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Effect of production method on surface roughness, marginal and internal fit, and retention of cobalt-chromium single crowns

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ABSTRACT

Statement of problem. New production methods have been developed for metal ceramic restorations. Different production methods may show different surface roughness and fit, which may affect retention and long-term success.

Purpose. The purpose of this in vitro study was to examine 3 different production methods with regard to surface roughness, marginal and internal fit, and the retention of cobalt-chromium alloy single crown copings.

Material and methods. A master abutment of a premolar mandibular tooth preparation with 4-mm height and a 0.6-mm deep 120-degree chamfer finish line with a 12-degree angle of convergence was replicated in die stone and scanned. Thirty-six cobalt-chromium alloy copings were produced using 3 different production techniques. Twelve copings were produced by laser-sintering (LS), 12 by milling (M), and 12 by milled wax/lost wax (MLW). The surface microstructure of 2 copings in each group was analyzed using interferometry. The remaining 10 copings in each group were used to evaluate marginal and internal fit by using an impression material replica method, and retention was evaluated by using a uniaxial tensile force pull-off test. The copings from each test group (MLW, M, and LS) were cemented with zinc phosphate cement onto resin abutments. Statistical analyses of differences in marginal and internal fit were performed using one-way ANOVA and the Mann-Whitney test. Differences in surface topography were analyzed with the Kruskall-Wallis and Mann-Whitney tests for nonparametric
Results. Differences in surface microstructure were seen. The LS copings showed increased surface roughness compared with M and MLW copings. Differences in marginal and internal fit were noted. LS copings showed significantly smaller spaces between coping and abutment than MLW copings ($P=.003$). At the margins, LS copings showed significantly smaller spaces than both MLW ($P=.002$) and M ($P=.002$). At the chamfer, LS copings showed significantly smaller spaces than MLW ($P=.005$). At the center of the axial walls, LS copings showed significantly smaller spaces than MLW ($P=.004$) and M copings ($P=.005$). No significant differences were noted between M and MLW copings ($P>.05$). No significant differences were detected regarding retentive forces in the pull-off tests ($P>.05$).

Conclusions. Laser-sintered Co-Cr crown copings showed increased surface roughness and better internal and marginal fit than copings produced by milling or the milled wax/lost wax technique. However, the crown pull-off tests did not reveal any significant differences.

CLINICAL IMPLICATIONS

Cobalt-chromium alloy copings produced by laser-sintering may reduce the risk of complications due to increased surface roughness and improved fit.

INTRODUCTION

The use of cobalt-chromium (Co-Cr) alloys for crowns and fixed dental prostheses has increased largely because of their excellent mechanical properties and their lower cost compared with high-noble alloys.¹ However, some problems in the traditional fabrication process, casting, are
known.\textsuperscript{1-3} Although casting shrinkage has largely been overcome, accuracy may be compromised; also the high hardness of the alloy makes finishing difficult.\textsuperscript{1-3} Recently developed production techniques, with computer-aided design and computer-aided manufacturing (CAD-CAM) provides better standardization.\textsuperscript{4,5} In addition, the working environment for dental technicians may be improved when production using base metal alloys with potential adverse health effects develops into controlled procedures with less exposure to vapor and airborne particles.\textsuperscript{6,7} The costs for CAD-CAM production were initially higher. The machines are expensive and subtractive techniques are associated with material waste.\textsuperscript{4} Nevertheless, this difference is outweighed by the fact that CAD-CAM techniques are more time efficient.\textsuperscript{4,5}

Several computer-aided manufacturing techniques are currently available, including milling (M), laser-sintering (LS), and milled wax/lost wax (MLW).\textsuperscript{4} Milling has the advantage that restorations are produced from optimal quality material blocks.\textsuperscript{4,5} However, limitations exist in the shape and fit of the restorations as this depends on the number of axes performing the milling and the size of the milling burs.\textsuperscript{4,5} With laser-sintering, an additive technique, there are no such limitations and left-over powder may be reused.\textsuperscript{4,5} Laser-sintering may thus provide advantages such as better material economy, improved fit, and unlimited complexity of the shape of the restorations.\textsuperscript{4,5}

