In Vitro Measurements of Precision of Fit of Implant-Supported Frameworks. A Comparison between “Virtual” and “Physical” Assessments of Fit Using Two Different Techniques of Measurements

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ABSTRACT

Background: Comparisons between different techniques measuring fit of implant-supported frameworks are few.

Purpose: The purpose of this study was to compare data on precision of fit from two highly accurate measuring techniques and, also, to compare results using software programs for fit assessments considering both a “virtual” as well as a “physical” (i.e., more clinical) situation.

Materials and Methods: Five computer numerical control-milled titanium frameworks (Procera® Implant Bridge, Nobel Biocare AB, Göteborg, Sweden) were fabricated from individual model/pattern measurements, simulating a clinical situation. Measurements of fit between frameworks and models were performed by means of a coordinate measuring machine (CMM; Zeiss Prismo Vast, Carl Zeiss Industrielle Messtechnik GmbH, Oberkochen, Germany) linked to a computer and an optical, high-resolution, three-dimensional scanner (Atos 4M SO, GOM International AG, Widen, Switzerland). Collected data on distortions between frameworks and models were analyzed and compared between the two measurement techniques. A comparison between “virtual” and “physical” fit assessments was also performed, based on data from the three-dimensional scanner.

Results: When using “virtual” fit assessment programs, overall mean three-dimensional distortion between implant and framework center points in absolute figures was 37 (SD 22) and 14 µm (SD 8) for the CMM and three-dimensional scanning measurements, respectively. Corresponding mean three-dimensional distortion when using a “physical” fit assessment program in the scanner was 43 µm (SD 24) ($p < 0.001$). Mean horizontal (x-axis) measurements of the distance between the two terminal implants of the models and the frameworks were 33.772 and 33.834 mm for the CMM technique. Corresponding measurements for the three-dimensional scanner was 33.798 and 33.806 mm, respectively. Horizontal distances from the three-dimensional scanner were, for most measurements, greater than for the CMM measurements.

Conclusion: Measurements of fit between frameworks and models may vary depending on what technique is used and how fit assessments regarding “virtual” or “physical” fit is approached.

KEY WORDS: dental implants, frameworks, precision

INTRODUCTION

Precision of fit between screw-retained frameworks and supporting implants has been discussed since the early introduction of osseointegrated implants.[1] This discussion has been based on the biomechanical concern of introducing too high stress levels in the prosthesis-implant interface when tightening misfitting frameworks to the osseointegrated implant.[1] Since the introduction of screw-retained implant-supported prostheses, clinical studies have related mechanical

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problems of the implant-supported prostheses to misfit between superstructures and the ankylotic implant.[2–4] Yet, no consensus exists of the biological impact of such a misfit.[5–10]

Many techniques have been used during the years to measure the precision of fit between frameworks and the supporting implants.[10–33] Thus, both direct techniques using light microscopes[21,26–28] or impressions materials,[31] as well as indirect techniques using strain gauges,[19,23,32] photogrammetry,[10,15–18,20,24] or optical/mechanical scanners in combination with computer software programs[11–13,15,25,29,34] have been used to assess the fit between implants and frameworks. When using scanners, it has been possible to produce data on implant/framework cylinder center point positions with a high precision.[33]

However, the fit assessments using digital programs have placed the framework cylinder center points in relation to implants in a "virtual" relationship (Figure 1A) rather than considering the physical limitations of the implant/framework hardware (see Figure 1B).[5–12,14,18,19] Another problem with these digital systems is that even though producing data with a high precision for individual measurements, it has been shown that fit measurements may deviate with some tenths of microns for the same framework when using different measuring hard and software techniques.[12,13]

The aim of this study was, first, to compare data on precision of fit from a new high-precision laser scanner (Athos 4M SO, GOM International AG, Widen, Switzerland) using software programs for fit assessments considering both a "virtual" as well as a "physical" (more clinical) situation and, second, to compare these fit measurements with measurements using a high-precision coordinate measuring machine (CMM; Zeiss Prismo Vast, Carl Zeiss Industrielle Messtechnik GmbH, Oberkochen, Germany).

