# Three-dimensional evaluation of gaps associated with fixed dental prostheses fabricated with new technologies

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**Statement of problem.** One of the most important factors in determining the clinical outcomes of fixed dental prostheses is the gap between the fixed dental prosthesis and the abutment. However, reports that investigated these gaps in the context of fixed dental prostheses fabricated with new technologies are few.

**Purpose.** The purpose of this study was to measure and analyze the fit of fixed dental prostheses. The fixed dental prostheses for the study were produced with the subtractive method (milling soft metal blocks), additive method (selective laser sintering), and traditional method (lost wax and casting).

**Material and methods.** Ten specimens were fabricated with the soft metal block, selective laser sintering, and lost wax and casting methods. The 3-dimensional measurement method was adopted to obtain the measure gap figures of the specimens. To fabricate a digital replica, computer-aided design reference casts were prepared by scanning the study casts, and silicone replicas were fabricated for each specimen. These silicone replicas were scanned and obtained 40 000 point cloud data. The study also defined the mean gap for each specimen by averaging approximately 40 000 gap points to evaluate the fit of the specimens. Data were analyzed with 1-way ANOVA and the Tukey honestly significant difference ($\alpha$=.05).

**Results.** The mean gap was the smallest for fixed dental prostheses fabricated with the soft metal block, followed by the selective laser sintering, then the lost wax and casting. One-way ANOVA revealed statistically significant differences in the size of the gap among the 3 groups ($P<.001$), and the Tukey honestly significant difference test confirmed the specific differences among the groups ($P<.05$).

**Conclusions.** The fit obtained with the new soft metal block and selective laser sintering techniques was better than that obtained with the traditional lost wax and casting method. Thus, fixed dental prostheses produced by using these new techniques can be considered clinically acceptable. (J Prosthet Dent 2014;112:1432-1436)

## Clinical Implications

The fixed dental prostheses fabricated by the milling of soft metal blocks with a new subtractive method provided an improved fit.

Metal ceramic remains one of the preferred and frequently used materials for fabricating fixed dental prostheses (FDPs).[1] The lost wax and casting (LCW) technique is still mainly used to fabricate the metal framework but, although well established, is complex and time consuming. Recently, computer-aided design/computer-aided manufacturing (CAD/CAM) systems have become popular. Dental CAD/CAM systems can be broadly classified into subtractive and additive methods. Subtractive methods involve fabricating prostheses from block-shaped materials with diamond rotary instruments.[2] The advantage of this method is that it provides the desired restorations effectively and offers the freedom of choice of materials for the prostheses. Most of the current commercial dental CAD/CAM systems use this method, although it is wasteful because the FDP is made by removing material from a block. Previous studies reported that 90% of the starting material is discarded when fabricating FDPs with this method.[3]

Recently, the milling of a soft metal block (SMB) by the subtractive method has been introduced as a manufacturing technique for the metal substructure of FDPs. The SMB can be milled smoothly with a small milling

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machine because the SMB has mechanical properties similar to those of a wax block. This method, therefore, has the advantages of reducing stress on the milling machines, which extends the life of consumables such as rotary cutting instruments, and reduces the milling time compared with that required to mill hard metal blocks. After milling, the prostheses are completed by a sintering process. Dry milling techniques can be used because, due to the soft nature of the material, only a relatively small amount of heat is generated while milling. Thus, there is less risk of contaminating the finished materials because this method does not require water cooling.

