The Precision of Fit of Milled Titanium Implant Frameworks (I-Bridge®) in the Edentulous Jaw

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ABSTRACT

Background: New computer numeric controlled (CNC)–milled frameworks for implant-supported prostheses have been introduced. However, no data are available on the precision of fit of these new frameworks.

Purpose: The purpose of this study is to evaluate the precision of fit of a new CNC-milled framework technique (I-Bridge®, Biomain AB, Helsingborg, Sweden) using Brånemark System® (Nobel Biocare AB, Göteborg, Sweden) and NobelReplace™ (Nobel Biocare AB) system implants.

Materials and Methods: Ten test frameworks were fabricated for one master model for each implant system. Five additional frameworks were fabricated for five different models simulating clinical cases as controls (Brånemark System). The distortion of implant center point positions was measured in x-, y-, and z-axes and in three dimensions by using a contact-type coordinate measuring machine and a computer program developed specifically for this purpose. Mann–Whitney *U*-test was used to compare differences of distortion within and between the groups.

Results: The maximal distortion in arch width (x-axis) and curvature (y-axis) was within 71 and 55 μm for all frameworks, respectively. The mean distortion in absolute figures in x-, y-, z-axes and three dimensions was for "clinical control" frameworks 23, 26, 4, and 34 μm as compared with less than 12, 12, 2, and 17 μm for Brånemark and NobelReplace frameworks, respectively. Control frameworks showed significantly ($p < .05$) greater mean and range of distortions in x- and y-axes and in three dimensions compared with test frameworks.

Conclusion: All measured frameworks presented signs of misfit, indicating that no framework had a "passive fit." Frameworks produced in a more routine clinical environment seem to present greater levels of distortion as compared with frameworks produced in a strict test situation. However, all measured frameworks presented levels of precision of fit within limits considered to be clinically acceptable in earlier studies of frameworks placed on abutments.

KEY WORDS: CNC milling, dental implant, edentulous mandible, fit of prostheses, frameworks, in vivo study, titanium

The technique of using osseointegrated implants introduced higher demands on the precision of fit of the frameworks as compared with conventional tooth-supported prostheses because of the ancylotic character of the implant abutment. Because casting of frameworks inevitably results in distortions, different solutions have been tried to improve fit of frameworks in implant dentistry such as sectioning and soldering or laser welding horizontally or vertically, bonding gold cylinders to cast frameworks and cementating on conical abutments.[1–5] Horizontal laser welding used

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with the CrescoTi® Precision™ (Astra Tech AB, Mölndal, Sweden) method, where distortion of the prostheses is corrected by means of a horizontal sectioning and laser welding, can be used to exemplify such an alternative technique that has been proven to work well in short-term clinical follow-up studies.[6–9]

With high demands for precision of fit for implant-supported prostheses and the cost for precious alloys; the interest has also been focused on development of techniques using alternative materials such as titanium, nonprecious alloys, acrylic resins reinforced by carbon fibers, and zirconia.[1,10–13] From a biologic point of view, titanium and zirconium-oxide are clearly the most interesting materials because they are well-tolerated by the human body.[14,15]

Adapting industrial manufacturing techniques to dentistry resulted in the development of prefabricated machined titanium pieces assembled by laser welding.[16] The first two generations of implant frameworks fabricated from laser-welded, premachined, commercially pure (CP) titanium components have been investigated in several clinical studies.[12,17–20] However, with the introduction of a computer numeric controlled (CNC)-milling technique[21] (Procera® implant Bridge, Nobel Biocare AB, Göteborg, Sweden), a stronger framework fabricated from one piece of solid, CP titanium could be produced with a fit that has been proven to be superior to conventionally cast frameworks using high noble and silver–palladium alloys.[22–26]

The misfit of prosthesis unavoidably affects the preloads in the screw joints and in the bone surrounding the implants.[27–29] On the other hand, animal studies have not been able to prove that misfit of 1000 or 500 μm, *per se*, negatively influences the osseointegration and bone remodeling at implants.[30,31] Instead, the preload in the screw joint seems to be of more importance than the magnitude of the misfit with regard to the bone response.[29] However, good fit of the prosthetic framework improves the clamping forces executed by the prosthetic screw and, thus, probably reduces the risk of loosening of screw joints.[32,33] Recent clinical trends to improve esthetics have initiated fabrications of frameworks on the implant level, which may introduce higher preloads in the screw joints and surrounding bone because of higher tightening forces.[34,35]

Today, the CNC-milling technique has been further refined, and manual contouring of the framework has been reduced to a minimum. Hence, the interest for CNC-milled frameworks has increased not only among dentist but also among dental technicians. With the recently introduced I-Bridge® (Biomain AB, Helsingborg, Sweden), an alternative CNC-milled framework that can be fabricated in both CP titanium and CoCr alloy is available. Today, no data exist on the precision of fit of these frameworks. The present study is designed to evaluate the fit of I-Bridge® CNC-milled titanium frameworks using two different implant systems.