MATERIALS AND METHODS

Fabrication of Computer Numerical Control (CNC) Frameworks

Five CNC-milled frameworks (Procera® Implant Bridge, Nobel Biocare AB, Göteborg, Sweden) were fabricated in commercially pure titanium, also used in a previous study.[13] These were made from five similar mandibular master models (made from one "premium master model" to allow comparable dimensions), each provided with five Brånemark System® implants placed in the interforamina area (Figure 2).The fabrication started by producing a plastic framework replica (PiKu Plast HP36, Bredent, Senden, Germany) on each model.[13] Thereafter, the models and frameworks were distributed to three different dental laboratories and, from them, were sent to the metal framework manufacturer. The distribution to the three laboratories was made in order to avoid the metal framework manufacturer to get knowledge of the ongoing study. The replicas were laser-scanned and a

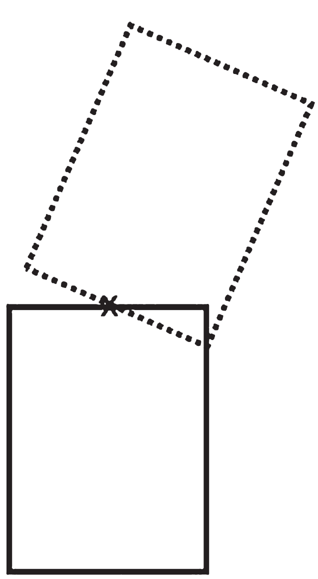

Figure 1A "Virtual fit" assessment between implant and framework center points.

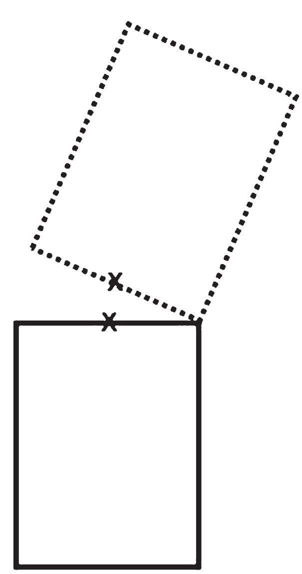

Figure 1B "Physical fit" assessment between implant and framework center points.

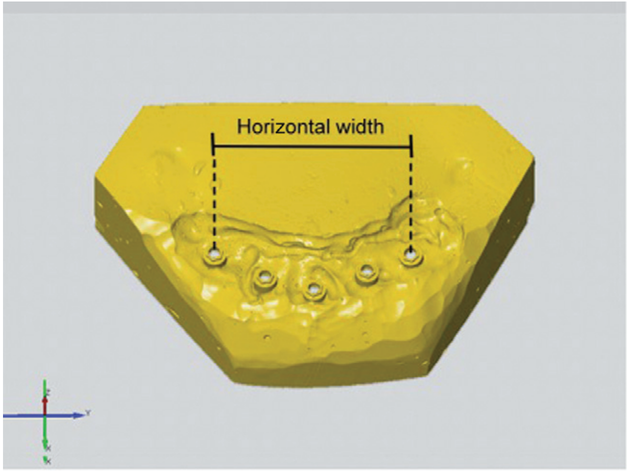

Figure 2 Model for framework fabrication. Horizontal width measured between terminal implant center points (x-axis).

CNC titanium framework was produced according to the Procera technique.[13] Measurements were performed after refining and polishing the frameworks, as described by Örtorp and colleagues.[25]

Measuring of Master Model and Frameworks

Two different techniques were used to measure the precision of the five frameworks and were performed by two independent laboratories: CMM and optical, three-dimensional, high-resolution scanner techniques.

CMM Technique

The first measurements were performed by means of a CMM, more described in detail in earlier publications.[12,13,15,25,29] For the measurements, a scanning head provided with a stylus (0.5 mm diameter) was used. The stylus could be placed in any position within the working space of the CMM. A light force was applied to the measuring stylus in order to facilitate contact between the stylus and the measured component surface. The data for each framework/model replica cylinder were condensed to a position of the center point of the cylinder in three-dimensional (x, y, z) on micrometer level.[12,13,25]

Analyses of precision of fit between the different frameworks and the corresponding models (see Figure 2) were made according to the least square (Lsq) method described by Bühler.[35] Accordingly, data from the measurements of each framework and master cast resulted in three-dimensional coordinates for each replica/framework cylinder in space. This data was orientated in the same three-dimensional coordinate system, and each framework was placed in the theoretically best possible position (Lsq group [CMM/Lsq group]) in the computer by means of special computer programs (based on Bühler[35]), disregarding the physical extensions of the frameworks and the replica cylinders ("virtual fit"; see Figure 1A). The shortest distances between the center points of the framework cylinders in relation to all the center points of the replicas of the model at the same time were calculated (Figure 3). The three-dimensional distortions between these center points were presented in microns using absolute (i.e., disregarding whether the value is positive or negative) and real values.[12,13,25] Furthermore, the width of the framework in horizontal aspect between terminal implants (x-axis) was compared with the width of the corresponding model (see Figure 2).

