In vitro evaluation of marginal and internal adaptation of three-unit fixed dental prostheses produced by stereolithography

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The purpose of this study was to investigate, by measuring the gap, the possible clinical use of three-unit fixed dental prostheses (FDPs) manufactured using stereolithography. A total of 20 epoxy models were built with a same case (abutment teeth 14, 16). The 40 specimens were produced using the stereolithography (SLA) and wax-up (LW). The 960 gaps of the 40 specimens produced were measured by a silicone replica. The Wilcoxon rank sum test was then used to compare and analyze the data obtained from the two groups (α=0.05). The total gap, as measured from the SLA and LW groups, was 98.6 and 66.6 µm, respectively. The results indicate that the gap in the SLA group is statistically significantly greater than that in the LW group (p<0.05). Further assessment and improvement of the SLA method for the fabrication of FDPs is evidently still required.

Keywords: Computer-aided design, Computer-aided manufacturing, Marginal gap, Internal gap, Rapid prototyping

INTRODUCTION

Recently, there has been an increased preference for ceramic prostheses with a similar color to teeth\(^5\). As the adoption of dental computer aided design/computer aided manufacturing (CAD/CAM) technology has become widespread\(^5\), the demand for all-ceramic crowns has also risen; although metal-ceramic crowns still remain one of the most widely used ceramic prostheses\(^6\). A metal-ceramic crown comprises a lower metal core and an upper porcelain part, the material used for the former being a dental alloy of precious or non-precious metals. Such alloys are mainly used for the manufacture of FDPs, and manufacturing techniques include the lost wax (LW) casting method. This LW technique has the advantage of providing a high-degree of accuracy; however, it also has its limitations in that it takes a long time, and the quality of the end result is highly dependent on the knowledge and skills of the dental technician\(^7\).

A number of dental CAD/CAM systems have recently been developed and marketed in response to these limitations of the LW technique\(^8\). For example, the manufacturing of prostheses using a dental CAD/CAM system takes notably less time, and is less dependent on the skill of the engineer. It also offers its own inherent advantages in allowing the mass production of a given form of prosthesis, and the ability to store and reuse the information about the oral cavity of the patient\(^9\).

Though the specific manufacturing processes involved in making a prosthesis with a dental CAD/CAM system varies between different suppliers, the overall procedure remains identical: i.e., following the construction of a digital model using a dental scanner, based on an impression taken from the patient or a model replicating their oral structure, the prosthesis is designed using a CAD program. The designed prosthesis is then finalized by processing with a milling machine, using either subtractive or additive methods\(^9\). With the subtractive method, blocks are removed from the material creating inherent shortcomings in terms of excessive material wastage and the impossibility of reproducing a heavy under-cut\(^9\).

The additive method was introduced in an attempt to overcome these shortcomings\(^9\), and refers to the well-known rapid prototyping (RP) method. In this, the material supplied to the milling machine is in the form of a powder or liquid, as opposed to the blocks used in the subtractive method. A thin layer is produced by selectively melting the desired parts of the material using lasers or a similar mechanism, and is based on a file containing the completed design. The final prosthesis is manufactured by stacking these layers, and consequently the material wastage is greatly reduced. Furthermore, the capacity for reproducing an under-cut is excellent when compared to subtractive methods using cutting tools, because of the selective melting\(^9\).

Among the many additive methods that have been introduced for the dental CAD/CAM system, the most commonly studied at present have been the stereolithography (SLA) and selective laser sintering (SLS) methods\(^9\). These methods make the manufacture of FDPs using metallic materials such as alloys much easier; however, information regarding the quality of the resulting prosthesis is still limited. Although many factors influence the quality of FDPs, the most important is the gap between the prosthesis and tooth forms or tooth preparations\(^9\). A few authors have previously reported assessments of the gap in FDPs manufactured using the SLS method\(^9\); however, similar reports on the gap of FDPs fabricated using the...
SLA method remain very limited. The purpose of this study, therefore, is to determine whether FDPs manufactured using the SLA method are clinically acceptable in terms of their gap. Three-unit FDPs manufactured by the SLA and LW methods from an identical model were used in this study as the experimental and control groups, respectively; their resulting gaps being measured and compared.

