4 universal investment; Neirynck & Vogt N.V., Schelle, Belgium), poured with a cobalt-chromium alloy (Wirobond® 280; Bego, Bremen, Germany), polished, and finished.

In the 2nd group, the stone dies were scanned using a laboratory scanner (an optical 3D scanner; Open Technologies, Rezzato, Italy). The frameworks were designed using the exocad® software (www.exocad.com), considering the same features as in the 1st group. The frameworks were milled from a cobalt-chromium block (ARUM Dentistry, Seoul, South Korea), using a milling machine (ARUM Dentistry).

Framework fitness evaluation

Stereomicroscopy: In both groups, the framework was seated on the related die and marginal discrepancy was observed under a stereomicroscope (SZX16; Olympus, Tokyo, Japan) at ×10 magnification. Photographs of the samples were taken and the gap size was measured in microns using the AxioVision Microscopic Imaging software (release 4.8; Carl Zeiss, Oberkochen, Germany) at the following points: 4 line angles; and the midpoints of the buccal, palatal, mesial, and distal margins. The mean values of these measurements were then compared.

Triple scanning method: In both groups, scan powder (Renfert® scan spray 1 × 200 mL (6.8 fl. oz.); Renfert) was sprayed onto the stone dies, the internal and external surfaces of the frameworks, and then all of the surfaces were scanned. Each framework was seated on the related die for the next scan. These scans were merged automatically in the software by reference points. After registration, marginal discrepancy was measured at the above points (Fig. 1).

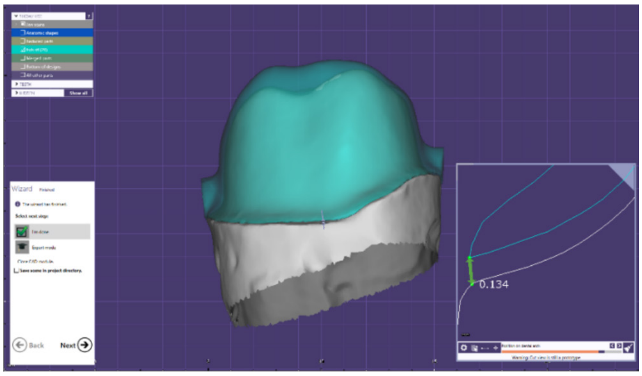

Fig. 1. Discrepancy measurement at the mid-buccal point of the margin

Porcelain application and fitness evaluation

In the next step, porcelain (Kuraray Noritake Dental Inc., Chiyoda-ku, Japan) with the same silicon index was applied in both groups by means of the layering technique (opaque, dentin and enamel) according to the manufacturer's instructions. The prepared crowns were evaluated for marginal discrepancy with stereomicroscopy and triple scanning as mentioned above.

Cementation and fitness evaluation

In the final step, all of the crowns were cemented to the related dies with zinc phosphate (Hoffmann, Berlin, Germany) under a 10-newton load, using a 1-kilogram weight. The cemented crowns were evaluated in terms of marginal discrepancy with stereomicroscopy and triple scanning. All crowns were then embedded in polyester and sectioned mesiodistally with a cutting machine (MECATOME® T 201 A; PRESI, Grenoble, France). The sectioned samples were evaluated under an electron microscope (Nova NanoSEM™ 450; FEI, Hillsboro, USA) at ×800 magnification. Marginal discrepancy was measured at 2 axial points and the mean value was used for comparison (Fig. 2).

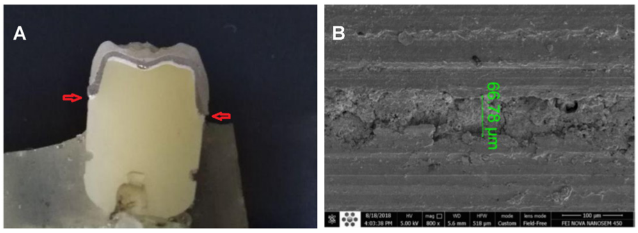

Fig. 2. Cross-sectional view of the cemented crown and marginal discrepancy measured at the 2 depicted points (A); evaluation at ×800 magnification, using the QUANTAX micro X-ray fluorescence (micro-XRF) software (www.bruker.com)

Data analysis and statistics

The statistical analysis was performed using IBM SPSS Statistics for Windows, v. 22.0 (IBM Corp., Armonk, USA). The independent *t* test was used to compare the different fabrication methods at each step (framework, porcelain and cementation). The one-way analysis of variance (ANOVA) was used to evaluate the discrepancy at different steps in each group (lost-wax and milling). The significance level was set at 0.05.

Results

Marginal discrepancy was measured at each fabrication step (framework, porcelain and cementation) in both study groups.

Framework

According to the independent *t* test results, triple scanning showed a smaller marginal gap in the CAD/CAM group ($p < 0.001$), while stereomicroscopy revealed no significant difference between the 2 groups ($p > 0.05$) (Table 1).

