The Accuracy of an Implant Impression Technique Using Digitally Coded Healing Abutments

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ABSTRACT

Background: A healing abutment (Encode®) provided with digitally coded information on length and diameter on the top was launched in 2007. So far, no study has evaluated working cast fabrication using impressions of the coded abutments and analogue placement using a robot technique.

Purpose: To compare the accuracy of implant analogue placement in working casts using a robot technique and an impression of Encode healing abutments, with the traditional technique.

Materials and Methods: One acrylic master model was fabricated, provided with two groups of three implant analogues. Encode healing abutments were mounted on the test side and conventional pickup impression copings were inserted on the control side. Fifteen impressions were made with a vinylpolysiloxane material. Implant analogues were placed by a robot on the test side. The center point of each implant analogue fitting surface was measured with a laser measuring machine in the x-, y-, and z-axis, as were also the angular direction of the center axis and the position of the antirotational hex. Two-way analysis of variance was performed using SPSS 17.0; the statistical significance was set at $p < .05$.

Results: Mean center point deviation for the test and control side was 37.4 µm versus 18.5 µm ($p = .001$) in the x-axis, 47.3 µm versus 13.9 µm ($p < .001$) in the y-axis, and 35.0 µm versus 15.1 µm ($p < .013$) in the z-axis. Mean angle error was 0.41 degrees for the test and 0.14 degrees for the control side ($p < .001$). Mean rotation of the hexagon was 2.88 degrees for the test side and 1.82 degrees for controls ($p < .001$).

Conclusions: Both conventional and robot technique presented low levels of displacement of the implant analogues in all casts. The test technique was less precise, but the difference in accuracy was small, and both techniques are precise enough for single crowns and short-span, implant-supported fixed partial prostheses.

KEY WORDS: digitized, impression coping, precision, vinylpolysiloxane (VPS) impression material

INTRODUCTION

Impression techniques for implant treatment are modifications of conventional prosthodontic techniques. Because the shape of the premachined implant or abutment is known, attention can be focused on the relationship between the implant and the surrounding teeth, rather than on the reproduction of its shape. Reports on materials and techniques used to fabricate casts in implant dentistry have not been consistent with regard to which technique is most accurate.[1–6] Both early and more recent studies on implant impression procedures report that working casts fail to exactly replicate the original situation and that no single impression procedure is more reliable than others.[2–14] In the cast, displacement of the implant components can be introduced in four main ways,[15] namely: (i) displacement of each impression coping on the fitting surface of each implant across the machining tolerance range; (ii) displacement of each impression coping, the degree of displacement depending on the impression technique or the material used; (iii) displacement of implant analogues on the fitting surface of each impression coping in the impression across the machining tolerance range;

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and (iv) displacement of each analogue in the definitive cast because of the dimensional change of the dental stone. With digitized impression techniques, it will be possible to circumvent these steps, and thereby reduce the risk of displacement.[16]

Digital impressions can now be made with intraoral scanners; however, scanning of implants at fixture level below the peri-implant mucosa is not yet possible. If implant impression could be made directly on the healing abutments, the soft tissue seal would be undisturbed, impression making would be simplified, and treatment time would be reduced. Consequently, the development of a "photogrammetric coping"[16] or digitally coded abutment[17–19] is necessary to allow scanning procedures. For this purpose, a digitally coded healing abutment (Encode®; Biomet 3i, Palm Beach Gardens, FL, USA) provided with all necessary information on implant restorative platform, hex position, and healing abutment collar height has been launched, and according to pilot studies,[17–19] it is sufficient to transfer all necessary information of implant platform and position to the working cast. Scanning of a stone cast (produced by a silicone impression of the Encode abutments) can transfer this digitized information of implant diameter and position to a robot that removes the stone duplicates of the healing abutment with a bur, and places an implant analogue of the right diameter in the correct position in the working cast (Robocast™ technology; Biomet 3i). Consequently, inserting the digitally coded healing abutment could be a single-step procedure in the future using digitized impressions with intraoral scanning techniques.[16]

By using Encode healing abutments in a one-stage surgical procedure, a healed and undisturbed soft tissue will be present both at impression making and prosthesis placement. Thus, the aim of this study was to evaluate and compare the accuracy of implant analogue placement in working casts using impressions of digitally coded healing abutments and a robot placement technique, to that of conventional impression technique using pickup impression copings and manual placement of analogues in the impression.