Fabrication procedures influence a restoration’s surface roughness, fit, and retention.\textsuperscript{5,8,9} Poor quality production may result in a poor fit and thereby increased risk of complications such as dental caries and loss of retention, 2 common reasons for the clinical failure of metal ceramic crowns.\textsuperscript{10-12} What constitutes an adequate fit has not been satisfactorily resolved. Theoretically
based goals for film thickness range from 25 to 50 µm, but a discrepancy of up to 120 µm is considered acceptable based on in vitro and clinical studies.\textsuperscript{13-16}

Different ways of measuring the fit of a restoration have been reported. The present study used a replica technique with proven reliability.\textsuperscript{17,18} The technique may present some practical problems such as the risk of air bubbles at the interface between light- and heavy-body impression material and tearing.\textsuperscript{14} An alternative method is to cement the copings onto the abutments and measure the cement film thickness after sectioning. However, that technique does not eliminate the risk of defects and is destructive.\textsuperscript{14,17,18} The method chosen in the present study allowed the same copings to be used in retention tests.

Surface roughness is one of several factors that influence retention.\textsuperscript{9,19-22} The impact of the production method has been addressed, suggesting that the surface roughness of Co-Cr crowns differs depending on production technique.\textsuperscript{8} Most studies suggest advantages for restorations produced by laser-sintering, but not all agree.\textsuperscript{5,23,24} Not enough data are yet available to provide clinicians with clear guidelines regarding which production technique to choose to achieve best possible fit and thereby reduce the risk of complications. Therefore, the purpose of this study was to compare a subtractive CAD-CAM-technique, milling, and an additive CAD-CAM-technique, laser-sintering, regarding surface topography, marginal and internal fit, and retention. A version of a manual technique, milled wax/lost wax, was included for comparison. This technique shows many of the drawbacks of a manual procedure but facilitates comparison as it allows for standardized coping shapes as the wax copings are milled from the same original master file used for the 2 CAD-CAM techniques.

The null hypothesis was that no differences would be found among groups in terms of surface roughness, fit, or retention.
MATERIAL AND METHODS

A brass master abutment resembling a mandibular premolar tooth preparation and with 4 mm-height and a 0.6 mm deep 120-degree chamfer finish line with a 12-degree angle of convergence was replicated using a polyvinyl siloxane (PVS) laboratory impression material (Dublisil 15; Dreve Dentamid) (Fig. 1). The mold was poured in stone (GC Fujirock EP; GC EUROPE N.V.) to create a working model which was scanned using a 3-dimensional (3D) scanner (Everest scan pro 4101; KaVo Dental).

A coping with a uniform material thickness of 0.5 mm was designed (Everest CAD-software v.2; KaVo Dental) and milled from a plastic material (Everest C-Cast ronde (100/20); KaVo Dental) in a milling machine (Everest engine 4140; KaVo Dental). A retention device was waxed onto the occlusal surface of the plastic coping with modeling wax (Thowax; Yeti Dental) and was attached to a sprue former. The wax pattern was invested (GC Fujivest Premium; GC EUROPE N.V.) and subsequently eliminated and cast in Co-Cr alloy (Wirobond 280; BEGO) using a vacuum casting machine (Nautilus SCC, BEGO) to create a prototype crown coping (Fig. 2).