Table 1. Mean marginal gap of the crowns fabricated with the computer-aided design/computer-aided manufacturing (CAD/CAM) and lost-wax techniques at the framework step

Evaluation method	Study groups	Marginal gap [µ]	*p*-value
Stereomicroscopy	CAD/CAM	94.44 ±22.02	0.970
	lost-wax	94.70 ±12.29	
Triple scanning	CAD/CAM	57.75 ±9.61	<0.001
	lost-wax	82.93 ±13.85	

Data presented as mean (*M*) ± standard deviation (*SD*).

Porcelain

After porcelain application, neither stereomicroscopy nor triple scanning showed significant differences in marginal discrepancy between the study groups ($p > 0.05$) (Table 2).

Table 2. Mean marginal gap of the crowns fabricated with the CAD/CAM and lost-wax techniques at the porcelain step

Evaluation method	Study groups	Marginal gap [μ]	*p*-value
Stereomicroscopy	CAD/CAM	100.81 ±19.52	0.690
	lost-wax	104.12 ±16.87	
Triple scanning	CAD/CAM	102.20 ±26.20	0.090
	lost-wax	118.32 ±12.27	

Data presented as *M* ±*SD*.

Cementation

According to the independent *t* test results, a smaller marginal gap was visible in the CAD/CAM group with triple scanning ($p < 0.05$), while stereomicroscopy did not reveal any significant difference between the 2 groups ($p > 0.05$). By contrast, SEM showed a smaller marginal gap in the lost-wax group as compared to the CAD/CAM group ($p < 0.05$) (Table 3).

Table 3. Mean marginal gap of the crowns fabricated with the CAD/CAM and lost-wax techniques after cementation

Evaluation method	Study groups	Marginal gap [μ]	*p*-value
Stereomicroscopy	CAD/CAM	119.87 ±30.76	0.730
	lost-wax	123.75 ±17.46	
Triple scanning	CAD/CAM	116.86 ±11.76	0.049
	lost-wax	131.28 ±17.07	
SEM	CAD/CAM	91.09 ±63.98	0.030
	lost-wax	40.60 ±20.85	

Data presented as *M* ±*SD*.
SEM – scanning electron microscopy.

Marginal discrepancy changes at the fabrication steps

The mean marginal gap was calculated at each step, for both methods and all samples. The results are presented below.

Triple scanning

Based on the triple scanning evaluation of the steps, the marginal gap was 71.00 μ for the framework step, 110.69 μ for the porcelain step and 124.45 μ for the cementation step. The difference was significant according to the one-way ANOVA ($p < 0.05$).

Stereomicroscopy

Based on the stereomicroscopic evaluation of each step, the marginal gap was 94.58 μ for the framework step, 102.55 μ for the porcelain step and 121.91 μ for the cementation step. The difference was significant according to the one-way ANOVA ($p < 0.05$).

Correlation of different measurement methods

Pearson's correlation test was used to evaluate the correlation of the results of triple scanning, stereomicroscopy and SEM at different steps:
– framework: there was no significant correlation between triple scanning and stereomicroscopy (correlation: −0.22; $p > 0.05$);
– porcelain: there was a moderate negative correlation between triple scanning and stereomicroscopy (correlation: −0.561; $p < 0.05$);
– cementation: there was no significant correlation between triple scanning and stereomicroscopy (correlation: −0.296; $p > 0.05$); a moderate positive correlation was found between stereomicroscopy and SEM (correlation: 0.546; $p < 0.05$), but there was no significant correlation between triple scanning and SEM (correlation: −0.417; $p > 0.05$).

Discussion

The purpose of this study was to compare the marginal fitness of PFM crowns between the lost-wax and CAD/CAM fabrication methods at different stages of the process (framework, porcelain and cementation), using 3 evaluation methods – triple scanning, stereomicroscopy and SEM. The null hypotheses were rejected. After cementation, SEM – as the gold standard method – revealed significantly higher marginal adaptation in the lost-wax group, and the marginal gap increased significantly through the fabrication steps (from framework to porcelain to cementation).

Stereomicroscopy

No difference was found between the CAD/CAM and lost-wax methods at the framework step. This finding was consistent with studies conducted by Gunsoy and Ulusoy[15] and Jung,[1] but it was in contrast to the results of studies performed by Nesse et al.[5] and Kim et al.[6] In 2015, Nesse et al. reported better marginal adaptation in the CAD/CAM group. The difference could be due to the evaluation method, since Nesse et al. observed the replica under a microscope, which is more sensitive than direct visualization.[5] In 2017, Kim et al. found higher marginal fitness in the lost-wax group. They used implant abutments as samples, and the detection of gaps under a microscope could have been more difficult due to the loss of adequate contrast between the framework and the abutment.[6]

No difference was found between the CAD/CAM and lost-wax methods at the porcelain step, which was not consistent with the results of a study by Shokry et al., who reported lower marginal fitness in the lost-wax group.[9]

Differences in the finish line, die material and CAD/CAM system could have caused these inconsistent results.