MATERIALS AND METHODS

Fabrication of Master Model and Trays

One master model was fabricated from heat-cured acrylic (SR Ivocap High Impact; Ivoclar Vivadent AG, Schaan, Liechtenstein) simulating the arch form of an edentulous maxilla. The master model was designed with a horizontal reference plane including three 10 mm Ø Tungsten carbide balls as reference spheres (type 5 tooling balls; Spheric-Trafalgar Ltd, Ashington, UK). The model was provided with six implant analogues with an external hexed-abutment connection system (ILA20, Lot. 842537; Biomet 3i) placed bilaterally in groups of three in the canine and premolar regions. The implants were sequentially numbered from 1 to 3 on both sides starting in the canine position. Implant analogue mating surface was placed 1 mm above the surrounding acrylic material in order to facilitate laser measurement. After fabrication, the master model was stored for 4 weeks to ensure that no volume changes would occur after impression taking.

One impression of the master model was made to produce a stone cast for fabrication of 15 impression trays (Nova Tray, Heraeus Kulzer, Copenhagen, Denmark). The trays were provided with external rests in order to secure correct positioning of the trays and an even layer of impression material. The trays were fabricated with an open tray design on the left (control) side and a closed tray design on the right (test) side.

Fabrication of Casts

Three 5 mm–long Encode healing abutments (EHA 453, Lot. 390653; Biomet 3i) were mounted on the right side of the master model, while traditional implant pickup copings (IIC 12, Lot. 833037; Biomet 3i) were mounted on the left side (Figure 1). A torque of 10 Ncm was applied on both Encode abutments and impression

Figure 1 Master model with conventional pickup copings and Encode® healing abutments surrounded by a silicone material simulating peri-implant tissue.

Figure 2 Encode® healing abutments provided with digitally coded information on length and restorative platform.

copings using a torque wrench. To facilitate the impression taking, a silicone material (R-SI-LINE®; R-dental Dentalerzeugnisse GmbH, Hamburg, Germany) was applied around the cervical part of the abutments to simulate peri-implant soft tissue, leaving 2 mm of the abutment free (Figure 2).

Silicone adhesive (VPS Tray Adhesive; 3 M ESPE, Seefeld, Germany) was applied in the trays 15 minutes before impression taking. Fifteen impressions for 15 working casts were made with a vinylpolysiloxane (VPS) impression material (Honigum® light- and heavy-body impression material; DMG, Hamburg, Germany), according to the manufacturer's instructions. For each impression, a new set of implant pickup copings and Encode abutments was mounted on the master model, as described above. On the left (control) side, an experienced dental technician mounted implant analogues on the pickup impression copings before pouring the impression with stone (GC Fujirock® EP; Alsip, IL, USA). All impressions were poured within 5 hours. After setting, the stone cast was removed from the impression and was sent to the Biomet 3i laboratory (West Palm Beach, FL, USA). The casts were placed in a scanning machine (3Shape model 250; 3Shape A/S, Copenhagen, Denmark), where information on implant diameter, size, and position was collected from the Encode abutments. This information was transferred to a robot. The duplicated Encode abutments on the test side were removed through a drilling procedure, and implant analogues were placed according to the scanned information. The analogues were glued to the working cast using a fast-setting glue with setting time <30 seconds (RITE-LOK; 3 M, St Paul, MN, USA).

Measuring of Master Model and Casts

The master model and the 15 working casts were measured with a laser measuring machine (LMM) (LK, Integra; Metris Metrology Solutions, Leuven, Belgium) provided with a high-accuracy three-dimensional laser sensor, by an independent laboratory (Design Control, Billdal, Sweden). The manufacturer of the LMM claims an accuracy of 10–15 microns (μm) in all dimensions.