MATERIALS AND METHODS

Fabrication of Master Model and Acrylic Frameworks

Two implant systems were chosen for this study, one with an external hexed-abutment system and one with an internal hexed-abutment system. Both have a flat-to-flat mating surface to the frameworks. The study protocol called for fabrication of two master models for regular platform implants, one for the Brånemark System® (Nobel Biocare AB) and one for NobelReplace™ implant system (Nobel Biocare AB), respectively. One cast of an edentulous mandible from a patient provided with five Brånemark System regular platform implants was chosen and duplicated to be used as masters, by using stone plaster (Pro-stone 21™, Brenntag Nordic AB, Malmö, Sweden), a vinylpolysiloxane gingival reproduction material (Gingifast Rigid™, Zhermack S.P.A., Badia Polesine, Italy), and implant replicas for the Brånemark System (31159) and NobelReplace System (29500) frameworks, respectively. Five additional models were produced by using Brånemark System replicas, used as "clinical controls."

The distance between the center points of the two terminal implant replicas (x-axis; arch width) was 33.76 mm, and the distance from a straight line through these center points to the center point of the central replica (y-axis; arch curvature) was 6.74 mm for the NobelReplace master (Figure 1). The arch width and arch curvature for the six Brånemark models were 33.71 ± 0.09 and 6.89 ± 0.05 mm, respectively.

Resin patterns were designed directly onto the implant replicas for both implant systems. This was performed by using self-curing acrylic resin (GC pattern resin, GC Corporation, Tokyo, Japan) combining the titanium cylinders, provided in the I-Pac® (Biomain AB). The resin patterns were designed with bilateral cantilevers of 14 to 18 mm (Figure 2).

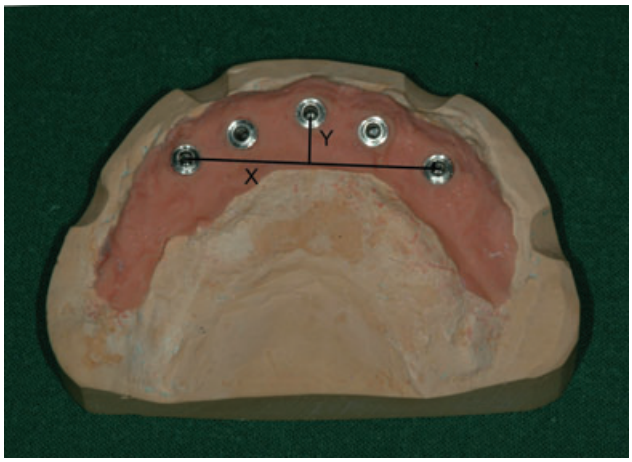

Figure 1 One out of six Brånemark System® master models on implant level. The lateral "arch width" (x; 33.62 mm) and sagittal "arch curvature" (y; 6.85 mm) distances between implant replica center points were measured.

Ten numbered individual resin test patterns were made for each master model and additional five individual resin patterns for the five "clinical control" models, respectively. The 20 resin test patterns were sent to the manufacturer together with the corresponding two master models. On the other hand, the five "clinical controls" were sent, one at a time, from different dentists participating in the study through different laboratories to be manufactured during a 2-month period. The "clinical controls" were not identified by the manufacturer of the frameworks, thereby simulating a routine clinical protocol.

Fabrication of Titanium Frameworks

According to the manufacturer, a high-resolution optical scanning was used to gather information on the contour of the 20 individual acrylic resin test patterns as well as the implant positions in the two master models. The study protocol called for the master models to be removed from the scanning equipment, repositioned, and rescanned together with each individual resin test pattern for both implant systems to simulate a new pair of resin pattern/cast for each occasion.