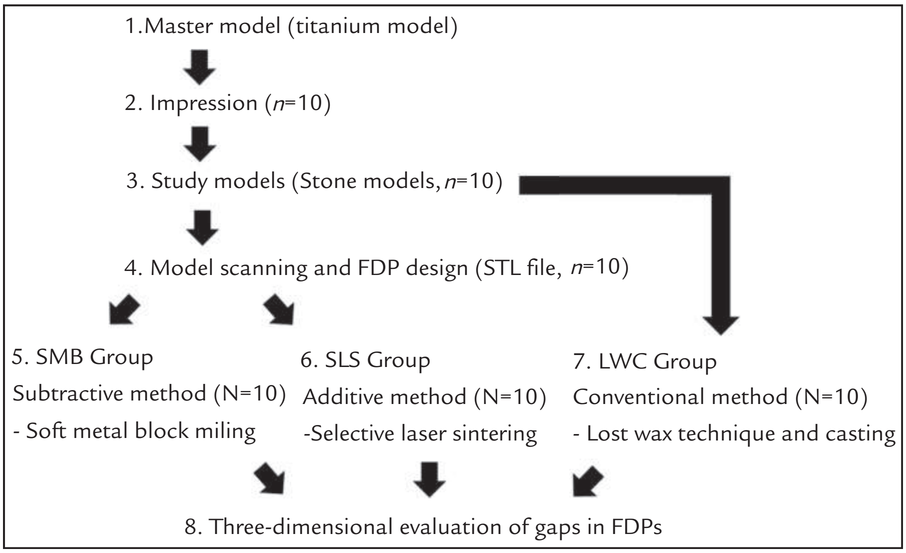
Alternatives to the subtractive method are CAM machines that incorporate the additive method into a rapid prototyping technology.[2] Among the many additive methods, stereolithography (SLA) and selective laser sintering (SLS) have been introduced as manufacturing techniques. These techniques produce prostheses by melting and stacking materials instead of subtracting them. Unlike the subtractive method, in which materials are provided in block form, materials are provided in a powder or liquid form. When selectively irradiating the material with a high-temperature laser, the irradiated portion melts into a thin layer.[4] By repeating this process, prostheses of the desired shape are prepared. These new techniques have undergone remarkable development, but insufficient research has been conducted as to their clinical acceptability. Various factors will determine whether these techniques are clinically acceptable. In particular, fit is most important with regard to the satisfactory functioning of FDPs in the oral cavity and to their longevity.[5-7] FDP fit can be defined in terms of the gap between the FDP and the abutment. Previous studies reported that more than 50 gap points must be measured for each tooth to characterize FDP fit.[8] However, most studies that evaluated FDP fit with traditional measurement methods could not meet this requirement.[9-12] Therefore, new methods of measuring FDP fit are needed. This study measured the FDP gap at various sites and analyzed fit 3-dimensionally with a computer. The objectives of this study were to 3-dimensionally measure and analyze the fit of FDPs fabricated with newly introduced SMB and SLS methods, and to compare them with FDPs fabricated with the traditional LWC method. The null hypothesis was that no difference would be found in the fit of FDPs manufactured by using the 3 different methods.

## MATERIAL AND METHODS

A maxillary right first molar with a 1.2-mm chamfered margin and a total occlusal convergence of 12 degrees were used to make the abutment (Frasaco GmbH). A titanium master model was fabricated from the finished preparation. To prepare study models, 10 molds were made from titanium master models with silicone impression material (Deguform; DeguDent GmbH) and were poured with a dental scannable stone (Everast ROCK; KaVo Dental GmbH). Digital casts were produced with a dental laser scanner (D-700; 3shape A/S). FDP frameworks were designed based on the digital cast by using dedicated software (3shape Dental Designer; 3Shape A/S). All the details of the design were based on the recommendations of the program, as follows: the specimen thickness was 0.5 mm, and a 30-µm cement space was evenly provided 0.5 mm from the margin. To produce specimens in various devices, the information on the 10 FDPs was stored in the standard template library file format.

After the information had been entered into the standard template library files and after the FDP design had been completed with the dedicated program (Ceramill Mind; AmannGirrbach AG), the final margin evaluation was made for milling the SMBs. Thereafter, the frameworks were milled with a dedicated milling machine (Ceramill Motion 2; AmannGirrbach AG) and SMBs of cobalt (Co) chromium (Cr) alloy (Co, 66%; Cr, 28%; molybdenum, 5%, manganese; silicon; iron, <1%; organic binder, 1%-2% [Ceramill Sintron 71 XXS; AmannGirrbach AG]). After milling, the specimens were sintered at 1280°C for a total of 5 hours in the dedicated sintering box (Ceramill Sinter box; AmannGirrbach AG) of the sintering furnace (Ceramill Argotherm; AmannGirrbach AG). The manufacturer states that the amount of specimen shrinkage during sintering is 11% (Fig. 1).

