A Comparison of the Accuracy of Fit of 2 Methods for Fabricating Implant-Prosthodontic Frameworks

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Purpose: To compare the in vitro 3-dimensional (3D) accuracy of fit of laser-scanned Computer Numeric Controlled (CNC)–milled implant titanium frameworks to that of conventional cast frameworks. ***Materials and Methods:*** Nine cast frameworks were fabricated on the mandibular master casts of 9 patients with 5 implants each following the well-established conventional fabrication technique. The frameworks were then laser scanned, and 9 CNC-milled titanium frameworks matching the outline of the conventional frameworks were fabricated. The accuracy of fit of both framework types was measured using a contact-type coordinate measuring machine and a computer program developed specifically for this purpose. Statistical analysis was done by a series of paired *t* tests. ***Results:*** The laser-scanned CNC-milled frameworks showed significantly less distortion along the x-axis (transversal, d_x) compared with the conventional frameworks (means: 33.7μm and 49.2 μm, respectively) (P = .011). The titanium frameworks also demonstrated significantly less distortion on the horizontal plane compared with the conventional frameworks (means: 56 μm and 85 μm, respectively) (P = .012). The d_y (sagittal) and d_z (vertical) axes and total 3D distortion ($\sqrt{d_x^2 + d_y^2 + d_z^2}$) showed less distortion overall in the laser-scanned CNC-milled frameworks, but this was not statistically significant (mean: 22.3 vs 35.6 μm, 13.3 vs 59.2 μm, 51 vs 114.1 μm, respectively, for y, z, and 3D distortion). ***Conclusion:*** Within the limitations of this study, fabrication of an implant-prosthodontic framework using the CNC milling technique yields a more accurate fit than the currently used cast technique. In vivo studies are needed to investigate the clinical significance of this recorded difference. *Int J Prosthodont 2007;20:125–131.*

In 1982, the Toronto Conference on Tissue-Integrated Prostheses introduced the concept of inducing controlled interfacial osteogenesis between a dental implant and the host bone. Since then, treatment of partial and complete edentulism has become a predictable therapeutic procedure, and dental implants continue to play a significant role in oral rehabilitation.[1–5] Consequently, selected biomechanical aspects and biologic consequences of such treatment have been investigated in an effort to expand and better understand the scope of this treatment modality. One aspect believed to affect the long-term prognosis of the bone-implant interface is the accuracy of prosthesis framework fit.

Passive fit is assumed to be a significant prerequisite for maintaining the integrity of the bone-implant interface.[6–12] Failure to produce passive fit may cause mechanical failure of the prostheses or implants and biologic complications in the surrounding tissues.[10,11,13–15] However, animal studies[16,17] have suggested that it is possible for no biologic or mechanical complications to arise with "nonpassive" implant frameworks. Michaels et al[17] evaluated misfitting implant frameworks using a white rabbit tibia model and found no significant clinical, radiographic, or histomorphometric evidence of implant integration failure, although bone remodeling around the implant was noted.

Human studies reported similar findings. Jemt and Book[18] correlated in vivo measurements of prosthesis misfit with changes in marginal bone levels around im-

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Fig 1 Conventional cast framework *(bottom)* coated with a special paint and laser scanned to fabricate a CNC-titanium framework with the exact same contour and outline *(top)*.

plants placed in the edentulous maxilla. Two groups, each comprising 7 patients, were followed up either prospectively for 1 year or retrospectively for 4 years. The measurements were performed by means of a 3-dimensional (3D) photogrammetric technique, and marginal bone levels were measured from standard intraoral radiographs. Results showed that none of the prostheses presented a completely passive fit to the implants. Moreover, no statistical correlation ($P > .05$) between changes in marginal bone levels and different parameters of prosthesis misfit were observed in the 2 groups. The authors concluded that a certain biologic tolerance for misfit may be present. This suggests that both implant components and bone appear to tolerate a degree of interfacial misfit without adverse problems. However, in the absence of scientifically well-established quantitative tolerated fit guidelines, it seems prudent to optimize fit by using a combination of the best available clinical and laboratory materials and methods when fabricating implant frameworks.

One of the most recent approaches to the problem of misfit is the introduction of the laser-scanned Compuer Numeric Controlled (CNC)–milled titanium framework (Nobel Biocare).[19] This technique provides lower prices for the titanium metal and the potential for a lower risk of oral corrosion. Further, the fabrication process is less dependent on manual laboratory procedures compared to conventional casting protocols.[19,20] By using an industrial manufacturing protocol for the frameworks, many factors related to manual handling of the conventional cast frameworks are controlled and avoided. Controlling these factors makes it possible to provide patients, especially those with severely resorbed edentulous arches, with an implant-supported fixed prosthesis that is lighter in weight, fits better, and costs less than a conventional cast framework with large amounts of gold or comparable alloy substitutes. Moreover, early clinical studies have concluded that this type of framework is a viable alternative to conventional cast frameworks.[20,21]

The accuracy of fit of frameworks fabricated using this technique compared to the conventional technique has been tested in only 1 study.[20] Further, the researchers compared only the intraindividual precision of the 2 techniques performed on the same cast, not the interindividual precision on different casts. Moreover, critical factors that have been shown to affect the framework fit, such as amount of metal alloy and curvature of the framework, were not accounted for. Therefore, the present study was conducted to compare the accuracy of fit of conventional cast frameworks and of laser-scanned CNC-milled frameworks when these parameters are controlled.