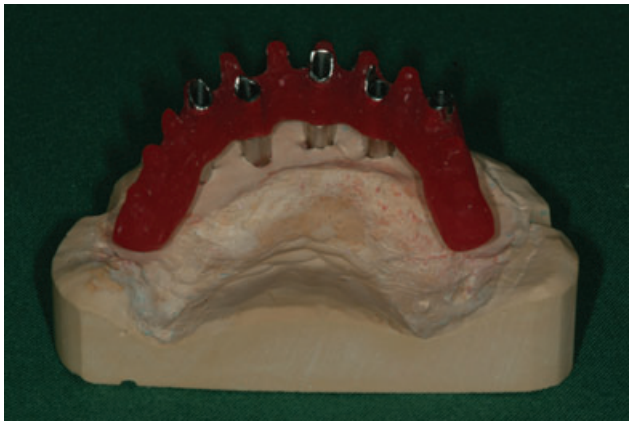

Figure 2 Acrylic resin pattern with Biomain titanium cylinders (I-Pac®) incorporated.

The data were used to produce 10 individual titanium test frameworks for each master model. The titanium frameworks were milled from one piece of grade 2 CP titanium in a CNC-milling machine with 5 degrees of freedom. The mating surface of the framework and the inside contour of each cylinder, corresponding to the external hex of the Brånemark System implants, was milled with a specific tool in order to optimize surface finish and precision of fit. No manual polishing of the frameworks was performed before the measuring procedures.

The five individual resin patterns ("clinical controls"), together with the five corresponding copies of the original master model (Brånemark System) were scanned, and frameworks were milled according to the same routine fabrication as described. These frameworks were not processed during one and the same procedure as the 20 test frameworks described. Instead, these frameworks were manufactured according to routine protocols for ordinary production for external laboratories.

Measuring of Master Model and Frameworks

Position of the center point of all the implant replicas and framework fit surfaces was measured with a coordinate measuring machine (CMM, Zeiss Prismo Vast, Carl Zeiss Industrielle Messtechnik GmbH, Oberkochen, Germany) by an independent laboratory (Mylab AB, Hisings Backa, Sweden). The measuring machine and procedures were similar as described by Örtorp and colleagues.[24] In brief, the two master models were measured and used as the reference for comparison of the 10 different frameworks for each implant system. For the "clinical controls," each unique model was measured together with its corresponding framework.

Prior to measuring, all master models and frameworks were placed in a mold seated on a stable, reinforcedconcrete table (Figure 3). The CMM had a scanning head equipped with a 0.5 mm diameter stylus that could be positioned in anywhere within the working space of the CMM. To facilitate the measuring

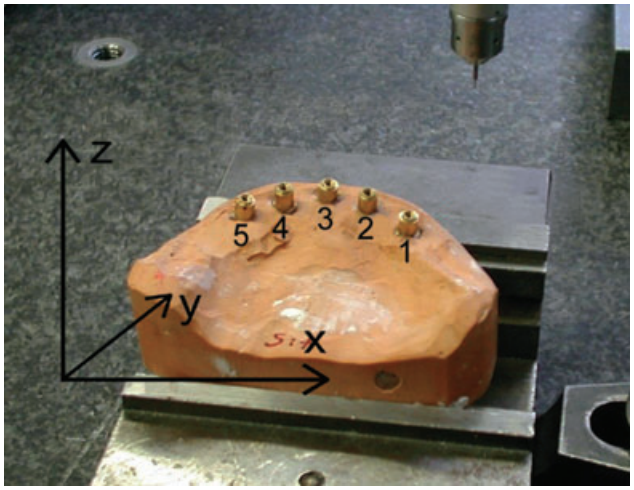

Figure 3 Coordinate system (x-, y-, and z-axes) and setup of CMM measuring machine for the measurements. Master model with implant replicas numbered from 1 (*right*) to 5 (*left*) mounted in the mold.

and to ensure contact between the stylus and surfaces to be measured, a light force (0.1 N) was applied to the stylus. The data for each cylinder were condensed to a position of the center point of the cylinder in three dimensions by using the x-, y-, and z-axes. The nominal linear accuracy of the machine was described by the manufacturer to be within 1 micron (μm) in all axes, confirmed by Örtorp and colleagues.[24]

Analysis of Fit

After the measurements of all frameworks and master models, data of the center points of the implants were analyzed for fit between each framework and corresponding master model. The method used to analyze distortion between frameworks and master models was the "least square method," described by Bühler.[36] This was performed by superimposing the frameworks to the theoretically best possible fit on the master models in the computer. All data were presented as distortion of the center point of individual framework cylinders in relation to the center points of the master cast replicas. The three-dimensional (x-, y-, and z-axes) directions of displacement of the center points were calculated in μm in real and absolute values. Furthermore, the three-dimensional distance between the center points of the frameworks and the master model replicas was calculated for each individual cylinder by using the formula ($3D = \sqrt{x^2 + y^2 + z^2}$).