The information in the standard template library file of the completed FDP design used in manufacturing specimens of the SMB group was entered into an SLS system (EOSINT M270; EOS GmbH). When the Co-Cr alloy powder (Co, 61.8%-65.8%; Cr,




1 Work flow of study.

23.7%-25.7%; tungsten, 4.9%-5.9%; molybdenum, 4.6%-5.6%; silicon, 0.8%-1.2%; iron, maximum 0.5%; manganese, maximum 0.1% [EOS Cobalt Chrome SP2; EOS GmbH]) was partially melted with a high-temperature laser based on the entered information, an approximately 20-μm-thick layer was formed. The substructure was completed by repeatedly depositing layer on layer in the same manner.[13] The production of a total of 10 SLS group specimens were then completed with these materials (EOS Cobalt Chrome SP2; EOS GmbH) (Fig. 1).

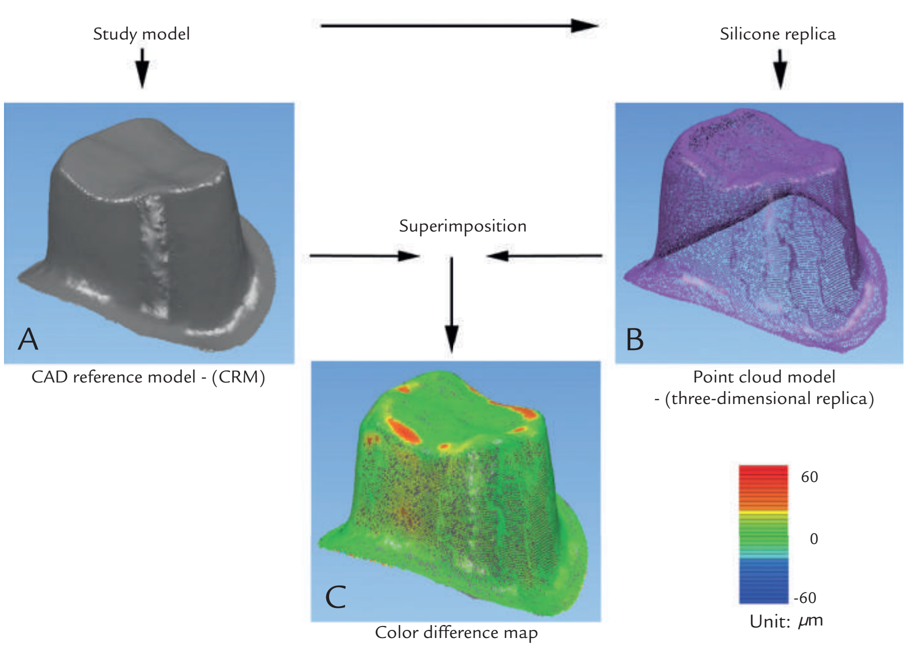
The LWC group (control) specimens were prepared with the traditional LWC manufacturing method for the same 10 study casts. To produce specimens under the same conditions as the other 2 groups, the die spacer (NICE FIT; Shofu INC) was applied a total of 4 times to the 10 stone casts (30-μm-thick layer[14,15]), 0.5 mm from the margin. Ten wax patterns (ABF Wax Special; Metalor Dental AG) were made by the same technician. The margins were finalized under magnification (AIS-10L, 10x; Daemyung Optical). The control group specimens were completed by spruing and investing (Bellavest SH; Bego GmbH), and by wax elimination (Midtherm 200 MP; BEGO GmbH) from room temperature to 250°C at 5°C/min, held for 60 minutes and then increased by 7°C/min until 900°C, held for another 60 minutes before casting the Co-Cr alloy (Co, 63.3%; Cr, 24.8%; tungsten, 5.3%; silicon, maximum 1.0%; cerium, maximum 1.0% [Wirobond C; BEGO GmbH]). The fabrication of the casts in the LWC group was completed by adjusting the intaglio surface of the specimens after devesting (Fig. 1).

To analyze the fit of the 3 groups (SMB, SLS, and LWC), 3-dimensional analysis was performed by using a computer. After scanning the study casts with a dental scanner (Identica; Medit) in accordance with this method of analysis, a CAD reference cast (CRM) was produced. Thereafter, the specimen was loaded in the direction of the long axis of the study cast after filling the intaglio with a light-body silicone impression material (Aquasil Ultra XLV; Dentsply DeTrey GmbH). A force of 50 N was maintained for 10 minutes until the silicone polymerized. The silicone that flowed out of the specimen was removed before polymerization because it may have interfered with the 3-dimensional analysis.