MATERIAL AND METHODS

Manufacturing of the epoxy model
The model selected for use in this study was of a missing maxillary right second premolar, which abutted onto the maxillary right first premolar and maxillary right first molar (Model #3017, Viade products, California, U.S.A). Abutment preparation was performed using a chamfer margin, and the 20 individual impression trays for the master model were manufactured using a dental resin (Trayplast, Vertex, Netherlands). A further 20 impressions were also made using a light body silicone (Fresh, DentamidDreve GmbH, Unna, Germany), with dental epoxy (Modralit® 3K, DentamidDreve, Unna, Germany) being poured into these to produce 20 epoxy models.

Manufacturing of specimens
A requirement for manufacturing FDPs using the SLA method is suitable 3D CAD data; and thus the 20 epoxy models were all separately scanned using a dental scanner (D-700, 3shape A/S, Copenhagen, Denmark) to obtain a digital model of each. To improve the resolution of the scans, the whole model was scanned first and the missing and abutment parts (maxillary right first premolar and maxillary right first molar) were then exposed and scanned separately. The images obtained were then rearranged to produce a suitable digital model. The final three-unit FDPs were fabricated from 20 digital models crafted by a skilled engineer using specialized software (3shape Dental Designer, 3shape A/S, Copenhagen, Denmark). In each instance, the thickness of the specimen was set to 0.5 mm and a cement space of 30 µm was allowed.

From the file containing the completed design, a total of twenty three-unit FDPs were made from an acrylic plastic material (Visijet® Dentcast) using the SLA method (ProJet™ DP3000, 3DSystems, Rock Hill, South Carolina, USA). The 20 specimens for the experimental group were then manufactured by casting and polishing (Fig. 1), utilizing a commonly used Co-Cr alloy (Wirobond®C, BEGO, Bremen, Germany).

For the specimens used for the control group, the epoxy models were painted in 4 coats of die spacer (Nice Fit, Shofu Inc, Kyoto, Japan). In previous studies, this painting of die spacer reportedly results in a thickness of approximately 30 µm. Twenty three-unit FDP wax patterns were then manufactured using dental wax by a dental technician skilled in epoxy modeling. The quality of the manufactured wax patterns was verified microscopically (10×), (AIS-10L, Daemyung optical PRODUCT, Dae-jeon, Korea), and 20 specimens were manufactured via LW, casting, and polishing of the Co-Cr alloy (Wirobond®C B) (Fig. 1).

Definition and measurement of gaps
Marginal and internal gaps were measured from the
gaps on 12 points for each abutment (Fig. 2). These 12 points were classified as one of margin (points 1, 6, 7, and 12), axial wall (points 2, 5, 8, and 11), and occlusal (points 3, 4, 9, and 10). The gap was defined as the vertical distance between the model and the FDP, the silicone replica technique being used in accordance with prior studies. For measurement, the FDPs were filled with a light body silicone, and approximately 50 N of finger pressure was then applied to the epoxy model along the long-axis of the abutment. In order to confirm accurate pressure intensity and put pressure, pressure was applied with the epoxy model placed on an electronic scale. This pressure was maintained for 10 min, in order to allow for sufficient setting of the light body silicone.

The FDPs were next carefully removed from the epoxy model. As it is very difficult to measure the thickness of light body silicone due to the microscopic distance between the FDPs and the model, it was therefore fixed using a heavy body silicone to form a final silicone replica. These silicone replicas were subsequently separated using a sharp cutter into four pieces along the center of both the bucco-lingual and mesio-distal directions (Fig. 3). The cross section of the cut silicone replicas was magnified by 140-times using a digital microscope (KH-7000, HIROX, Hackensack, NJ, USA), and the gaps were then measured (Fig. 4). Since there were 12 points for each abutment, and each of the 40 specimens had 2 abutments, a total of 960 points was formed and measured.