An alternative technique for measurement of fit, here called the "zero method," was used for comparison. For orientation purposes, a specially designed software program placed the center point of framework cylinder 1 at the origin of the corresponding master replica cylinder (see Figure 3) for all three coordinates (x, y, z), that of cylinder 5 was placed at the origin of the corresponding master replica cylinder in the y and z planes, and that of cylinder 3 was placed in the z-axis. With this orientation of the individual center points, the distance between the replicas 1 and 5 (arch width) and between the center point for replica 3 and a straight line through replicas 1 and 5 (arch curvature) could be calculated for each framework (see Figure 1).

Statistical Analysis

Conventional descriptive statistics were used to present the distortion of frameworks.[37] All measurements were also calculated in absolute figures to present the degree of distortion in all axes without consideration of the direction of distortion. Wilcoxon signed-ranks test was used for evaluation of differences in arch width and curve between masters and frameworks and Mann–Whitney *U*-tests were used for comparisons of fit between the groups of frameworks. The Bonferroni–Holms method was used to account for multiple testing. A paired *t*-test was used for comparison of registered mean distortion between zero method and least square method. The level of statistical significance was set at $p < .05$.

RESULTS

Distortions of frameworks with regard to arch width and arch curvature (see Figure 1) are given for the three groups in Table 1. It can be noticed that frameworks for the Brånemark System implants presented a small but significant ($p < .01$) reduction of lateral dimensions (see Figure 1; x-axis) as compared with the master cast. On the other hand, both frameworks for NobelReplace implants, as well as control frameworks, presented significantly ($p < .05$) wider dimensions (x-axis) as compared with master models (see Figure 1). Distortion in arch width between masters and frameworks differed significantly between Brånemark System and NobelReplace ($p < .05$) and between Brånemark System and Brånemark System "clinical controls" ($p < .05$), respectively. With regard to the sagittal dimension (see Figure 1; y-axis), frameworks for Brånemark System implants showed a small but significant decrease compared to master casts ($p < .01$), and Brånemark System

TABLE 1 Mean Difference (SD) in Arch Width (x-axis) and Arch Curvature (y-axis) for Test and Control Frameworks Compared with Master Models in Microns Using Least Square Method. Number or Frameworks/Master Models (n/n) are Given Within Brackets. Positive Values Correspond to Wider (x-axis) and More Curved (y-axis) Frameworks, Compared with the Master Models

	Difference in arch width				Difference in arch curvature			
Group of frameworks	Mean	(SD)	Min	Max	Mean	(SD)	Min	Max
NobelReplace								
NobelReplace ($n = 10/1$)	23	(24)	−16	65	−3	(20)	−26	31
Brånemark System								
Brånemark System ($n = 10/1$)	−8	(6)	−19	−1	−22	(4)	−29	−16
Clinical control ($n = 5/1$)	47	(15)	35	71	31	(18)	5	55

"clinical controls" presented a significant increase ($p < .05$) in the arch curvature, the differences observed between all three groups in sagittal distortion being significant ($p < .05$).

The maximal ranges of distortion of individual center points are presented in Table 2 for the three different groups. It can be observed that vertical distortion (z-axis) is smaller than the horizontal dimensions (x- and y-axes) for all three groups. Furthermore, it can be observed that the Brånemark System frameworks showed the smallest range of distortion and that "clinical controls" showed the greatest range (see Table 2). "Clinical controls" differed significantly in range of distortion in x- and y-axes and in three dimensions compared with Brånemark System and NobelReplace frameworks ($p < .05$). The range of distortion for NobelReplace frameworks was significantly higher in the x-axis compared with Brånemark System frameworks ($p < .05$).