After complete polymerization of the light-body silicone, the specimen was removed. A silicone replica and the cast with its specimen removed were scanned with a dental scanner. The scanned image was used to produce a digital replica on a computer monitor. To 3-dimensionally measure the gap between the digital replica and the CRM, point cloud data were obtained from the digital replica file by using a dedicated program (Copy CAD; Delcam). Approximately 40 000 points were obtained for each digital replica, and the gap was measured by superimposing all the points of the point cloud data and the CRM after evenly rearranging them. The discrepancy of each point of the point cloud and the CRM was measured by superimposing the two, and this was presented in the color difference map. The average of the means measured at all points was automatically calculated with a dedicated program (PowerINSPECT; Delcam) and was defined as the gap of the specimen (Fig. 2). This program's measurement capability is 1 μm and this delivers the levels of discrepancy. A 1-way ANOVA was performed to determine whether differences in the average gap measured were statistically significant for the 3 groups. To verify the statistical significance of the differences between each pair of groups after initial testing, the Tukey honestly significant difference post hoc test was performed ($\alpha$=.05) The IBM SPSS 20 (SPSS Inc) software package was used for all statistical analyses.

## RESULTS

The means (standard deviations) of the 3-dimensional gaps analyzed in the 3 groups (SMB, SLS, and LWC) are shown in Table I. The gaps in the LWC group were the largest, followed by the SLS group, then the SMB group. Statistically significant differences were found among the groups ($P<.001$) (Table II). The post hoc Tukey honestly significant difference test revealed




**2** Three-dimensional measurement for gap. A, Computed-aided design reference cast: digital cast by scanning stone cast with dental scanner. B, Point cloud model: model with point cloud data from digital replica. C, Color difference map: discrepancy of each point of models B and A presented in different colors.

Table I. Means (SDs) of 3-dimensional gaps associated with FDPs fabricated with 3 different methods and results of Tukey HSD multiple comparisons analysis

| Group | n | Mean (SD) (μm) | *P* | Tukey HSD analysis[a] |
|---|---|---|---|---|
| SMB | 10 | 32.6 ±4.8 | <.001 | A |
| SLS | 10 | 47.3 ±8.6 | | B |
| LWC | 10 | 64.1 ±14.2 | | C |

SD, standard deviation; FDP, fixed dental prosthesis; HSD, honestly significant difference; SMB, soft metal block milled by subtractive method; SLS, selective laser sintering; LWC, lost wax technique and casting.
[a]Different letters indicate statistically significant differences at $P<.05$.

Table II. Results of 1-way ANOVA of gaps measured 3-dimensionally

| | Sum of Squares | *df* | Mean Squares | F value | *P* |
|---|---|---|---|---|---|
| Between groups | 4968.6 | 2 | 2484.3 | 24.849 | <.001 |
| Within groups | 2699.4 | 27 | 99.978 | | |
| Total | 7668.0 | 29 | | | |

statistically significant differences between the LWC and SMB groups ($P<.001$), the LWC and SLS groups ($P=.002$), and the SMB and SLS groups ($P=.008$) (Table I). The SMB group exhibited the smallest mean gap, of 32.6 μm; the mean gap of the SLS group was 47.3 μm; and that of the LWC group was 64.1 μm.

## DISCUSSION

The null hypothesis that no difference would be found in the fit of FDPs manufactured with SMB, SLS, and LWC was rejected. According to the results of this study, the fit yielded by the SMB technique was the best, followed by that of the SLS method, then the LWC method. Based on these results, FDPs manufactured with the SMB and SLS methods are clinically acceptable. This study is significant in that the fit was 3-dimensionally analyzed and evaluated to examine the clinical acceptability of FDPs manufactured with new techniques. Although various methods have been used for measuring fit in earlier studies, the most commonly used methods are of observing cross-sections after cutting the cast and specimen (cutting method),[16,17] which confirmed the thickness by cutting the replica after replicating the gap between the specimen and the abutment tooth or cast with the use of silicone (silicone replica technique)[18] and confirming the marginal gap under the microscope after evaluating the specimens on the abutment tooth or cast (direct measuring method).[19]

The cutting method involves fixing the specimen by embedding it in epoxy or stone after evaluation on the cast. The specimen is then cut by using a dedicated machine to observe the cross sections of the specimen and the cast.[16,17] Although this method is comparatively accurate because the cross sections of the specimen and the cast are measured directly, the specimen is sectioned, and, therefore, the fit cannot be measured in the oral cavity. Moreover, the process of measurement is somewhat inconvenient, and measuring the fit at various points is not possible because both the specimen and the cast are cut in cross sections.