A copy of the master abutment and the prototype coping were sent to a dental laboratory (M-Tec Dental). A double scan was made using a 3D laser scanner (3Shape D700 3D Scanner; 3Shape), resulting in a master file which was used for the production of all copings irrespective of production method. The cement film thickness was set to 50 µm except for the 0.5 mm proximal to the finish line where it was set to zero. Twelve copings were produced for each of the experimental test groups (M and LS) and the control group (MLW). No power analysis was performed for the present study. The choice of number of specimens was based on the results of
a literature review which revealed that the majority of publications on this topic evaluate between 8 and 12 specimens per group.\textsuperscript{4,5,8,9,23,24}

The M copings were produced from Co-Cr alloy disks (Gialloy CB type 5; BK Giulini) using a computer-controlled milling machine (Roeders RXD5; Roeders). LS copings were produced from a powdered Co-Cr alloy (Remanium Star CL, Powder 10-40 μm; Dentaurum) using direct laser metal sintering (Mlab cusing; Concept Laser). The copings in the MLW group were produced by a dental technician at the Faculty of Odontology (Malmö University). Plastic copings (Everest C-Cast ronde (100/20); KaVo Dental) were milled from the master file, attached to a sprue former, invested, and eliminated. The copings were cast in Co-Cr alloy (Wirobond 280; BEGO) in a vacuum casting machine (Nautilus CC; BEGO).

The copings of all test groups were airborne-particle abraded using 125-μm aluminum oxide particles at 0.2 MPa pressure at a distance of 5 cm between copings and nozzle (Renfert basic classic; Renfert). The copings were cleaned of aluminum oxide particles using compressed air.

Two copings from each test group were embedded in epoxy resin (EpoFix; Struers). After 24 hours of autopolymerization, the copings were sectioned into 3 pieces with 2 perpendicular cuts. The surface was analyzed with an interferometer (MicroXAM; ADE Phase Shift Technology Inc) with MapVue software (MetaMAP). The arithmetic average height deviation from the mean plane, $S_a$, was measured at 6 areas, $200 \times 260 \, \mu\text{m}$ at $\times50$ magnification, on each coping. A Gaussian filter of $50 \times 50 \, \mu\text{m}$ was applied to remove errors.

To measure the cement space, the original master abutment was duplicated with a PVS impression material (Dublisil 15; Dreve Dentamid). The impression was poured with epoxy resin (EpoFix; Struers) and left to autopolymerize for 24 hours. Each coping was filled with a green light-body PVS (Express 2; 3M ESPE) and fitted to the epoxy resin abutment under a constant
force of 11 N for 5 minutes. Once polymerization was complete, the epoxy resin abutment was removed and the void was filled with a lilac heavy-body PVS (Flexitime; Heraeus Kulzer) and left to polymerize for 5 minutes. All 30 silicone replicas were then sectioned with a fine blade (Carbon Steel Blade #15; BRAUN, Aesculap AG). The blade was changed before sectioning each group. Sectioning was performed in the center of, and perpendicular to, the occlusal surface (Fig. 3). The measurements were performed by 1 observer (SK). Nine points per replica were registered using a stereomicroscope (Wild M7A; Wild Heerbrugg AG) at x31 magnification (Fig. 4). Images were made with a digital camera (Leica DFC 420; Leica Microsystems), and observations were aided by corresponding software (Leica Application Suite v.4.1; Leica Microsystems).

For the pull-off retentive tests, the original master model was duplicated using PVS (Dublisil 15; Dreve Dentamid). The master abutment was set into a wider brass cylinder, which allowed for a collar that served as a retentive device when attached to the universal testing machine (UTM). Thirty impression molds were made. The molds were poured with epoxy resin (EpoFix; Struers) that was allowed to autopolymerize for 24 hours. The copings from each test group (MLW, M, and LS) were cemented onto the resin abutments with zinc phosphate cement (Harvard; Harvard Dental International). Before cementation, the intaglio surfaces of the copings and the resin abutments were cleaned with 70% ethanol and dried. After cementation, the test specimens were stored in plastic containers with moisture to prevent desiccation before testing.

Retention testing was performed in a universal testing machine (UTM) (Instron 4465; Instron) at a crosshead speed of 0.5 mm/min. A clamp connected to a chain was used to attach the copings to the UTM. The suspension allowed the force to be perpendicular to the copings’
occlusal surface. A metal disk kept the abutment in place (Fig. 5). Retention was determined as the peak uniaxial tensile force needed to dislodge the copings from the abutments.