TABLE 2 Maximal Range of Individual Center Point Distortion of Frameworks (Positions 1 to 5) for the Different Groups of Frameworks in Microns, Using Least Square Method

	Least square method		
Group of frameworks	Min	Max	Range
NobelReplace frameworks			
x-axis	−37	34	71
y-axis	−27	25	52
z-axis	−5	5	10
Three dimensions	3	40	37
Brånemark System® frameworks			
x-axis	−13	12	25
y-axis	−15	19	34
z-axis	−5	6	11
Three dimensions	10	21	11
Clinical controls (Brånemark System)			
x-axis	−48	58	106
y-axis	−54	43	97
z-axis	−8	12	20
Three dimensions	12	71	59

Results from measuring distortion of frameworks using absolute figures (disregarding the direction of distortion) are presented in Table 3 and Figure 4, indicating low levels of distortion in all dimensions. Mean distortions are comparable for NobelReplace and Brånemark System frameworks and higher for "clinical controls" (see Table 3 and Figure 4). "Clinical control" frameworks presented significantly ($p < .05$) more distortion in x- and y-axes and in three dimensions as compared with NobelReplace and Brånemark System test frameworks, respectively ($p < .05$). NobelReplace frameworks showed statistically significantly less distortion in the y-axis compared with Brånemark System frameworks ($p < .05$).

When the direction of distortion for individual center points was analyzed in relation to position of the implants, no clear pattern could be observed except a significant increase ($p < .05$) in arch width for NobelReplace and "clinical controls," respectively (Table 4; x-axis: #1 to #5). Again, it could be noticed that control frameworks presented, in general terms, higher values for distortion, especially observed in x- and y-axes, and presented in overall three-dimensional measurements.

Data were also calculated by using the "zero method" but only presented in overall absolute figures (see Figure 4). It can be observed that the "zero method"

TABLE 3 Mean Distortion (SD) (in Microns) of the Center Point of the Frameworks Presented with the Master Model as Reference, in Absolute Figures Using Least Square Method

	Distortion in absolute figures							
	x-axis		y-axis		z-axis		Three dimensions	
Group of frameworks	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
NobelReplace ($n = 10$)	11	(5)	10	(4)	1	(1)	17	(6)
Brånemark System ($n = 10$)	7	(1)	12	(2)	2	(0)	15	(1)
Clinical control ($n = 5$)	23	(5)	26	(4)	4	(2)	37	(6)

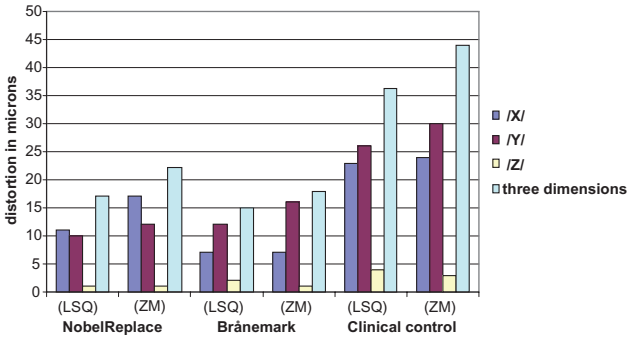

Figure 4 Mean distortion of the center point of the frameworks presented with the master model as reference, in absolute figures using least square method (LSQ) and zero method (ZM) measurements for the different framework groups.

resulted generally in greater displacements in x- and y-axes and in three dimensions and less distortion in z-axis as compared with the "least square" fit measuring method. Overall statistical calculations revealed significant differences between the two measuring methods in y- and z-axes and in three dimensions ($p < .05$) and showed a tendency for significant in x-axis ($p = .051$).

DISCUSSION

Results from this study indicate that the present new CNC frameworks displayed levels of precision of fit that

TABLE 4 Mean Center Point Distortion (SD) in Microns for the CNC Frameworks with Regard to Group and Implant Position in Real Values

	Center point distortion in μm							
	x-axis		y-axis		z-axis		Three dimensions	
Group of frameworks and position	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
NobelReplace ($n = 10$)								
Position # 1 (right side)	11	(15)	2	(12)	0	(1)	19	(11)
Position # 2	0	(13)	−2	(12)	0	(2)	15	(8)
Position # 3	−2	(8)	−1	(10)	1	(1)	11	(6)
Position # 4	1	(13)	−1	(12)	−3	(2)	16	(4)
Position # 5 (left side)	−11	(17)	2	(15)	1	(1)	22	(12)
Brånemark System ($n = 10$)								
Position # 1 (right side)	0	(3)	14	(2)	1	(0)	15	(2)
Position # 2	−9	(7)	−11	(3)	−2	(1)	16	(2)
Position # 3	10	(1)	−6	(2)	−2	(1)	12	(1)
Position # 4	−7	(1)	−12	(1)	3	(1)	15	(1)
Position # 5 (left side)	8	(3)	16	(2)	−1	(1)	18	(1)
Clinical controls ($n = 5$)								
Position # 1 (right side)	4	(12)	−22	(9)	−2	(3)	25	(10)
Position # 2	8	(4)	22	(6)	1	(7)	25	(5)
Position # 3	−12	(9)	−1	(17)	3	(5)	20	(7)
Position # 4	43	(10)	31	(9)	1	(3)	54	(10)
Position # 5 (left side)	−43	(4)	−42	(9)	−4	(2)	61	(8)