No difference was found between the CAD/CAM and lost-wax techniques after cementation; this finding was not consistent with a study by Kaleli and Saraç, who reported significantly higher marginal fitness in the CAD/CAM group.[2] This difference could be due to the use of different CAD/CAM systems, alloys and cementation procedures, or other unknown confounding factors.

The comparison of the marginal gap through different fabrication steps by means of stereomicroscopy revealed a gradual increase in both the CAD/CAM and lost-wax groups. This finding was consistent with studies conducted by Kaleli and Saraç,[2] Shokry et al.[9] and Hafezeqoran et al.[10]

Triple scanning

According to the results of triple scanning, significantly higher marginal fitness was observed in the CAD/CAM group at the framework step, no significant difference was found between the 2 groups at the porcelain step and significantly higher marginal fitness was noted in the CAD/CAM group after cementation. The comparison of the marginal gap through different fabrication steps by means of triple scanning revealed a gradual increase in the gap size in both groups.

Scanning is a non-destructive 3D measurement method. In 2011, Holst et al. described the triple scanning method, tested it in 50 samples, and suggested it as a reliable and repeatable technique.[14]

In 2015, Kuhn et al. used a charge-coupled device (CCD) camera to digitize a die with and without a respective replica.[12] The scans were recorded with a direct registration tool in the same alignment, and the difference in the point cloud of the die with and without the replica represented the gap space. They claimed that a digital, computer-based method could be beneficial for a 3D analysis, without information loss.[12]

Furthermore, Kane et al. used a 5-axis laser scanner to produce 3D models of dies with and without a replica, and evaluated marginal and internal fitness by superimposing 2 scans.[4] This method has the sensitivity of the replica technique, but may lead to silicon tearing and scan errors.

In 2017, Park et al. used an intraoral scanner and software for the 3D analysis of fitness.[16] In their recommended technique, an intra-coronal, ceramic-type restoration was used, which has less reflection and does not require the application of powder. Moreover, registration and superimposition were performed through intact nearby teeth. The authors only suggested the method and no further research was done regarding its accuracy.[16]

In 2017, Dahl et al. used the triple scanning method as used in the present study to compare the internal fitness of single crowns (made of ceramic and cobalt-chromium) fabricated with different methods.[17] This study found that lost-wax and conventional casting resulted in better adaptation than CAD/CAM (the ceramic and metal framework),[17] which was in contrast to the results of the triple scanning method in the present study. The difference could be due to the smaller sample size of the former study and the different scanners and software used.

Scanning electron microscopy

The SEM evaluation after cementation showed better marginal fitness in the lost-wax group as compared to the CAD/CAM group.

It is worth noting that the mean marginal gap was clinically acceptable in both the CAD/CAM (91.09 μ) and lost-wax (40.60 μ) groups according to McLean and von Fraunhofer, who considered a gap size of less than 120 μ as a criterion for long-term stability and success.[7]

Comparison of different evaluation methods

Scanning electron microscopy is considered a valid and reliable method and the gold standard, as it is based on different conductivities of elements and is more accurate. However, this method is not routinely used, because it requires advanced equipment and gold coating, and is therefore costly.[3] It is destructive and evaluation is limited to the sectioned area.

Stereomicroscopy correlated with the gold standard, SEM. It is a non-destructive method and can be performed in all the parts of the margin. However, it is unable to evaluate the internal fitness and horizontal discrepancy.[14] The following points are important in stereomicroscopy: fixing the samples during photography; setting the same angle in all samples; setting the appropriate image contrast in the software; avoiding human error in determining the points for gap measurement; and calibrating the measurement software.

Triple scanning showed no correlation with SEM and stereomicroscopy. One reason could be the inability to apply a uniform layer of the scan powder (especially on the inner surfaces of the crowns), which affects the accuracy of scans. Furthermore, difficult access to some areas (undercuts and fissures) should be considered.[12] Moreover, optical scanners cannot detect the thin edges or margins of the framework, which may result in the incorrect interpretation of large discrepancy.

The application of titanium oxide powder to scan the reflective intaglio surface of the crown would produce a model that has a tighter fit than in reality because of the powder thickness. Holst et al.[14] and Matta et al.[18] found that this error was insignificant whereas it resulted in a major inaccuracy in the present study. In the current study, the intaglio surface was registered as tighter, overlapping and passing the die surface in some areas after superimposition, and the cement space was omitted, resulting in negative discrepancy. According to the results, the discrepancy measured by this method did not correlate with direct visualization under a stereomicroscope or SEM.

After scanning, the data should be recorded. This can be performed by superimposing points or surfaces to position the data in the same coordinates. This is one of the key steps of a 3D analysis. This step is also prone to some errors.[19] We believe that triple scanning may not be trusted yet, and that more research is needed.

Conclusions

The cobalt-chromium crowns had a clinically acceptable marginal fitness from both the CAD/CAM and lost-wax methods; however, the lost-wax method was associated with lower marginal discrepancy after cementation. According to the results, triple scanning could not be trusted with regard to evaluating the fitness of PFM crowns.

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