With respect to the silicone replica technique, its accuracy and reliability have been confirmed,[11] and it has been investigated in a number of studies.[18] This method entails producing replicas of the gap between the specimen and the abutment tooth or the cast by exerting constant pressure in the direction of the tooth after filling the inside of the specimen with silicone. After cutting the manufactured replicas, the fit is analyzed by measuring the thickness of the replicas under a microscope. Compared with the cutting method, this method is simpler and also nondestructive with regard to the specimens, abutment teeth, and casts, which thus allows measurement in the oral cavity. However, as in the cutting method, measuring the fit at various sites is not possible with this technique. Neither the cutting method nor the silicone replica technique can meet the requirement proposed by Groten et al[8] of measuring the gap at a minimum of 50 points while evaluating the fit of a single tooth. The direct measuring method involves confirming and measuring the marginal gap directly on a computer monitor with the aid of a microscope, with the specimen evaluated on the stone cast.[19] Although it allows measurement of the marginal gap at various sites because of its nondestructive nature, this method also has the disadvantage of not facilitating measurement of the internal gap. In addition, it can measure only the vertical distance.

Recently, new measurement methods have been attempted to overcome the limitations of these existing measurement methods. This study measured the FDP gap 3-dimensionally and evaluated the fit by using a computer. This method overcomes the disadvantages of the 3 earlier methods because it is nondestructive[20]; facilitates easy measurement; allows storage of specimens, abutment teeth, and casts; and permits measurement in the oral cavity. The accuracy and reliability afforded by 3-dimensionally analyzing gaps with a computer have been reported by previous studies.[21] It has been reported that more than 30 000 points could be measured when evaluating the fit of a single FDP.[20] When using this method, meeting the requirement of measuring more than 50 points is possible for evaluating the fit of a single tooth. This study improved the reliability of this method by measuring approximately 40 000 points to evaluate the fit for each specimen. The limitation of this method is that the absolute marginal discrepancy cannot be measured because the margin is not a face but a line, and accurate point cloud data are difficult to obtain from the digital replica.

With remarkable developments in digital dentistry technology, the production of various types of prostheses has been simplified and standardized. Further studies are required to evaluate the clinical acceptability of prostheses fabricated with a variety of techniques. Although the SMB and the SLS methods selected as the experimental methods in this study have been frequently used in dentistry, studies that investigated these methods are few. In particular, no study exists that evaluated the fit of FDPs fabricated with the SMB method, and only a few studies can be found that evaluated the fit of FDPs fabricated with the SLS method and compared it with that of FDPs fabricated with the LWC method.[22]

Ucar et al[22] reported that the internal gap of FDPs fabricated with the SLS method was larger than that of FDPs with the LWC method, and Örtorp et al[16] reported that the fit of FDPs fabricated with the SLS method was better than that of FDPs fabricated with the LWC method. This study obtained results similar to those of Örtorp et al.[16] Although there are several reasons why the results of this study do not agree with those of some previous studies, the primary reasons are that the shape of the study casts, the types of abutment teeth, and the measurement methods for the fit differ. Therefore, this study attempted to improve the reliability of study results by analyzing the fit by measuring approximately 40 000 gap points for each specimen.

An increasing amount of interest has been shown not only in the development of new technologies and materials in digital dentistry but also in the discovery of new methods of evaluating the fit of FDPs. Therefore, new measurement methods that overcome the limitations of those used in this study should be introduced to evaluate the fit of FDPs. The limitations of this study may be that a close study was carried on specimens of only 1 cast and that the samplings of the gaps were from study casts, not from patients. The gaps of FDPs from many restorations based on specimens made from patients should be studied. In addition, throughout this study, gaps were measured extraorally, which may result in the surface abrasion of the casts and issues related to the dimensional stability of the stone. These weaknesses could negatively influence the amount of the final gap measurement. To minimize error, future studies should evaluate gaps intraorally.

## CONCLUSIONS

In this study, the null hypothesis that no difference can be found between the fit of FDPs manufactured with SMB, SLS, and LWC was rejected. The fit of FDPs fabricated with the SMB method was the best, followed by that of the SLS and LWC methods. Thus, analysis of the results indicate that FDPs fabricated with the new SMB and SLS techniques are clinically acceptable.

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