Factors affecting the success of partial fixed dental prostheses (FDPs) are multiple and complex. Internal and marginal fit are relevant when considering retention, marginal seal, and cement gap.1 No consensus exists on a clinically acceptable cement gap. A cement gap of 120 μm has been suggested as the maximum,2 whereas other studies have shown that 50 to 100 μm is acceptable.3 Poor marginal fit increases the chance of developing periodontal disease and caries.4-9 Metal ceramic restorations can be made with noble and non-noble alloys. The noble alloys are well documented and give the best fit for cast restorations.10,11 Metal ceramic restorations with cobalt-chromium (Co-Cr) alloys are increasingly used because of their low cost, biocompatibility, and ease of production with modern digitalized methods. However, scientific documentation is scarce.

The fabrication method for Co-Cr restorations has been conventional casting with the lost-wax method. Milling and selective laser melting (SLM) are more cost effective and thereby increasingly used. The precision of the different methods regarding internal and marginal fit, however, is not fully known.12-14 Metal ceramic restorations with Co-Cr alloys are increasingly used because of their low cost, biocompatibility, and ease of production with modern digitalized methods. However, scientific documentation is scarce.

The fabrication method for Co-Cr restorations has been conventional casting with the lost-wax method. The many steps in the production increase the number of variables that can cause discrepancies in the definitive product. Dental technicians, for instance, commonly use a die spacer to make room for the cement when waxing the restorations. The thickness of the spacing layer is difficult to standardize, which explains some of the variation in the internal fit for cast restorations.12-14 A technology that involves fewer manual steps in the
Fabrication method affects the internal and marginal fit of dental restorations. The selective laser melting method examined here had clinically unacceptable fit. Poor fit reduces the clinical survival of both the restoration and the abutment tooth.

Manufacturing process and that may reduce some of the errors is the computerized system, computer aided design/computer aided manufacturing (CAD/CAM). However, the following factors can affect the fit of CAD/CAM restorations, as well: scanner precision, transformation of the scanning data into 3-dimensional models, and precision of the milling machine. The disadvantages of this method are expensive milling tools, time-consuming processes, waste products, and wear of equipment. Selective laser melting (SLM) uses a high-temperature laser to sinter a metal powder, which is then fused together layer by layer. The add-on production method is cost effective, produces little waste, and does not wear the equipment. The mechanical properties are similar to or better than those of cast or milled alloys. The precision of the milling machine is considered a reliable way of measuring in vivo, and low interoperator repeatability. The replica technique is considered a reliable way of measuring internal fit nondestructively but may be less suited for the assessment of marginal fit.

The purpose of this in vitro study was to evaluate whether the fabrication method affected the internal and marginal fit of 3-unit FDPs in Co-Cr. The null hypothesis was that no differences would be found in internal and marginal fit among the 3 methods.

**MATERIAL AND METHODS**

Plastic model teeth were positioned in a complete-mouth dental model (Frasaco) and manually prepared for a metal ceramic 3-unit FDP from maxillary first premolar to first molar, with a shallow circumferential chamfer preparation. Preparations were inspected with light microscopy and a surveyor to ensure they were free from undercuts, that both preparations had the same path of placement, and that the taper was between 10 and 15 degrees. A 2-step technique with light body and putty (Affinis; Coltène/Whaledent) was used for making an impression. Thirty Co-Cr metal frameworks were fabricated with 3 different methods: conventional casting, milling, and SLM (Table 1). Ten FDPs were fabricated using each of the 3 techniques. Specifications given for the design were to use 1 layer of die spacer for the cast specimens and a 50- to 55-μm cement gap for the milled and SLM restorations. The gingival 1 to 1.2 mm at the cervical margin was without spacer or with a constricted cement gap with a smooth transition between the regions.

A white silicone indicator material (Fit Checker; GC Corp) was used to simulate the cement space. The inner surfaces of the restorations were coated and placed on the corresponding tooth abutments, using firm hand pressure to simulate a clinical situation. The silicone cement film was fixed with a heavy-body silicone (Xantopren; Heraeus Kulzer) before removal and sectioned with a scalpel in a buccolingual direction and subsequently in a mesiodistal direction. Thirteen measurements were made for each crown, equaling 26 points for each FDP (Fig. 1). The cement gap was measured on images made with light microscopy at ×20 magnification and a digital measurement program (NIS Elements). Two examiners (D.M.U., M.M.V.) performed all measurements in a blinded procedure. A reliability analysis was made from 7 measurement points on 4