CNC = computer numeric controlled.

compare favorably with cast and CNC-milled frameworks shown in other studies.[1,22,25,26,29] Better precision of fit has been reported by Örtorp and colleagues,[24] however, using only one pair of master and resin pattern for repeated machining from one and the same occasion of measurements. Thus, even though all frameworks in the present study displayed different degrees of misfit, and none presented a completely "passive fit," it can be noticed that this new framework procedure could be considered as precise enough for clinical use, as also in accordance with other studies.[1,22,24–26,29]

There are different techniques available to assess precision of fit, where "the least square method" and the "zero method" are some of the most used techniques of measurements of precision of frameworks in implant dentistry.[38] Both techniques are based on measurements in the computer, using a "virtual" approach, thereby disregarding the limitations of the physical implant and framework components. With a generally slightly lower level of distortions for the "least square" technique, still it can be observed that both techniques result in similar levels of distortion, where both techniques present low levels of vertical distortion (z-axis). However, in the clinical reality, the physical components would have prevented such low levels of vertical distortion. Accordingly, vertical distortion is underestimated by using these analyzing techniques, and interpretations of results regarding "vertical gaps in the clinic" should be approached with much caution.

The statistical analysis showed a significant difference between frameworks milled for study purpose and those made for "clinical controls." This difference highlights the planning stage of the study and if the study should focus on the production procedure itself or rather try to mimic the "standard clinical protocol." Earlier, Örtorp and colleagues[24] reported measurements from a strict manufacturing protocol with a higher degree of precision as compared with the more clinical-oriented study by Al-Fadda and colleagues,[26] presenting measurements of CNC frameworks with more distortion from one and the same framework manufacturer (Nobel Biocare AB). Al-Fadda and colleagues[26] used models from different clinical situations, while Örtorp and colleagues[24] used one and the same model for all CNC frameworks. In the present study, several master models (in total, 7) with a similar distribution of implants have been used in a more strict laboratory setup as well as simulating a clinical protocol. Still, this approach has allowed for displaying significant differences between "laboratory" and "clinical" protocols, presenting levels of distortions that could be assumed to be somewhere between the results of Örtorp and colleagues[24] and Al-Fadda and colleagues[26], respectively.

There were significant differences in arch width and curvature between frameworks fabricated for the different implant systems and the "clinical control" frameworks. Frameworks fabricated for NobelReplace and "clinical control" frameworks had a wider arch (mean 23 μm respective 47 μm) and Brånemark System frameworks a smaller arch (mean −8 μm) compared with the master models. The curvature of the frameworks also differed between the groups, with "clinical control" frameworks presenting an increased curvature (mean 31 μm) and Brånemark System a decreased curvature (mean −22 μm). Al-Fadda and colleagues reported an increase in arch width and curvature for CNC-milled frameworks, the same pattern as was seen in the present study for "clinical controls."[26] The reason for this is not clarified.

In the present study, the range of distortion in x-axis was significantly larger for NobelReplace frameworks as compared with Brånemark System frameworks, with a range of 71 and 25 μm, respectively. Whether this is a result of different implant-abutment connecting systems, differences in interpretation of the scanning, fabrication problems, or pure coincidence are open for question. The range of distortion for "clinical control" frameworks was even larger, with 106 μm in x-axis and 97 μm in y-axis, indicating that fit of frameworks produced in a routine clinical environment exhibits a greater variation in fit of the prosthesis. Still, the fit is within the tolerances designed into the I-Bridge because all frameworks could easily be seated on the corresponding master model without "clinically" detectable misfit.