All statistical calculations were made with software (IBM SPSS Statistics v22; IBM Corp) in collaboration with a statistician at Lund University. Statistical analyses of differences in marginal and internal fit were performed using one-way ANOVA and the Mann-Whitney test. Differences in surface topography were analyzed with the Kruskall-Wallis and Mann-Whitney tests for nonparametric data. Differences in retentive values were analyzed using the Mann-Whitney test for nonparametric data (all $\alpha=.05$).

RESULTS

Differences in surface microstructure were seen among the 3 groups regarding average height deviation, $S_a$. The M copings showed a lower average deviation from the mean plane than MLW and LS copings. The MLW copings displayed a lower average deviation than LS copings. The LS copings displayed grooves and peaks, while copings of the M and MLW groups displayed a more homogenous surface topography (Fig. 6).

LS copings showed significantly smaller spaces between coping and abutment than MLW copings when all measurement points per coping were added ($P=.003$). At the margins, measurement points 1 and 9, LS copings showed significantly smaller spaces than both MLW ($P=.002$) and M ($P=.002$). At the chamfer, measurement points 2 and 8, LS copings showed significantly smaller spaces than MLW ($P=.005$). At the center of the axial walls, measurement points 3 and 6, LS copings showed significantly smaller spaces than MLW ($P=.004$) and M ($P=.005$). No significant differences were noted between M and MLW copings ($P>.05$) (Table 1).
No significant differences ($P>.05$) were detected regarding retention in the pull-off tests. The cement was detached unevenly in the different groups. In the LS group, all cement was detached from the abutment. In the MLW and M groups, the cement was detached partly from the copings and partly from the abutments (Fig. 7).

**DISCUSSION**

The present study found improved fit and increased surface roughness for the additive production technique. Therefore, the null hypothesis concerning fit and surface roughness was rejected. The pull-off tests did not, however, reveal any significant differences among the test groups, and the null hypothesis regarding retention was accepted.

The finding that LS copings showed increased surface roughness is supported by a similar study.\(^8\) The surface topography analysis was, however, performed at no more than 2 copings per test group, as this analysis required the copings to be sectioned and thereby lost to further testing. No statistical analysis was therefore performed, and the results have to be viewed merely as indicators for future studies which are needed to provide reliable conclusions.

In the present study, the marginal discrepancies of all production methods were within the 120-μm limitation that is considered clinically acceptable.\(^{13-16}\) The laser-sintered copings exhibited the lowest values. This is in agreement with most other studies. Castillo-Oyagüe et al\(^{25}\) found better fit for laser-sintered single crowns than for vacuum-cast Co-Cr or vacuum-cast Ni-Cr-Ti. The same research group also found better marginal adaptation for laser-sintered Co-Cr 3-unit fixed partial dentures, followed by vacuum-cast gold and Co-Cr.\(^{26}\) Ortorp et al\(^4\) found significantly better fit for laser-sintered Co-Cr 3-unit fixed partial dentures than for milled ones.
In the present study, MLW crown copings showed the largest cement space. The MLW-technique includes several steps, each susceptible to small errors, which may accumulate and affect overall fit. Techniques that reduce the number of steps may produce crowns with a higher quality of fit.\textsuperscript{5,8}

The pretreatment of the crown intaglio surfaces with airborne-particle abrasion might have affected fit and retention. The process was, however, standardized and the same for all groups, which makes this factor an unlikely explanation for the differences noted.

Despite the standardization of cementation and measurement procedures, a recurring problem was seen. The copings were positioned at an oblique angle to the long axis of the abutments. This was most clearly seen on the marginal measurement points (1 and 9), where one point exhibited high values while the second point showed much lower values. This should not affect the overall analysis though, as it is based on the average space of the 2 corresponding points.