The accuracy of the CMM technique has been presented by the manufacturer to be within 1 µm and, also, tested in a similar study design as here, showing a standard deviation within a precision of ±3 µm for the center point positions for all five implant cylinders in repeated measurements.[13]

Optical, Three-Dimensional, High-Resolution Scanner Technique

The second measuring technique was an optical, high-resolution, three-dimensional scanner (Atos 4M SO). Similar scanners have been accounted for in earlier publications.[36,37] The scanner measured the surfaces of the models and the frameworks by projecting different light fringe patterns onto the object, which were recorded by two video cameras. The pixels from the images of the two cameras were then calculated to three-dimensional coordinates with a calculated three-dimensional accuracy of 3–4 µm according to the manufacturer.[37] Also, in this technique, framework and model replica center points were calculated in three-dimensional in micrometer, similar to calculations performed in the CMM technique (see Figure 3). Besides these data, a high accurate image in three-dimensional of frameworks and models could be achieved for visual observations of positions of the frameworks in relation to the models (see Figures 2–4).

Analyses of precision of fit between the frameworks and the models were made according to the Lsq method (Scan/Lsq group) described by Bühler[35], using similar but not the same computer programs as for the CMM technique.[12,13,25] Accordingly, first, each framework was

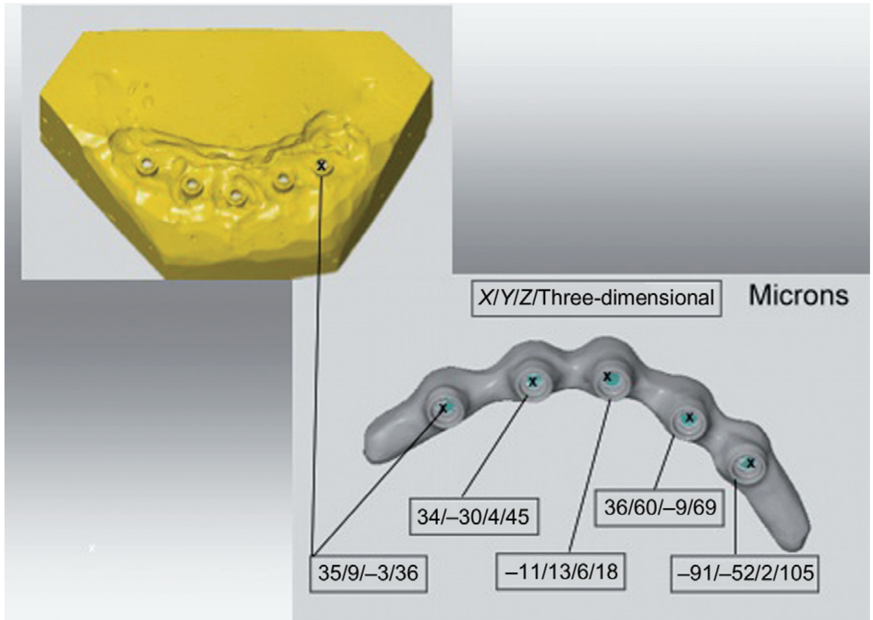

Figure 3 Center point measurements. The shortest distances (μm) between the center points of the framework cylinders (x) in relation to all the center points of the replica of the model at the same time were calculated.

placed in the theoretically best possible position in the computer (see Figure 1A), disregarding the physical extensions of the frameworks and the replica cylinders ("virtual fit"). Thereafter, a second measurement was performed (Scan/physical group) where the physical extensions of the components were considered in the program (see Figure 1B). In this latter situation ("physical fit"), fit contact to at least one replica should be present at both sides of the central implants, creating at least a tripod contact situation between frameworks and model (see Figure 4). The shortest distance between the center points of the framework cylinders in relation to all the center points of the replicas of the master model at the same time was calculated for both "virtual" (Lsq) and "physical" fit measurements. Similar to the CMM technique, the three-dimensional distortions between these center points were presented in micrometer using both absolute and real values.[12,13,25] In addition, the width of the frameworks and models between the terminal abutments were calculated similarly to the CMM technique. Besides these measurements also, three-dimensional views of the relationship between frameworks and models were available in the present scanning technique (see Figure 4).