Misfit in vertical aspect (z-axis) produces gaps and should be reduced to a minimum. However, as discussed, data on distortion in this dimension should be approached with caution when using the present methods of measurements. Still, on a theoretical level, the distortion in z-axis should preferably be kept to a minimum if possible to avoid unnecessary preloads in the screw joints and the bone surrounding the implants. The level of proposed acceptable vertical (z-axis) misfit differs from 30 to 150 μm in the literature, but no consensus has been reached.[1,39] According to Riedy and colleagues,[22] a gap in the range of 50 to 100 μm is the

smallest that can be detected by the human eye without magnification. Hobkirk and Cheshire[28,29] showed in an in vivo study that the vertical gap between the framework and the implants was reduced with 7 μm by increasing the screwdriver torque from 10 Ncm to maximum hand force. This indicates that reported vertical distortions may be reduced when prosthetic screws are tightened,[29,40] and, subsequently, a preload is introduced in the prosthesis implant connection as well as in the surrounding bone.

In the present study, frameworks were fabricated on implant level, and the prosthetic screws used for these occasions are designed for tightening to 35 Ncm, which is much higher than for prosthetic screws on the abutment level. With the higher tightening torque used on implant level, this inevitably increases not only the preload in the screw joint but also the stress at the implant-bone interface when misfit is present. Because no long-term studies are available on prostheses connected to the implants, the consequences of this potential risk of higher stress levels due to misfit on the implant-bone interface are unknown. However, short-term static load of implants in animal models has not negatively influenced the osseointegration and bone remodeling at implants.[31,41,42] Duyck and colleagues tested in a rabbit model immediate loading and conventional loading of implants connected to prostheses with a vertical misfit of 500 μm. The immediately loaded implants were displaced toward the prosthesis, thus reducing the gap during healing, and no difference in biologic response was registered.[31] Controversy on whether a framework with "poor" fit, including microgaps, is responsible for any adverse biologic effects still exists. However, Kallus and Bessing have indicated a correlation between technical complications and misfit.[32] Jemt and colleagues observed that preload stress in a rabbit model seemed to promote bone remodeling at the tip of the implant threads.[30] In patients, the stress values in the bone-implant interface created by a combination of static loading caused by prosthesis misfit and occlusal loading of implants cannot easily be calculated, and tolerated levels of stress have not been determined. Thus, the level of framework misfit should probably be kept as low as possible even if a minor misfit *per se* may promote osseointegration.

From studies on fit of prostheses, the conclusion can be made that no prostheses have a "passive fit."[1,21,22,24–26,29] Still, short- and long-term experiences have been shown to be very good for implant treatment in the edentulous jaw.[12,18,20] Because the present frameworks present a level of distortion well in comparisons with other studies, it can be assumed that the present frameworks have an acceptable fit for clinical use. However, it is reasonable to assume that distortion of frameworks connected to the abutment level induces lower levels of stress when the prosthetic screws are tightened as compared with when prostheses are placed directly to the implants. Studies presenting short-term results on prostheses fabricated on implant level have not presented increased incidences of prosthetic complications or bone loss compared with those prostheses fabricated on abutment level, but prosthetic screw fractures have been reported.[7,43] Still, this does not imply that detrimental effects on the prosthesis implant connection and bone interface in the long run will not emerge. Accordingly, long-term, follow-up studies comparing prostheses fabricated on implant and abutment levels are needed, and higher demands on precision could possibly be claimed for prostheses placed close to the marginal bone in connection to the implant head.

A good clinical fit depends on all steps of framework fabrication such as precision of fit between implants, copings, replicas, impression technique, and fabrication of master cast. Thus, fabrication of frameworks with a built-in tolerance for minor displacement in x- and y-axes is probably a prerequisite for achieving acceptable clinical fit. So far, no clinical studies presenting clinical results with the I-Bridge have been conducted. However, the present data indicate that it is possible to produce CNC-milled frameworks according to the I-Bridge technique with a high degree of precision.

CONCLUSION

Within the limitations of this study, the following conclusions can be made:

- Significant distortions of frameworks were observed in relation to the master models. Mean distortion for all frameworks was largest in the horizontal plane (x- and y-axes) with only small distortions in the vertical direction (z-axis).
- Significant differences were observed in distortion between the different groups of frameworks. Frameworks fabricated in a laboratory setup tend to show less distortion as compared with similar frameworks fabricated on a more routine basis.

- Distortions of the frameworks were within the limits for earlier published data on implant frameworks with no framework presenting a "passive fit" to the models.
- Small but significant differences were observed between different methods of analyzing distortion of frameworks.

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