No significant differences were detected regarding retention in the pull-off tests. This is in contrast to a previous study comparing surface roughness, fit, and retention of Co-Cr crowns produced by laser-sintering and a traditional casting technique.\textsuperscript{8} The retention of a crown is influenced by several factors.\textsuperscript{9,20-22} The results might have differed if a polymer-based cement had been used as in one study where significantly higher values for retentive forces were noted when resin cement was compared with zinc phosphate cement.\textsuperscript{21} Zinc phosphate cement was chosen as the luting agent in the present study since it is widely used for the cementation of Co-Cr restorations.\textsuperscript{22} Satisfactory fit and surface roughness are likely to be more critical factors for the retentive capacity of water-based cements than resin-based cements.
The LS copings displayed adhesive failure of the cement to the abutment rather than the coping. In the other 2 groups, the adhesive failures occurred partly from the abutments and partly from the copings. These findings indicate increased cement retention of laser-sintered crowns due to higher surface roughness.

Other factors such as preparation design, convergence angle, and surface area also affect retention. The abutments and copings in the present study were of a standardized shape. Anatomically shaped abutments and copings might produce different results. However, nonstandardized abutments contribute to differences in results that make comparisons difficult.

Although 2 of the tests in the present study found advantages for the additive production technique, all groups performed within what is considered clinically acceptable concerning fit, and the retentive test did not provide proof that either technique was superior. This is in agreement with a clinical trial which did not find any significant differences in the long-term follow-up of Co-Cr single crowns fabricated by laser-sintering or traditional casting. This suggest a complex relationship between different factors that influence clinical performance, and further research is clearly needed in the form of clinical trials comparing the performance of crowns fabricated with different production techniques.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Laser-sintered Co-Cr alloy crown copings showed increased surface roughness compared with copings produced by milling or milled wax/lost wax.

2. Laser-sintered Co-Cr alloy crown copings showed a significant ($P=.003$) improvement in internal and marginal fit compared with copings produced by milling or milled wax/lost wax.
3. No significant differences ($P > .05$) were observed between the test groups in the retention pull-off tests.
REFERENCES


TABLES

Table 1.

Mean cement film thickness (µm) ± standard deviation (SD). (Combined values for two corresponding points presented together).

Groups denoted by same superscript letter indicate significant differences ($P \geq .05$)

<table>
<thead>
<tr>
<th></th>
<th>MLW</th>
<th>M</th>
<th>LS</th>
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<tr>
<td>Marginal</td>
<td>104(^a) ± 33</td>
<td>91(^b) ± 24</td>
<td>53(^{ab}) ± 19</td>
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<tr>
<td>Chamfer</td>
<td>163(^c) ± 24</td>
<td>148 ± 27</td>
<td>128(^c) ± 20</td>
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<tr>
<td>Axial wall</td>
<td>99(^d) ± 15</td>
<td>94(^c) ± 11</td>
<td>79(^d) ± 8</td>
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<tr>
<td>Transition</td>
<td>87 ± 30</td>
<td>82 ± 13</td>
<td>98 ± 14</td>
</tr>
<tr>
<td>Occlusal</td>
<td>140 ± 34</td>
<td>136 ± 27</td>
<td>125 ± 30</td>
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FIGURES

Figure 1. Master preparation.

Figure 2. Prototype crown coping.

Figure 3. Cross section of silicone replica for internal and marginal fit measurement.

Figure 4. Schematic of points at which measurements were made on silicone replicas: marginal (1, 9), chamfer (2, 8), midpoint of axial wall (3, 7), transition between axial wall and occlusal surface (4, 6), and occlusal surface (5).

Figure 5. Test arrangement for crown pull-off test.

Figure 7. Representative cement remnants on abutments after retention tests: A, Milled wax/lost wax (ML). B, Milling (M). C, Laser-sintering (LS).
Figure 4

1. marginal

2. chamfer

3. axial

4. angle

5. occlusal

6. angle

7. axial

8. chamfer

9. marginal
### TABLES

**Table 1**

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**Table 1.** Mean cement film thickness (µm) and standard deviation (SD). (Combined values for two corresponding points presented together).

*Groups denoted by the same superscript letter indicate significant differences (p ≥ 0.05)*