Photogrammetry and Conventional Impressions for Recording Implant Positions: A Comparative Laboratory Study

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ABSTRACT

Background: The development of digitized techniques for manufacturing implant frameworks has made possible alternative "impression" techniques for recording implant positions.

Purpose: The objective of the present study was to test the precision and accuracy of a three-dimensional photogrammetric technique to record implant positions in vitro and to compare casts made with this technique with conventional casts fabricated with two conventional impression techniques.

Materials and Methods: Twenty casts were fabricated from 10 polyether (Impregum™, ESPE Dental AG, Seefeld, Germany) impressions and 10 plaster (Kühns Abdrucksgips, Ernst Hirnischs GmbH, Goslar, Germany) impressions of one master model. The casts were measured in a coordinate measuring machine (Zeiss Prismo VAST, Oberkochen, Germany) and compared with the master model. Six separate three-dimensional photographs of the master model were taken with a special camera. After the photographs were measured with an analytic plotter, results were analyzed and compared to the coordinates of the original model and casts.

Results: A systematic pattern of distortion in the x-axis was found for the two impression techniques. Expansion of the implant arch at the terminal implants ($p < .01$) averaged 22 μm and 94 μm on photographs and plaster casts, respectively. Polyether casts contracted an average of 52 μm when compared with the master ($p < .01$). In absolute figures, photogrammetry and the polyether technique reproduced the x-axis and three-dimensional parameters more accurately than the plaster technique did when cylinder center point distortion was compared ($p < .05$ to $p < .001$). However, angular cylinder distortion in absolute figures was greater with the photographic technique than with either of the impression techniques ($p < .05$–$p < .001$).

Conclusion: Photogrammetry is a valid option for recording implant positions and has a precision comparable to that of conventional impression techniques. At present, however, it is limited to framework fabrication techniques that are based on digital platforms.

KEY WORDS: fit, framework, implant positions, impression, photogrammetry

The fabrication of master casts for conventional crown and bridgework has been documented in many reports over the years.[1–8] Studies on the materials used in the different steps of master cast fabrication have reported acceptable accuracy for clinical use in crowns and bridgework, but until now no studies have demonstrated that the master casts accurately reproduce the dimensions of the oral cavity.[1–8] However, the periodontium often allows for adjustments of minor distortions, and the cement will fill in the residual gaps between the castings and the tooth abutments.

Impression techniques for implant treatment have been developed from modified conventional prosthodontic techniques and use either direct or indirect methods.[9,10] Since the shape of the premachined implant abutments is known, attention can be focused more on the relationships between the implants than

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on the reproduction of the shape of the abutments. Yet techniques for the fabrication of implant master casts are less than optimal,[11] and since the osseointegrated implant is ankylotic, the restoration dentist cannot rely on minor adjustments in implant position to compensate for minor fabrication distortions, as has been observed with periodontally supported abutment teeth. Therefore the three-dimensional reproduction of implant positions in the oral cavity may be more critical in restorative treatment of the implant patient. Reports on materials and techniques used for the fabrication of master casts for implant dentistry have not been entirely consistent.[9,12–17] Humphries and colleagues reported that tapered reseating copings (indirect technique) correlated more highly with coordinate values on the master than did unsplinted or splinted squared copings (direct techniques).[12] On the other hand, Carr found that the direct technique using squared impression copings produced a more accurate working cast than did t

for recording implant positions and to compare this technique with two conventional impression techniques that are routinely used to fabricate implant master casts.

MATERIALS AND METHODS

Master Model

One experimental master model (Figure 1) was fabricated in acrylic resin (SR Ivocron, Ivoclar Vivadent, Schaan, Liechtenstein).[29] Five multiunit abutment replicas were inserted in the model (Brånemark System® No. 26782, Nobel Biocare AB, Göteborg, Sweden), and the three-dimensional positions of these replicas were measured with a coordinate measuring machine (Zeiss Prismo VAST, Carl Zeiss AG, Oberkochen, Germany).[29]

Photogrammetric Technique

The camera used to take three-dimensional photographs of the master model has been described in detail