The three reference spheres incorporated in the master model were used to create a reference plane in the master model and in the working casts. The scanning procedure created a dense point cloud, digitally describing the object in three-dimensional. Data for each analogue were condensed to a position of the center point of the implant analogue fitting surface in 3D using the x-, y-, and z-axis. The position of each implant analogue center point, the inclination of the analogue toward the reference plane, and the position of the external hex were registered (Figure 3).

To evaluate the precision of the LMM and the reproducibility of the reference plan, the master model was scanned six times as a control. The differences in center point positioning of implant analogues (in the x-, y-, and z-axis) between measurements were within 2–23 μm on all axes, with no difference between the test and control sides. Furthermore, the angle errors of the analogues were within 0.04–0.19 degrees, and the deviation in the position of the external hexagon was within a 0.10–0.35 degree range. The mean values from the six scannings of the master model were used as reference values for calculation of displacement and angular deviations.

Analysis of Accuracy

An analysis of accuracy was performed by calculating the difference between the reference values for the master model and the measured values in the 15 working casts. All data were presented as displacement

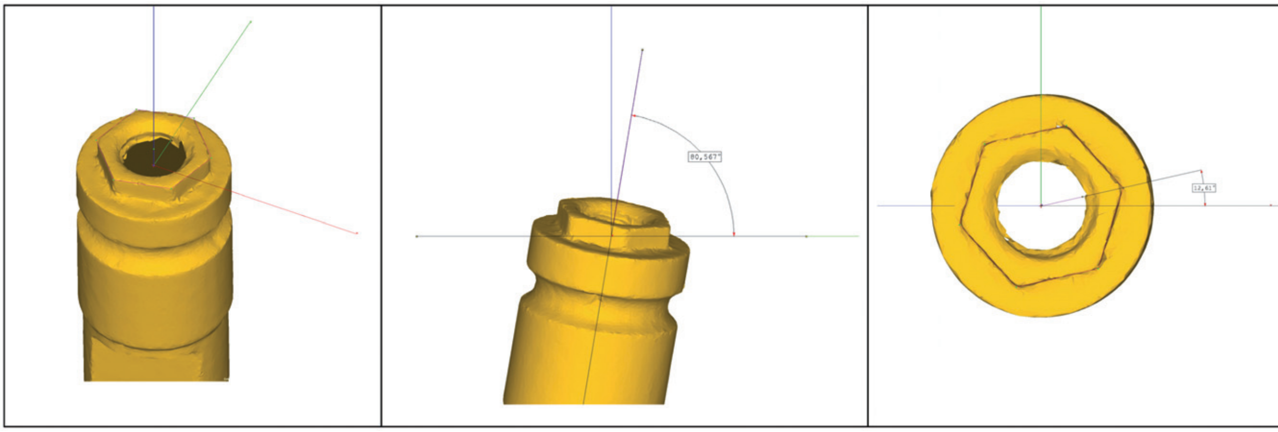

Figure 3 Center point position of the fitting surface on the x-, y-, and z-axis, the analog angulation, and the position of the implant/abutment connection hexagon as compared with the reference plane.

of the center point of individual implant analogues in relation to the center points of the analogues in the master cast. The three-dimensional directions of displacement of the center point (x-, y-, and z-axis) were calculated in µm in real and absolute values for all analogues. Furthermore, the three-dimensional distortion of the center points was calculated for each analogue using the formula (three-dimensional $= \sqrt{x^2 + y^2 + z^2}$). Angulation of each analogue in the working casts was compared with the reference value for the implant analogues in the master model as well as the position of the external hexed-abutment connection system.

Statistics

Conventional descriptive statistics were used to present displacement of implant analogues on the test and control side. Displacement, angle error, and rotation of the external hex in absolute figures (without consideration of direction of displacement and angulations) were used for the analyses performed with two-way analysis of variance controlling for implant analogue position, test and control side, and the working cast itself, with the level of statistical significance set at $p < .05$.