**Statistical analysis**

The Windows-based program SPSS 12.0 KO (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. The comparison of the gaps between the SLA and LW groups was performed by the Wilcoxon rank sum test, a non-parametric test (α=0.05).

**RESULTS**

The mean values and SDs of all gaps measured from each point of the three-unit FDPs manufactured using by the two different methods (SLA, LW) are summarized in Table 1. The results of the analyses of the statistical significance of differences between the gaps according to the production method used, measurement points (point 1–12), abutment types (premolar, molar), and measurement parts (margin, axial wall, occlusal) for the 960 points of the two groups are described below.

From the total mean and SD values for all measurement points of the light body silicone thickness (n=240), the gaps of the SLA group were found to be significantly greater than those of the LW group, as shown in Table 1 (p<0.05). Comparison of all of the means of the gaps measured also revealed that the gaps from the premolar tooth were all greater in the SLA
Table 1  Mean and SD of the gaps (µm) for all measurement points in premolar and molar teeth for two different manufacturing methods

<table>
<thead>
<tr>
<th>Point</th>
<th>n</th>
<th>Group</th>
<th></th>
<th>Group</th>
<th></th>
<th>p value&lt;sup&gt;b&lt;/sup&gt;</th>
<th></th>
<th>p value&lt;sup&gt;b&lt;/sup&gt;</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Premolar</td>
<td></td>
<td>Molar</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LW&lt;sup&gt;a&lt;/sup&gt;</td>
<td>SLA&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td>LW&lt;sup&gt;a&lt;/sup&gt;</td>
<td>SLA&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>20</td>
<td>71.8 (17.1)</td>
<td>99.8 (14.5)</td>
<td>0.023</td>
<td>75.6 (22.2)</td>
<td>106.4 (13.0)</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>20</td>
<td>36.2 (15.3)</td>
<td>84.4 (16.7)</td>
<td>0.001</td>
<td>49.0 (  5.0)</td>
<td>73.2 (21.0)</td>
<td>0.037</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>20</td>
<td>84.0 (15.3)</td>
<td>115.6 (22.1)</td>
<td>0.039</td>
<td>87.6 (19.7)</td>
<td>108.2 (21.3)</td>
<td>0.151</td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>20</td>
<td>85.4 (14.6)</td>
<td>114.2 (21.9)</td>
<td>0.040</td>
<td>100.4 (13.6)</td>
<td>118.0 (15.5)</td>
<td>0.092</td>
<td></td>
</tr>
<tr>
<td>P5</td>
<td>20</td>
<td>42.2 (12.9)</td>
<td>82.8 (15.7)</td>
<td>0.002</td>
<td>54.8 (17.0)</td>
<td>83.8 (18.3)</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td>P6</td>
<td>20</td>
<td>65.2 (18.3)</td>
<td>95.0 (17.5)</td>
<td>0.030</td>
<td>62.6 (13.9)</td>
<td>102.2 (28.4)</td>
<td>0.023</td>
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<tr>
<td>P7</td>
<td>20</td>
<td>60.4 (16.2)</td>
<td>91.0 (13.1)</td>
<td>0.011</td>
<td>68.6 (16.5)</td>
<td>94.8 (13.8)</td>
<td>0.026</td>
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</tr>
<tr>
<td>P8</td>
<td>20</td>
<td>44.8 (15.8)</td>
<td>93.6 (13.6)</td>
<td>0.001</td>
<td>57.2 (17.8)</td>
<td>91.4 (21.1)</td>
<td>0.024</td>
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<tr>
<td>P9</td>
<td>20</td>
<td>76.8 (28.3)</td>
<td>112.0 (10.1)</td>
<td>0.031</td>
<td>84.2 (24.6)</td>
<td>116.0 (18.2)</td>
<td>0.049</td>
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<tr>
<td>P10</td>
<td>20</td>
<td>84.2 (25.0)</td>
<td>118.6 (18.8)</td>
<td>0.040</td>
<td>86.0 (13.0)</td>
<td>111.0 (12.4)</td>
<td>0.014</td>
<td></td>
</tr>
<tr>
<td>P11</td>
<td>20</td>
<td>41.4 (21.1)</td>
<td>83.4 (16.1)</td>
<td>0.008</td>
<td>44.4 (11.1)</td>
<td>85.0 (15.7)</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>P12</td>
<td>20</td>
<td>61.4 (19.7)</td>
<td>90.8 (18.7)</td>
<td>0.042</td>
<td>71.2 (16.7)</td>
<td>95.0 (23.9)</td>
<td>0.106</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>240</td>
<td>63.0 (24.5)</td>
<td>98.4 (19.9)</td>
<td>&lt;0.001</td>
<td>70.1 (22.4)</td>
<td>98.8 (21.9)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Methods = LW (lost wax technique), SLA (stereolithography).
<sup>b</sup>Obtained by the Wilcoxon rank sum test.