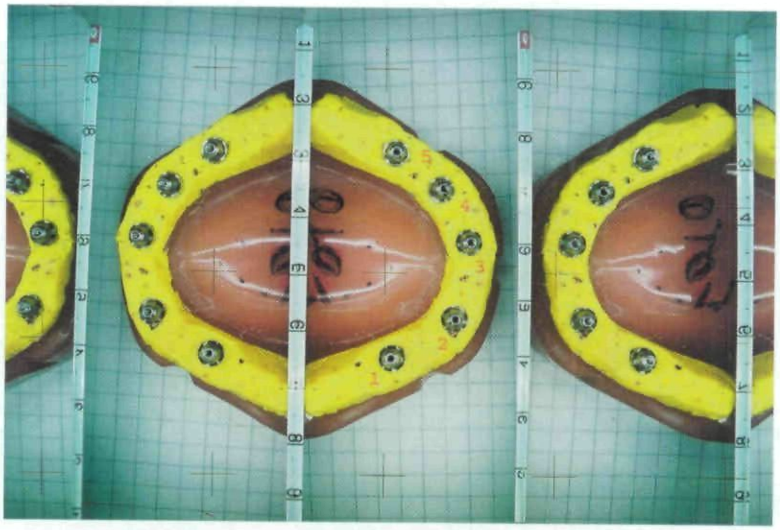

Figure 2 A stereoscopic analytic plotter was used to analyze the three-dimensional photographs.

The three-dimensional orientation of the center points and the inclination of the abutments were calculated in a coordinate system.

Conventional Impressions

Impressions of the master model were obtained by using five squared impression copings (No. 26696, Nobel Biocare) secured by five guide pins to the abutment replicas. Mandible acrylic resin trays (Solo® plus, Davis Healthcare Services Limited, Hertfordshire, UK) with open tops were used for direct ("pick-up") impressions. The openings in the tray were approximately 2 × 4 cm and were covered with Tenax wax (SS White, Gloucester, UK) prior to the taking of the impression.

Twenty impressions were made with either impression plaster (Kühns Abdruckgips, Ernst Hirnischs GmbH, Goslar, Germany) or polyether (Impregum™ Penta™, ESPE Dental AG, Seefeld, Germany), according to the manufacturers' recommendations. The same amount of material was used for each impression, and the impressions were made at 23°C. Before the polyether impressions were taken, the trays were coated on the inside with polyether adhesive (ESPE Dental AG) and allowed to set for 5 minutes.

The impressions were removed after the recommended setting time. After 30 minutes, five multiunit abutment replicas (Brånemark System No. 26782) were then connected to each impression. The impressions were filled with equal amounts of plaster (Gildur pink SP 1, Giulini Chemie GmbH, Ludvigshafen/RH, Germany). Stone casts were separated after 1 hour and stored at 23°C.

Measurement of Models

The orientation of the implant replicas in the master model and in all 20 stone casts was measured with the coordinate measuring machine (CMM).[29] In brief, the model was placed in a mold on a stable reinforced concrete table. The CMM was equipped with a scanning head fitted with a stylus with a diameter of 0.8 mm. The stylus could be positioned at any location (in dimensions X, Y, and Z as shown in Figure 3) in the CMM working space, and the positions and contact planes

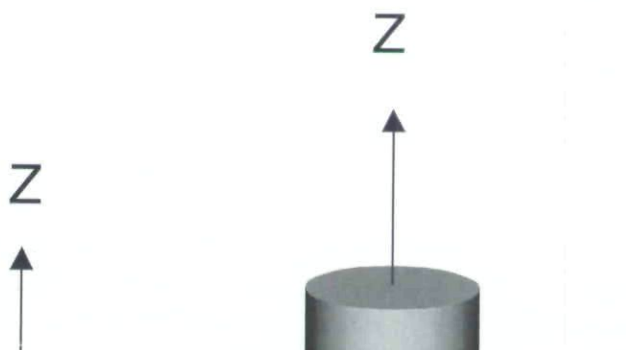

Figure 3 Lateral (X), sagittal (Y), and vertical (Z) coordinates for the measurements of the centers of the cylinders.

of the implant cylinders were found by stylus contact scanning of the component. A force was electronically applied to the measuring stylus to ensure consistency in contact between the stylus and the component being measured. The movement of the contacting stylus was controlled by a subroutine in the standard UMESS-UX software (Zeiss). An automatic measuring program based on the design architecture of the abutment component recorded the measurements from the position of the stylus. The data for each implant cylinder were condensed to the position of the center point (X, Y, and Z; see Figure 3) and information about angular distortion.

According to the manufacturer, the accuracy of the CMM is less than 1 μm for measurements of small volumes. Five repeated measurements of five components made it possible to calculate a standard deviation for the positions within 1 μm.