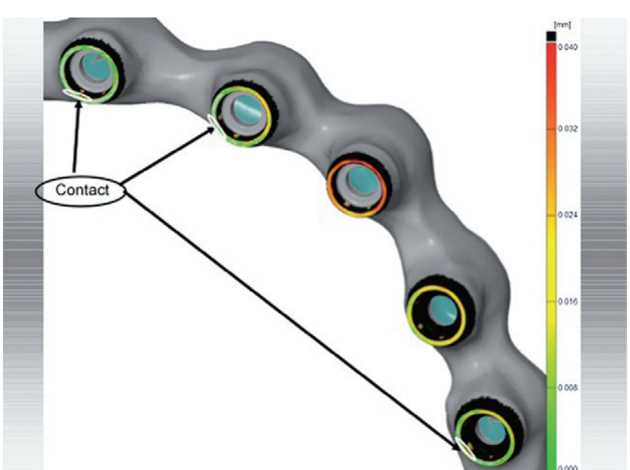

Figure 4 Optical three-dimensional scanning analysis considering the physical limits of the components. Fit contact should be present as a minimum at one replica on both sides of the central implant.

The accuracy of the present optical scanner (Athos 4M SO), specially designed for small range measurements, has been presented by the manufacturer to be: probing error (max sigma) 4 μm, sphere spacing error (max sigma) 3 μm, and flatness measurement error (max sigma) 4 μm.

Statistics

Conventional descriptive statistics were used to present the results of the measurements.[38] *t*-Test[38] was used for comparisons between the groups considering distances between terminal implants on the models and the

TABLE 1 Recorded Horizontal Width (mm) of the Models as Registered with the CMM and the Optical Three-Dimensional Scanner Techniques, Respectively

Model	Recorded Horizontal Width of Models (Width and Difference in mm) CMM	Scanned	Difference of Width between Used Techniques CMM – Scanned
1	33.790	33.795	−0.005
2	33.802	33.796	0.006
3	33.744	33.785	−0.041
4	33.767	33.805	−0.038
5	33.758	33.810	−0.052
Range	0.058	0.015	0.058
Mean	33.772	33.798	−0.026
SD	0.0236	0.0100	0.025

SD, standard deviation; CMM, coordinate measuring machine.

frameworks as well as the fit assessments. The level of statistical significance was set to 5% ($p < 0.05$).

RESULTS

Comparison of Width at Terminal Implants

Measurements of width of *models* (see Figure 2) at terminal implants are presented in Table 1. No statistically significant differences between the means of the CMM and the optical three-dimensional scanner measurements were found ($p > 0.05$). It can be observed that the distance between the terminal implants were greater for four out of five models, when using the scanning measurement technique (see Table 1). The difference ranges between −0.006 and 0.052 mm, corresponding to −0.02–0.15% of the distance, measured by the scanning technique (see Table 1).

Table 2 presents the horizontal width between the terminal cylinders of the *frameworks* using both measuring techniques. For the measurements achieved from the three-dimensional scanning technique, the width was again greater for all five frameworks, as compared with the CMM technique measurements. However, no statistically significant differences between the means of the CMM and the optical three-dimensional scanner measurements were found ($p > 0.05$). Comparing the fit of the frameworks in relation to the terminal implants in the models, smaller values were observed for all frameworks when using the three-dimensional scanning technique (see Table 2).

Comparison of CMM and Optical Scanning "Virtual" Fit Assessments

Greater mean distortions were registered for the CMM than for the optical three-dimensional scanner measurements in three-dimensional (Table 3). For individual frameworks also (1–5), greater variations were observed for the CMM technique in both x- and y-axes (see Table 3). Yet, the only statistically significant difference

TABLE 2 Recorded Horizontal Width (mm) of the Frameworks as Registered with the CMM and the Optical Three-Dimensional Scanner Techniques, Respectively

Framework	Recorded Horizontal Width of Frameworks (Width and Distortion in mm) CMM	Scanned	Difference of Width between Used Techniques CMM – Scanned	Distortion of Frameworks Related to Models CMM	Scanned	Difference of Distortion between Used Techniques CMM – Scanned
1	33.804	33.790	0.014	−0.014	−0.005	−0.009
2	33.842	33.799	0.043	−0.040	0.003	−0.043
3	33.832	33.794	0.038	−0.088	0.009	−0.097
4	33.855	33.789	0.066	−0.088	−0.016	−0.072
5	33.884	33.860	0.024	−0.126	0.050	−0.176
Range	0.080	0.071	0.052	0.112	0.066	0.167
Mean	33.834	33.806	0.037	−0.071	0.008	−0.079
SD	0.0294	0.030,2	0.0198	0.044	0.025	0.063

SD, standard deviation; CMM, coordinate measuring machine.