Table 2  Mean and SD of gaps (µm) for three positions, and two different manufacturing methods

<table>
<thead>
<tr>
<th>Position&lt;sup&gt;a&lt;/sup&gt;</th>
<th>n</th>
<th>Group</th>
<th></th>
<th>p value&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>LW&lt;sup&gt;b&lt;/sup&gt;</td>
<td>SLA&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Margin</td>
<td>160</td>
<td>67.1 (16.9)</td>
<td>96.9 (17.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Axial wall</td>
<td>160</td>
<td>46.3 (15.3)</td>
<td>84.7 (16.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Occlusal</td>
<td>160</td>
<td>86.3 (19.2)</td>
<td>114.2 (16.7)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<sup>a</sup>Position = margin (points P1, P6, P7, P12), axial wall (points P2, P5, P8, P11), occlusal (points P3, P4, P9, P10).
<sup>b</sup>Methods = LW (lost wax technique), SLA (stereolithography).
<sup>c</sup>Obtained by the Wilcoxon rank sum test.

group than in the LW group, these differences being statistically significant (p<0.05), (Table 1). This pattern was also evident in the molar; however, in the case of some points such as P3, P4 and P12, the difference observed was not statistically significant (p>0.05), (Table 1). Moreover, there was no significant difference between the gaps of each abutment type in either group (p>0.05) (Table 1). The means of the gaps for each part (margin, axial wall, occlusal) were; however, found to be statistically significantly greater in the SLA group than in the LW group for all parts (p<0.05) (Table 2).

**DISCUSSION**

One of the most important factors determining the clinical viability of FDPs is their adaptation. A poorer adaptation refers to a greater gap between the FDPs and the abutment, and is associated with a sharp decline in the FDPs life owing to the higher incidence of secondary caries resulting from the invasion of pathogens from saliva or food<sup>7</sup>). Previous studies regarding the adaptation of FDPs fabricated by the SLA method have thus far been very limited<sup>5</sup>). This study therefore investigated the clinical potential, in terms...
of gap, of three-unit FDPs made by a newly introduced SLA method for manufacturing dental restorations. For the sake of comparison, three-unit FDPs were also manufactured using the traditional LW method as a control group. The gaps in the SLA group were found to be greater than those found in the LW group for all points measured. The mean of marginal gap, however, did not exceed the clinical acceptance limit suggested by the several preceding studies.