Data Comparison and Analysis

The techniques used to analyze data have been previously described.[29] All data are presented as distortions of the different cylinders in relation to the master model, which was the reference when each pair of measurements was superimposed in the computer. A software program made it possible to fit theoretically calculated surfaces to each other by means of the least-squares method described by Bühler.[35] The distance (distortion) between the center point of the stone cast replica and the master model in the x, y, and z coordinates and in three dimensions was calculated in micrometers for each individual cylinder.

The distortion was also presented as a calculated "gap" between the cylinders by superimposition of the center points of the two individual cylinders in the computer (stone cast to master model), as described earlier.[29] These measurements are referred to as the angular gap distortion (Figure 4).

Similar comparisons were made between measurements of the master model and data collected from measurements of the three-dimensional orientation of the cylinders in the photographs.

Statistics

Conventional descriptive statistical values (mean, standard deviation [SD], and range) were used to describe the distortion measured in the models and photographs.[36] The measurements were also calculated in absolute figures to show the degree of distortion without consideration to the direction of the displaced cylinder. These data, and data regarding the mean distance between the terminal implants (width) and curvature of the arch (depth) (see Figure 1), were analyzed with the Wilcoxon signed rank test.[36] The level of statistical significance was set at 5%.

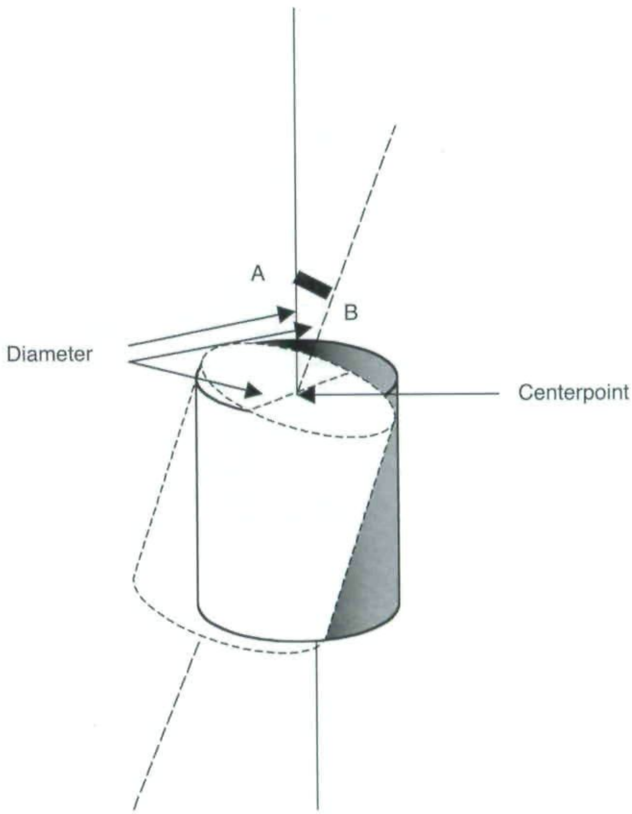

Figure 4 The center points of the two cylinders were superimposed, and the distance between the ends of the two normal vectors with the same length as the diameter of the cylinder was measured. The distance A–B represents the angular gap distortion.

RESULTS

Range of Distortion

For all three techniques, the greatest range of overall displacement of the center point of individual abutment replicas was observed at the lateral axis (x-axis) (Table 1).

Reproduction of the Implant Arch

The impressions made with all three techniques differed significantly in all axes from the master model except for the y-axis of the impression made with the three-dimensional camera technique (Table 2). In

TABLE 1 Maximal Range of Individual Center Point Distortion of Casts and Photographs

	Center Point Distortion (μm)		
Technique	Min	Max	Range
3-D camera (n = 6)			
x-axis	−40	40	80
y-axis	−30	40	70
z-axis	−40	20	60
3-D	10	60	50
Polyether (n = 10)			
x-axis	−70	64	134
y-axis	−37	39	76
z-axis	−22	14	36
3-D	0	75	75
Plaster (n = 10)			
x-axis	−61	74	135
y-axis	−31	24	55
z-axis	−10	11	21
3-D	11	74	63

3-D = three-dimensional; Max = maximum; Min = minimum.

a comparison of the different techniques, measurements from the plaster models were found to be statistically wider (x-axis) than measurements from the polyether models ($p < .001$) or from the photographs ($p < .001$). Implant arches measured on the photographs were significantly wider (x-axis) than those measured on casts from polyether impressions ($p < .01$). Measurements showed the implant arch (see Figure 1) to be significantly more curved (depth) in polyether ($p < .05$) than in plaster or on photographs.