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Production Method</th>
<th>Composition in % by Weight</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cara Co-Cr milled</td>
<td>Milled</td>
<td>Co, 59-63; Cr, 27-29; W, 8-9</td>
<td>Heraeus Kulzer GmbH</td>
</tr>
<tr>
<td>Cara Co-Cr SLM</td>
<td>Selective laser melting</td>
<td>Co, 61-65; Cr, 23-25; Mo, 5; W, 5-10</td>
<td>Heraeus Kulzer GmbH</td>
</tr>
<tr>
<td>Wirobond C</td>
<td>Casting</td>
<td>Co, 61; Cr, 26; Mo, 6; W, 5</td>
<td>BEGO Implant Systems</td>
</tr>
</tbody>
</table>

Figure 1. Thirteen measurement points for internal fit measurements in cross-sections in buccopalatal and mesiodistal direction. B, buccal; P, palatal; M, mesial; D, distal.

Table 1. Overview of materials used, production method, composition, and manufacturers of 3 different methods used for manufacturing of 3-unit Co-Cr FDPs.
crowns measured on 4 separate occasions. The intra-class correlation coefficient (ICC) for the repeated measurements was .98 (P<.001).

The marginal fit was evaluated with direct-sight technique at a 90-degree angle on the tooth surface at ×4.6 magnification. Preparations were colored with a red marker so that the preparation border could be clearly seen. A grading system from 1 to 5 was developed for the evaluations, where 1 was poor fit and 5 was excellent fit (Table 2). Each tooth surface was graded on all abutments. The result for each tooth was determined by the poorest tooth surface. All over-extended crowns were registered as 3, a moderate, marginal fit. This was because of the difficulties of evaluating the magnitude of the overextension based on this method. To validate the grading system, 4 different examiners tested and retested 10 FDPs before the main study. The result of the ICC between operators was .6, which is good. The grading system was slightly modified after these tests to further improve reliability.

Two specimens from each group were selected for examination of the internal surface using scanning electron microscopy (SEM) (Zeiss). Furthermore, 1 specimen from each group was sectioned through the axial wall, and the cross-sections were examined by light microscopy.

Statistical software (SPSS v22; IBM Corp) was used to calculate means ±standard deviations of the internal and marginal fit. One-way ANOVA and Tukey HSD tests were used to evaluate differences among groups with regard to internal fit. The Kruskal-Wallis and Mann-Whitney U tests were used to calculate differences among groups with regard to marginal gap. The Pearson r was used for correlations calculations (α=.05). Calculations showed that 10 specimens were necessary in each group to find a 20% difference among groups with a power of .80 and a level of significance of .05.

Table 2. Grading system used to assess marginal fit

<table>
<thead>
<tr>
<th>Grade 5</th>
<th>Grade 4</th>
<th>Grade 3*</th>
<th>Grade 2</th>
<th>Grade 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description: Excellent marginal fit: crown has a perfect seating and covers entire prepared tooth surface. Red marking is not visible.</td>
<td>Description: Good marginal fit: crown extends to preparation margin on most parts of surface. Modest red line visible in small areas.</td>
<td>Description: Moderate marginal fit: crown generally does not fully extend to preparation margin. Not very pronounced red line.</td>
<td>Description: Unsatisfactory marginal fit: large parts of crown do not extend to preparation margin. Clearly visible red line.</td>
<td>Description: Particularly poor marginal fit: No part of crown extends to margin. Large areas of red line visible.</td>
</tr>
</tbody>
</table>

*Grade 3 was also used for overextended crowns.

Figure 2. Mean ± SD values of internal fit, as error bars in axial walls, occlusal wall, and overall for each fabrication method. Bars marked with same letters were not statistically significantly different from each other (P<.05). SLM, selective laser melting.

Figure 3. Mean ± SD marginal fit on a scale from 1 to 5, where 5 is optimal fit and 1 is poor marginal fit. Score is given for 2 abutments in 3-unit FDPs in 3 groups. Bars with same superscript letters were not statistically significantly different from each other (P<.05). FDP, fixed dental prostheses; SLM, selective laser melting.
RESULTS

Statistically significant differences were found in internal fit among the 3 fabrication methods (P<.001, 1-way ANOVA) (Fig. 2). The mean measurement point within each group showed that the milled group had the best internal fit (95 μm), followed by the cast (116 μm) and SLM groups (156 μm); the range was 0 to 630 μm.