RESULTS

Neither of the two techniques for working cast fabrication resulted in working casts without implant analogue displacement, as compared with the master model. Mean displacement of analogue center point positions for test and control analogues (in absolute values) was 37.4 µm versus 18.5 µm ($p = .001$) in the x-axis, 47.3 µm versus 13.9 µm ($p < .001$) in the y-axis, and 35.0 µm versus 15.1 µm ($p < .013$) in the z-axis (Table 1). The three-dimensional displacement was 79.5 µm on the test side and 31.2 µm on the control side (Figure 4).

Furthermore, the range of displacement was larger on the test side in all axes, with no apparent difference between positions in the working casts, as illustrated by the boxplot of displacement in the z-axis (Figure 5).

The mean angle error of implant analogues was larger on the test side, with a mean of 0.41 degrees versus 0.14 degrees on the control side ($p < .001$). There was a larger rotation displacement of the implant analogues in the working casts on the test side as compared with the control side, with a mean rotation of the hexagon of 2.88 degrees for the test and 1.82 degrees for the control side ($p < .01$) (Table 2).

DISCUSSION

To achieve passive fit of prostheses, the impression technique must result in working casts without distortion. So far, several studies have, in different ways, evaluated existing and adjusted impression techniques but none report a technique without displacement.[2–11,14,15] It has been concluded that connecting a component produced as great a displacement as produced with an impression or cast fabrication.[15] This implies that traditional impression techniques using impression copings, VPS, or polyether impression materials and dental stone inevitably result in displacement of implant analogues in the casts.[13] In the present study, impressions on the test side were conducted without impression copings. Thereby, displacement resulting from manual analogue

TABLE 1 Mean Displacement, in μm, of the Implant Analog Center Point Position on the Test and Control Side for Each Position in the 15 Casts, as Compared with the Master Model

		Displacement of Center Point (μm)				
		Test		Control		
Axis	Position	Mean	(SD)	Mean	(SD)	*p* Value
x	1	46.6	(30.1)	10.9	(5.5)	
	2	27.3	(23.0)	13.7	(9.8)	
	3	38.4	(30.4)	30.9	(11.6)	
	All	37.4	(28.5)	18.5	(12.7)	0.001
y	1	33.6	(19.2)	11.9	(9.2)	
	2	42.1	(39.2)	13.1	(8.5)	
	3	66.1	(36.8)	16.7	(15.4)	
	All	47.3	(35.1)	13.9	(11.4)	<0.001
z	1	30.6	(30.0)	15.0	(12.2)	
	2	37.7	(34.4)	15.6	(13.1)	
	3	36.7	(24.0)	14.8	(18.5)	
	All	35.0	(29.2)	15.1	(14.6)	<0.013

placement in the impression was eliminated.[15] Although manual handling is avoided by the Robocast technology placement system, displacement introduced by the technique itself cannot be excluded.

In most studies,[2–7,10–12,14,15,20] displacement evaluation was restricted to one or two dimensions, while in the present study, displacement of analogues was evaluated in the x-, y- and z-axis, and angular inclination and hexagon position were measured using an LMM.

An LMM was used because it is more suitable and less costly for scanning whole casts compared with a computer coordinate measuring machine. To evaluate the accuracy of the LMM, repeated measurements of the master model were performed, giving a range of 2–23 μm in the x-, y-, and z-axis, which compares well with the horizontal inaccuracy of 14–21 μm reported by Wenz and colleagues using a computer-aided microscope.[21]