Center Point Distortion

No clear systematic pattern was observed for the photographs when mean center point distortion was analyzed in relation to the positions of the abutment replicas. However, both polyether and plaster impression techniques displayed systematic distortions, mainly in relation to the positions of the abutment replicas in the x-axis. Polyether appeared to undergo a symmetric contraction and plaster a symmetric expansion in the x-axis.

When the same measurements were calculated as the mean of the displacement in absolute figures (Figure 5), the vertical distortion (z-axis) was of a lower magnitude than the horizontal distortion (axes x and y) for all three techniques. When the results were analyzed in absolute figures, the differences between the techniques were significant (see Figure 5).

The overall mean three-dimensional distortion was 24 μm (SD, 12 μm) for the photogrammetric technique, 25 μm (SD, 15 μm) for the polyether technique, and 33 μm (SD, 16 μm) for the plaster technique.

Angular Gap Distortion

The angular gap distortion (AGD) of the position of the replicas was greatest in the y-axis in all three groups. In absolute figures, for all three techniques

TABLE 2 Mean Distances between Positions 1 to 5 in Width (x-axis) and between Highest and Lowest Values in Depth (y-axis), with the Master* as Reference

	Distance (μm)				
Technique	Min	Max	Mean (SD)	Δ Master	p Value
3-D camera (n = 6)					
x-axis	37,372	37,474	37,421 (40)	22	<.01
y-axis	13,554	13,607	13,572 (18)	11	ns
Polyether (n = 10)					
x-axis	37,265	37,413	37,347 (40)	−52	<.01
y-axis	13,582	13,637	13,604 (17)	43	<.01
Plaster (n = 10)					
x-axis	37,467	37,534	37,493 (19)	94	<.01
y-axis	13,556	13,608	13,589 (16)	28	<.01

Δ = difference; 3-D = three-dimensional; Max = maximum; Min = minimum; ns = not significant; SD = standard deviation.

*Master: 37,399 μm for width (x-axis) and 13,561 μm for depth (y-axis).

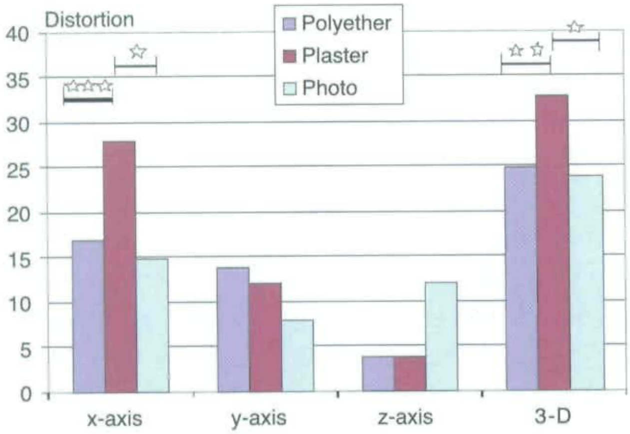

Figure 5 Mean distortion (in micrometers) of the center point of the casts and photographs, compared with the master model, in absolute figures (* $p < .05$; ** $p < .01$; *** $p < .001$). (3-D = three-dimensional)

the horizontal (axes x and y) and the three-dimensional distortions of the AGD were greater than the vertical distortion (z-axis) (Figure 6). The photographs incorporated significantly ($p < .05$–$.001$) more AGD in all measured dimensions than did the polyether and plaster casts (see Figure 6).

DISCUSSION

In accordance with earlier studies on implant impression techniques and master cast fabrication,[9,12–16] all the techniques in this study failed to exactly reproduce the orientation of the implants in the master model. The magnitude of the distortion was similar for all three techniques and was comparable with results from other studies.[9,12,16] Accordingly the two impression procedures as well as the photogrammetric technique must be considered to be accurate enough for conventional clinical use, and this conclusion has been well supported in clinical experience of the daily use of the present impression techniques for many years. Favorable clinical trials using photogrammetry as an option for impression procedures in combination with CNC-milled titanium frameworks also support this conclusion.[30]

Casts made in the two impression procedures displayed a symmetric distortion when compared with the reference; the plaster impression technique tended to expand the implant arch (+0.25%) whereas the polyether technique tended to reduce the width of the implant arch (−0.14%; see Table 2). Both trends were strong and significant ($p < .05$ to $p < .001$) in comparisons between each other as well as with the master model (see Table 2). Other researchers have reported similar trends of symmetric distortion of master models.[2,8,9]

According to the manufacturers, the linear setting expansion of the impression plaster is about +0.06% to +0.12%, and the linear dimensional contraction of the polyether used (Impregum) is about −0.3%. An additional expansion of about +0.10% could be expected in the plaster models after setting.[7] In light of these figures, the final mean distortion observed for these casts (width; see Table 2) are in good agreement with the distortion anticipated by the manufacturers, indicating that the materials have been handled according to the manufacturers' recommendations. In the light of these observations, it can also be noted that the use of standard plastic impression trays instead of custom-made acrylic resin trays did not seem to have any negative impact on the result, as could otherwise be expected.[37] The selection of these trays was based on the routine protocol at this clinic, which has used standard plastic trays for many years without any clinical problems.