Many authors have investigated this clinical acceptance limit of the marginal gap. Örtorp et al. reported that the range should in fact be on the order of <50 µm; whereas Moldovan et al. reported that a gap of 100 µm is excellent, and that the acceptable range could be as high as 300 µm. The most commonly cited criteria for the clinically acceptable limit of the marginal gap in recent years has been that reported by McLean and von Fraunhofer, who argued that 120 µm is the clinically acceptable limit. When comparing the results of these preceding studies with those of this study, it was confirmed that the average marginal gap of 3 unit FDPs fabricated by the SLA method was within the range of clinically acceptable values that were suggested by several researchers. Whilst for Ostlund, this figure for the average marginal gap was considered beyond a clinically acceptable value. As with some specimens, however, the marginal gap figures were even beyond 120 µm which was considered a clinically acceptable value.

The silicone replica technique, which was used as a gap measure in this study, has been widely used in previous studies. Harris and Wickens reported that the advantage of this method is its non-destructiveness, in that the FDP models or tooth preparations are protected. In this study, however, the gap is measured from a cross section following the cutting of a silicone replica of the internal gap, and thus only 2D measurement along a limited direction is possible. Many authors have used this method, despite its limitations, owing to its high reliability and accuracy. The alternative method of gap measurement entails the use of dental cement in 3D measurement, and it requires destruction of the FDP and the model. Yucel et al. used the direct measuring technique for the measurement of the marginal gap of FDPs, this method recording data directly onto a computer monitor. The advantages of this method are in its non-destructive nature and ability to allow measurements from various positions; while its disadvantages are that the model needs to be cut if measurement of internal gaps is required, and that some errors may arise due to the fact it measures only in simple vertical direction.

Studies assessing the adaptation of FDPs manufactured by RP techniques are still quite limited. There are, however, various RP techniques available, the SLA and SLS methods currently being the most widely utilized. Ucar et al. reported the internal gap of cast Ni-Cr, cast Co-Cr, and SLS Co-Cr to be 58.2 (SD 19.9), 50.6 (SD 25.1), and 62.6 (SD 21.6) µm respectively, indicating that the internal gap is the most favorable in cast Co-Cr and poorest in SLS Co-Cr. Quante et al. compared the gap of three-unit FDPs fabricated with four different techniques; a conventional lost wax method Co-Cr (LW), milled wax with lost-wax method Co-Cr (MW), milled Co-Cr (MC), and direct laser metal sintering of Co-Cr (DLMS/SLS). They reported that the mean value was best with the DLMS method, at 84 (SD 60), followed by MW 117 (SD 89), LW 133 (SD 89), and MC 166 (SD 135) µm.

Comparison of the findings of this study with those of other studies pertaining to the gap of FDPs fabricated by the RP, SLS methods shows that this study is most concordant with that of Ucar et al. in that the FDPs manufactured by the LW method had better adaptation. It is also in agreement with the study by Quante et al., in that the marginal discrepancies are within the clinically permissible range. The inconsistency between the findings of this study and that of Örtorp et al. is likely to be due to the differences in the master model used. While Örtorp et al. replicated teeth using a cylinder shape; this study used more realistically shaped model teeth. In addition to the various errors that may arise due to the differences in the shape of the model, the skillfulness of the engineers who manufacture the FDPs using the LW method, and design the CAD for RP processing, may provide other reasons for the inconsistency in findings.

This study has presented some limitations in that the cases were not variable, being instead limited to three-unit FDPs. Studies investigating the clinical adaptation of FDPs, using a wider variety of surveyed samples and FDPs manufactured with a long span, are therefore warranted.

CONCLUSIONS

Even though the average gap of FDPs fabricated by the SLA method was found within the clinically acceptable range in several preceding studies, gaps found in some specimens were beyond clinically acceptable values. The values of this average gap of FDPs fabricated by the SLA method were nonetheless greater than those of FDPs fabricated by the traditional LW method. With regard to the foregoing, it may be considered difficult to affirm that FDPs fabricate by the SLA method are clinically acceptable. It can therefore be concluded that the SLA

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method still requires improvements, and that further research should be done on this method for verification.

ACKNOWLEDGMENTS

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