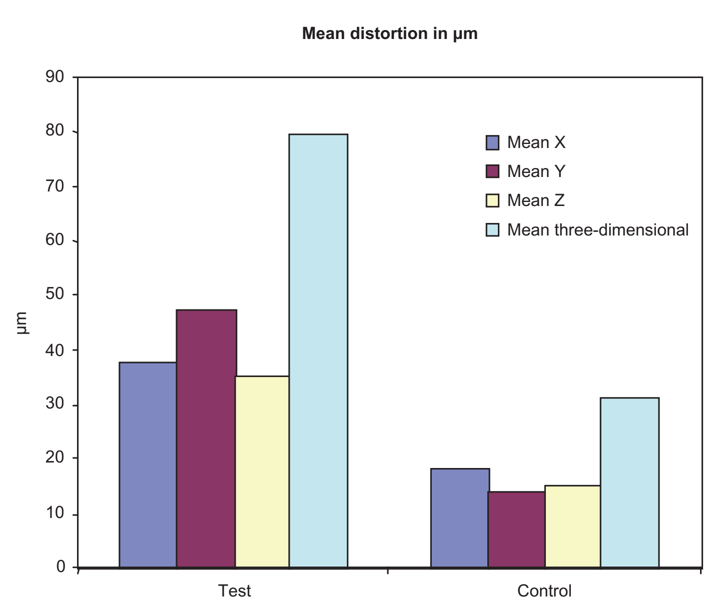

Figure 4 Mean distortion in micron (μm) in all axes and in three-dimensional on the test and control side.

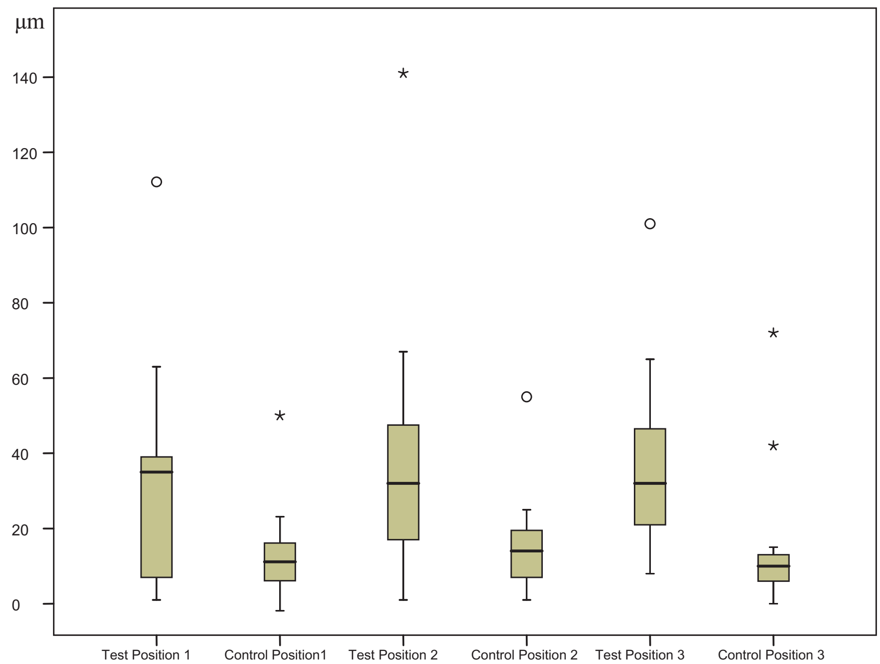

Figure 5 Boxplot of displacement, in micron (µm), in the z-axis. The boxplot shows data in absolute figures, with the horizontal line giving the median value and boxes representing 25% of the values above and below the median value. Extreme values are given by the symbols "°" and "*".

To reduce the influence of distortion from the impression material and cast fabrication, a split model was used; hence, differences in displacement should depend solely on the impression technique. The use of a master model with three incorporated referenced spheres made it possible to create a reference point and reference plane for registration of displacement in all directions for all implant analogues, without using some of them as reference points.

The results in the present study coincide with earlier reports, indicating that impression of digitally coded abutments (Encode), in combination with the Robocast technology, result in working casts with low levels of distortion. Still, the Encode/Robocast technology presented higher levels of mean center point displacement in the x-, y-, and z-axis and in three-dimensional compared with the conventional technique. In spite of the statistically significant difference in accuracy between

TABLE 2 Mean Angle Error of Implant Analog Angulations and Rotation of the External Hexagon on the Test and Control Side for Each Position in the 15 Casts, as Compared with the Master Model