Materials and Methods

Nine master casts were randomly selected from a list of completely edentulous patients treated with mandibular implant-supported fixed prostheses at the Implant Prosthodontic Unit of the Faculty of Dentistry, University of Toronto, Canada, between 2000 and 2002.

The inclusion criteria were as follows: *(1)* mandibular master cast of a completely edentulous patient with 5 Brånemark implants (Nobel Biocare) used to fabricate a mandibular implant-supported fixed prosthesis was available; *(2)* multiunit abutments were used (Nobel Biocare); *(3)* at least 3 mm of clearance existed between the abutment sides (lateral walls) and adjacent dental stone to facilitate the measurements at a later stage; *(4)* a silicone index (Ruthinium, Dental Manufacturing) of the original teeth setup was available as a guide for the technician when waxing the conventional cast frameworks.

On each of the 9 master casts, 2 sets of frameworks were fabricated. The first was the conventional cast framework (50% silver, 30% palladium, 3% gold, 15.9% copper, 1% zinc, < 1% iridium) (Maestro, JELENKO). The second was the laser-scanned CNC-milled titanium framework (grade 2 titanium, Nobel Biocare) (Fig 1).

Fabricating the Conventional Cast Frameworks

Cast frameworks were fabricated following the well-established laboratory protocol that has been previously described.[22,23] All frameworks were fabricated by 1 technician using the same laboratory materials. To control for possible provider bias, the technician was blinded, meaning he was not aware that these frameworks were to be used as part of the present study.

Multiunit gold cylinders (DCA 072-0 Brånemark, Nobel Biocare) were hand screwed at 10 Ncm using gold alloy screws (DCA 075, Nobel Biocare) onto the abutment analogs in the master cast. The frameworks were waxed up (Thowax, YETI Dental) on the gold cylinders using the silicone index as a guide for the dimensions of the framework.

The assemblies were allowed to set for at least 12 hours at room temperature (25°C) to reduce stresses and their consequent distortions. The wax pattern was then tested for passivity using the 1-screw test.[24]

Five 8-gauge round wax sprues (Kewax, Keystone) were attached to each of the wax patterns. The sprued patterns were left screwed onto the master cast for at least 30 minutes before investing. Each sprued pattern was assessed for possible warpage prior to investing.

Patterns were then removed from the master cast and invested immediately (Micro-Fine 1700 Casting Investment, Talladium) in a 2.5-inch diameter ringless mold (Proven Ringless Casting System, Talladium).

Prior to casting the alloys, the invested waxup went through a gradual (2-hour) burnout process in a calibrated oven (Accu-therm II 150, Jelenko) at 704°C. Each ring was held at its corresponding temperature for an additional 1 hour. The frameworks were cast using a centrifuge (TSI, Degussa). All frameworks were cast in silver-palladium alloy.

Following casting, each ring was allowed to bench cool before divesting and polishing as per the manufacturer's recommended protocol.

Fabricating the CNC-Milled Titanium Frameworks

The 9 conventional cast frameworks and corresponding master casts were sent to Nobel Biocare laboratories for fabrication of laser-scanned CNC-milled titanium frameworks. To control for possible provider bias, the technician was blinded, meaning he was not informed that these frameworks were to be used as part of the present study.

To maintain standardization, the conventional frameworks were coated with a special paint to facilitate scanning and then placed in a laser scanner to feed information on the contour and outline of the framework into a computer.

The positions of the implant replicas in the master cast were measured using a contact-type coordinate measuring machine (CMM). Next, a block of grade 2 titanium was milled in a CNC milling machine with 5 degrees of freedom to produce an identical copy of the contour and outline of the conventional cast frameworks in 1 piece of titanium. The titanium frameworks were then polished by the dental technician.

Measuring the Accuracy of Fit

To measure the amount of distortion of the superstructures on their respective supporting abutments, a "moving bridge"–type CMM (ZeissPrismo) was used.[25] The probe size was 0.3 mm. The nominal linear accuracy of the machine was 4 μm in the z-axis, the nominal repeatability against known datum was 3 μm, and the nominal resolution was 0.5 μm. Reference points were established on the master cast to which the frameworks were compared.

Each framework and master cast was scanned once. Prior to each measurement session, the machine was calibrated against a datum sphere of known diameter (30.0 mm) according to the manufacturer's instructions.