Statistically significant differences were also found in marginal fit among the groups (P<.003, Kruskal-Wallis) (Fig. 3). The mesial and distal surfaces of the premolar had the best marginal fit in general, whereas the buccal surface of the molar had the poorest marginal fit for all groups. SEM analyses and cross-sectional images showed evident differences in surface structures and tortuosity among the 3 different groups (Figs. 4, 5). A statistically significant correlation was found between internal and marginal fit (r = −.434; P = .001) (Fig. 6).

DISCUSSION

The results show that the null hypothesis that no differences would be found in internal and marginal fit for the 3 different production techniques can be rejected. The SLM method differs most from the 2 other methods. Similar results have been found in other studies of SLM 3-unit FDPs in Ni-Cr. The mean internal fit for the 3 groups was influenced largely by the occlusal gap but more so for the SLM FDPs than for the other 2 groups. This is in accordance with other studies. The measurement point on the buccal cusp had the largest cement gap, independent of fabrication method and abutment. Differences in cement gap along the axial walls may be a result of differences in taper on the different walls or a nonideal path of placement. These factors, however, were equal for all specimens. The measurement points with the smallest gap were along the axial walls, and this was similar for the cast and SLM groups.

Several factors can explain why the occlusal and axial spaces differ in general and why they vary among the 3 groups. The cervical constriction was more marked on the silicone film for the SLM restorations than for the other restorations (Fig. 7). A tight cervical restriction reduces the risk of marginal leakage and dissolution of the cement. A disadvantage is that this complicates the cement escape during insertion, creating a larger axial...
discrepancy and accumulation of cement on the occlusal surface.

The FDPs in the cast group had the best internal fit occlusally. In addition, they had the lowest scatter in internal space at all measurement points. The axial cement gap was largest for the cast group, which may indicate that the excess cement escaped easily during insertion and therefore did not accumulate occlusally.
The cast restorations, however, did not have better marginal fit than the milled group, indicating no differences in seating in these 2 groups.

Most of the examined FDPs, regardless of fabrication method, were underextended. The milled FDPs had the best marginal fit. Both the overextended and the underextended restorations can have poor marginal fit. Overextended crowns represent the biggest risk for retaining periodontal pathogens and reduce the prognosis for the abutment tooth.17 Underextended crown margins can have a good marginal seal, but the rough surface of the uncovered prepared tooth can enhance bacterial accumulation.6,7,17-19 Underextended margins may be due to poor seating or nonide axial wall tapers. Underextension was especially marked at the mesiolingual surface of the premolar, where all restorations were short. This may have been due to a system error in either the impression or cast and thus not an error caused by the fabrication method. The mesiolingual point was therefore excluded from the analyses.

FDPs in this study were not completely processed for clinical use because they were delivered directly from production without internal airborne-particle abrasion, external polishing, or the final adjustments usually performed by the dental technician before clinical evaluation. The lack of internal airborne-particle abrasion probably has the greatest impact on the SLM restorations, as this production method had the largest surface roughness on the intaglio. Cast and milled restorations are not necessarily subjected to airborne-particle abrasion before insertion. A cross-sectional image of the crown wall of an SLM restoration shows clearly that protruding metal pearls may have prevented optimal seating (Fig. 5). The correlation between marginal and internal fit supports this. It is unlikely, however, that the largest observed pearls would have been removed by airborne-particle abrasion. Other studies have found internal fit of SLM-fabricated restorations that were both better and poorer than that of conventional casting and milling.12,13 Precision may differ among the production systems; furthermore, the method will certainly be further developed and refined in the future.

Different methods have been used to evaluate marginal fit. The replica method is widely used and has several advantages, although detecting overextended and underextended restorations is difficult.10,19-21 SEM images of replicas of the crown margins in situ are part of an established and reproducible procedure, based on comparable conditions and semiquantitative analyses.3 This method is complicated, and small errors in impressions or casts can reduce the value of the method. The in vivo method is the most clinically relevant, but it is difficult to make precise measurements. There is disagreement regarding which method is best suited to evaluate marginal fit. The direct-sight technique is the method most widely used and gives the most reproducible results.22 Image analysis software may be used to calculate the degree of misfit. This does not detect all aspects of marginal fit, as the software cannot distinguish between perfect fit and overextended margins. Interoperator measurements indicated that evaluation of the marginal fit was somewhat operator-dependent. The intraoperator measurement for internal fit revealed that measurements of the cervical measurement point had the lowest reliability. The use of 2 methods in combination increases validity.

CONCLUSIONS

The SLM technique produced the poorest internal and marginal fit, whereas the milling technique produced the best fit. As for internal fit, the SLM FDPs tested did not have clinically acceptable values.

REFERENCES


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