Angular Deviation and Rotation of Hexagon						
		Test		Control		
	Position	Mean	(SD)	Mean	(SD)	*p* Value
Angle error (degrees)	1	0.42	(0.27)	0.21	(0.07)	
	2	0.37	(0.27)	0.11	(0.14)	
	3	0.42	(0.21)	0.89	(0.07)	
	All	0.41	(0.25)	0.14	(0.11)	<0.001
Rotation of hexagon (degrees)	1	2.74	(1.84)	1.55	(0.58)	
	2	3.11	(1.71)	2.04	(0.74)	
	3	2.80	(1.28)	1.86	(0.50)	
	All	2.88	(1.60)	1.82	(0.63)	<0.001

the two methods, the clinical significance of the difference is unknown.[22–26] The horizontal displacement (x- and y-axis) was 37.4 and 47.3 µm for the test side and concurs with the horizontal discrepancies of 15–46 µm reported by Vigolo and colleagues (2004) and 17–39 µm reported by Wenz and colleagues (2008).[21,27] This implies that the horizontal displacement is well within the machining tolerances reported by Ma and colleagues for the Brånemark system.[28] The mean vertical displacement found in the present study, 35.0 and 15.1 µm for the test and control side, respectively, compares well to the vertical gaps of 38–141 µm for different impression and pouring techniques reported by Del'Acqua and colleagues.[11]

Deviation in implant analogue inclinations, here reported as angle error and rotation of the hex on the implant head, has been less frequently evaluated and may be of more clinical relevance for single crown restorations.[20] In the present study, the mean angle error was 0.41 degrees for the test and 0.14 degrees for the control side, compared with 0.1 and 0.6 degrees reported by Assunção and colleagues and 0.22 and 0.33 degrees reported by Filho and colleagues for straight implants.[10,14] In the present study, a mean rotation of the implant hex of 2.88 degrees for test and 1.82 degrees for control analogues was recorded, which is smaller than the rotational freedom between the Brånemark implant and a standard abutment of 6.7 degrees, reported by Binon.[29] The displacement in the x- and y-axis as well as the angle error and rotation of the implant hex recorded for the test technique is probably of no clinical significance. Furthermore, even though it could be debated, there is no evidence that a vertical displacement of 35 µm (which is hard to detect without magnification) impairs the prognosis for implants and prostheses.

Other methods have been used to evaluate accuracy of prostheses and working casts, for example, strain gauge measurements, but comparisons with these results are not possible.[30] So far, no other study has reported both displacement in all three dimensions and angular deviation and rotation of the implant hexagon. Overall, small displacements were recorded on both the test and the control side. Because the machining tolerance of impression copings and Encode healing abutments was not evaluated in the present study, some of the differences in the results may be due to differences in machining tolerance.

In the clinical situation, impression copings may be difficult to place properly because of interference with soft and hard tissue. Conversely, placement of coded healing abutments at implant placement, when soft tissue is raised by a flap procedure, is easy and may result in a more accurate placement. An impression or intraoral scanning of a coded healing abutment, placed under ideal circumstances, may result in a more accurate registration of the implant position and angulation. Thus, the use of coded abutments involves fewer steps than the conventional impression techniques, leaves the peri-implant soft tissue undisturbed, simplifies impression taking, and reduces chair time. The digitally coded abutment seems to be a viable alternative for implant impressions for single crowns and short-span implant-supported prostheses, although further clinical studies are necessary to verify the results and evaluate the technique in daily practice.

In the near future, the use of coded healing abutments, in combination with intraoral scanning, may further facilitate impression procedures and contribute to less distortion in the final prosthesis. When the scanning technique is fully developed, conventional impressions are unnecessary, and patient anxiety from impression making may be reduced. Furthermore, an impression technique that is entirely digital would probably shorten the production time by excluding time-consuming steps and support computer-aided design/manufacture fabrication techniques based on "digital platforms." So far, the computer numerically controlled milling technique has been proven to have high accuracy and precision.[16,31,32] These advances in the implant dentistry and the rapid development of digitized processes will continue, making computerized technique more cost effective and flexible. Initially, however, a new technique is often costly, technique sensitivities are a potential limitation, and more research is needed to further develop the digitized technique.

CONCLUSIONS

The following conclusions can be drawn: both the conventional and the robot analogue placement technique presented low levels of displacement of the analogues in the casts.

Working cast fabrication using Encode abutments and a Robocast analogue placement technique was less accurate than the conventional impression technique.

Both techniques seem precise enough for single crowns and short-span, implant-supported fixed partial prostheses.

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