TABLE 3 Real Mean Distortions (SD) in Micrometer between Frameworks and Models (n-5)

	x	y	z	Three-Dimensional
CMM (virtual)	0 (35)	4 (27)	0 (3)	37 (22)
Scanned (virtual)	1 (6)	−4 (7)	0 (1)	14 (7)
Scanned (physical)	−6 (12)	−3 (3)	−14 (19)	42 (19)

All fit measurements are performed using "least square method." Both "virtual" and "physical" assessments have been performed.

for the real mean distortions was found between measurements in three-dimensional ($p < 0.05$; see Table 3).

A similar pattern was present when mean distortions expressed as absolute values were compared, and a statistically significant difference was found again in three-dimensional ($p < 0.05$; Table 4). The absolute value comparisons showed greater mean distortions for the CMM than for the optical three-dimensional scanner measurements in all dimensions (x, y, z, and three-dimensional; see Table 4).

Comparison between "Virtual" and "Physical" Assessments Using Scanning Technique

The real mean distortions registered with the optical three-dimensional scanning technique and analyzed as "physical" values were generally greater than those analyzed as "virtual" values (see Table 3). A statistically significant difference was present in three-dimensional ($p < 0.001$). When the absolute values for the same analyses were compared, the differences were enforced and were statistically significant in y- and z-axes and three-dimensional ($p < 0.001$, $p = 0.001$, and $p < 0.001$, respectively; see Table 4).

DISCUSSION

The present study indicates that data on precision of fit may vary depending on what measuring technique is used. Accordingly, this study presents wider dimensions of frameworks and models when using high-resolution three-dimensional scanners as compared with high-resolution CMM techniques (see Tables 1 and 2). However, when using these high-resolution techniques, it is difficult to calibrate them against another even more accurate technique to determine which one is closest to the "true" value. The conclusion must be that measurements on the micrometer level must be judged with caution and is probably of a more theoretical than clinical level of relevance.

On the other hand, it seems to be of higher importance on what level of the fit assessments are performed ("virtual" vs "physical"; see Figure 1, A and B) than what measurement technique is used (see Tables 3 and 4). The critical vertical distortion, causing gaps between frameworks and implants, increases significantly when making fit assessments on a "physical" level (see Table 3). Today, when prostheses often are connected directly to the implants, without abutments, higher preload forces could be expected because the screw driver torque recommended for such prostheses are much higher. As a consequence, a higher stress is achieved in the peri-implant tissues for comparable gap distances when tightening the frameworks on the implant level. In addition, new and less flexible materials than the earlier commonly used gold alloys, such as

TABLE 4 Mean Distortions (SD) in Micrometer between Frameworks and Master Model in Absolute Figures

	x	y	z	Three-Dimensional
CMM (virtual)	27 (22)	21 (17)	3 (2)	37 (22)
Scanned (virtual)	7 (8)	9 (8)	1 (1)	14 (8)
Scanned (physical)	14 (14)	22 (16)	21 (20)	43 (24)

All fit assessments are performed using "least square method." Both "virtual" and "physical" assessments have been performed.

cobalt-chromium, might introduce even higher stress levels. However, the clinical significance of this difference is not yet known.

Another important aspect to consider when studying precision of fit of different frameworks is how the frameworks are fabricated. It is reasonable to assume that when the laboratories are informed about the study and know which the test frameworks are, the result will be much better than when frameworks are manufactured as a simulated clinical routine procedure, without knowledge of the study.[12]

The pattern of distortion in six degrees of freedom is very complex and multifactorial. The experience is that it is basically impossible to describe in detail all facets of this distortion, and therefore, more or less, simplified presentations, using only some few parameters, have been used in most publications.[39] It is then very difficult to judge whether chosen parameters are clinically relevant, reflecting important information for predicting clinical problems, or are more like surrogate end points, of no value for clinical prognosis or maintenance.

Accordingly, whether this data on fit measurements are valid information for the clinical use or only "surrogate" data that can be measured and compared but does not relate to any clinical parameter is today an open question. Clinical studies that have approached this problem have failed so far to establish a clear relationship between any fit parameter and short- or long-term maintenance of screw-retained implant-supported prostheses.[40,41] The present observations that use the technique of measuring misfit, as well as chosen technique for evaluating misfit, introduces further considerations into this complex discussion on clinical impact of misfit.

CONCLUSIONS

Within the limitations of this study, measurements of fit between frameworks and models may vary depending on what technique is used and how fit assessments regarding "virtual" or "physical" fit is approached.

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