A previous study on distortion of conventional castings found a symmetric framework contraction of −0.2% of the width at the terminal implants, as compared to the master model.[29] This observation was in accordance with the findings of other studies and indicated that symmetric contraction of metal frameworks takes place when they are cast in one piece.[17,19] If rehabilitation is thought of as an unbroken

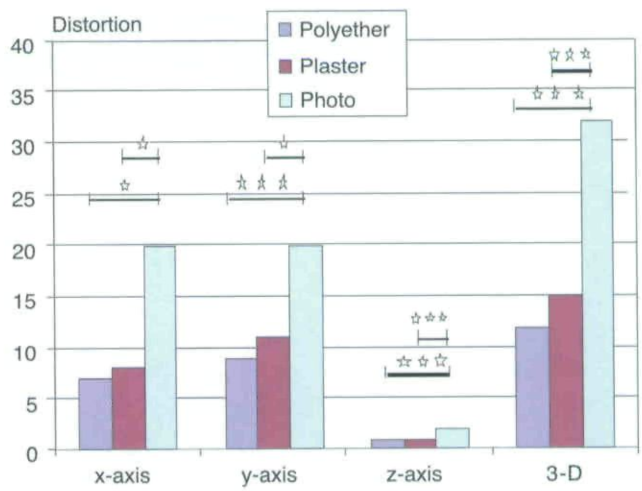

Figure 6 Mean angular gap distortion (in micrometers) of the casts and photographs, compared with the master model, in absolute figures (* $p < .05$; ** $p < .01$; *** $p < .001$). (3-D = three-dimensional)

chain from impression to placement of the final prosthesis, it would appear to be more advantageous to use a master model that has undergone slight expansion to compensate for casting shrinkage, as observed with frameworks cast in one piece.[19,29] Accordingly (at least on a theoretical level) casts from plaster impressions would then compensate for the distortion from the casting procedure better than would the slightly smaller casts from polyether impressions.

On the other hand, it has earlier been shown that CNC-milled frameworks present a statistically much better fit and precision than do conventional castings.[29] Thus when CNC-milled frameworks are used, probably the most precise model should be recommended, irrespective of whether a model has expanded or contracted.

Conventional impression procedures and fabrication of master casts involve many manual steps that may compromise the final precision of the master cast. The photogrammetric technique involves fewer steps and could be even further reduced if the measurements of the photographs were performed automatically instead of by an operator at a stereoscopic plotter, as in this study. Except for the obvious setting distortion of the materials discussed above, this difference of fewer manual steps could contribute to the lower range of individual center point distortion in x-axis and three dimensions from the photogrammetric technique (see Table 1). Accordingly the photogrammetric technique may be a more reliable and possibly easier clinical option for recording implant positions than are the conventional techniques.

The long axis of the implants underwent more distortion with the photogrammetric technique than with the impression techniques (see Figure 6). The distortion of the center point in the z-axis was also slightly higher than it would be with conventional techniques (see Figure 5). This distortion reflects the problem that the smallness of the upper area of the implant makes the periphery of the implant difficult to read in the plotter. Use of a specially designed screw with a wider top diameter and a sharper edge would probably significantly improve the angular orientation of the implants when the photogrammetric technique is used. Since the clinic will always encounter situations with subgingivally placed abutment margins, a further development of the photogrammetric technique for clinical use will most likely involve the introduction of some sort of a "photogrammetric coping" to be placed on top of the implant. Such a coping would improve the angular orientation of the implant and make it possible to photograph subgingivally placed abutments as well as record at the level of the implant head.

Photogrammetry is limited to fabrication techniques that are based on "digital platforms" (CNC technique), which confine its application today. As more and more computer-aided design/computer-aided manufacturing (CAD/CAM) techniques are developed in restorative dentistry, photogrammetry will become a valuable alternative in the development of dentistry.

CONCLUSION

The present study found that photogrammetry is a valid option for recording the positions of implants and has a precision comparable to that of conventional impression techniques. It is, however, limited to framework fabrication techniques based on digital platforms.

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