The coordinate frame for the master cast measurements was constructed using cylinders no. 1, 3, and 5 (C1, C3, and C5). For each cylinder, 2 features were measured: the cylindric surface and the top surface. The intersection of the top surface and cylinder results in a circle, which forms the cylinder's top base. The center points for the top bases of C1, C3, and C5 were used to construct the coordinate frame as follows:

1. The surface passing through C1, C3, and C5 was used as the xy plane.
2. C1 was used as the origin for the coordinate frame (0.0, 0.0, 0.0).
3. C5 was used to define the x-axis direction, ie, the line passing from C1 to C5 was the x-axis.
4. The y- and z-axes were constructed using the right-hand rule, such that the z-axis was pointing upward and orthonormal to both the x- and y- axes. The same concept was used to construct the coordinate frame for the 2 types of frameworks. However, the z-axis was pointing in a direction opposite of the z-axis of the coordinate frame for the master casts. This was compensated for by reversing the angles' value sign of the framework measurements before analyzing the data.

The 3D distortion of the 2 types of frameworks relative to the implant analogs in the master casts was measured and analyzed using special computer software known as Implant Best-Fit.[25]

To test for differences in distortion (d_x, d_y, and d_z components and total 3D distortion) in the CNC-milled frameworks versus the conventional cast frameworks, a series of paired *t* tests were performed. Statistical significance was set at $P < .05$ ($\alpha = .05$). The measurements were analyzed in absolute figures, disregarding the direction of distortion.

Table 1 Mean Distortion of the CNC-Milled Titanium Frameworks and Conventional Cast Frameworks in the x-, y-, and z-Axes and Total (3D) Dimension (µm)

	Mean distortion				
Dimension	CNC (± SE)	Cast (± SE)	*t*	*df*	*P*
x-axis	33.7 ± 12.3	49.2 ± 12.4	3.283	8	.011
y-axis	22.3 ± 7.3	35.6 ± 7.8	1.928	8	.090
z-axis	13.3 ± 7.4	59.2 ± 30	1.532	8	.164
3D	51 ± 18	114.1 ± 31.3	1.941	8	.088

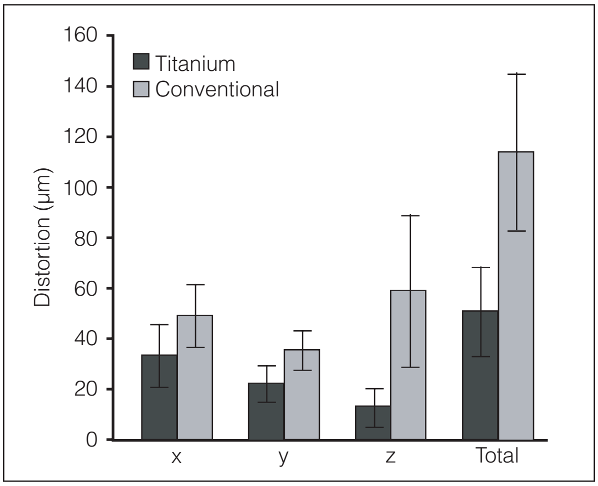

Fig 2 The mean distortion in absolute figures of the CNC-milled titanium frameworks and conventional cast frameworks (µm).

Results

The CNC-milled titanium frameworks showed significantly less distortion along the x-axis than the conventional cast frameworks ($P = .011$) (Table 1, Fig 2).

The data showed less distortion overall for the CNC-milled titanium framework compared to the conventional cast framework in the y- and z-axes, although this difference was not statistically significant (Table 1). This also applies to the 3D distortion, which was measured using the following formula:

$$\text{3D distortion} = \sqrt{d_x^2 + d_y^2 + d_z^2}$$

where "d" stands for distortion in each axis.

Moreover, in both types of frameworks, the z-axis showed the least amount of distortion compared to the x- and y-axes (Table 2). The range of the z-axis standard error in the conventional cast frameworks was higher than that of the x- and y-axes, indicating more variation of the measurements in this axis for that framework fabrication method. The opposite was true for the CNC-milled titanium frameworks (Table 2).

Discussion

Brånemark suggested that the precision of the prosthesis fit should be within a range of at least 10 µm.[26] However, recent studies showed that full-arch frameworks do not attain this level of accuracy, nor are clinicians capable of detecting this level of misfit during routine clinical examination.[27]

Since most of the conventional cast framework distortion occurs during the laboratory fabrication procedures,[28–30] a completely new technique for fabricating implant-prosthodontic frameworks was recently described. This technique attempts to improve the accuracy of fit by eliminating some of the laboratory steps known to cause distortion and subsequent misfit. However, it should be noted that it does not eliminate the impression-stage distortion.

In the present study, the sample size calculation was based on the study by Ortorp et al.[20] Consequently, a sample size of 10 for each type of framework was chosen to yield statistically significant results. However, 1 of the 10 master casts selected for this study was excluded. This resulted from the inability of the CMM to accurately record the objective measurements as a result of the orientation and proximity of 2 of the 5 implants.

Although all 9 frameworks were sent to Nobel Biocare at the same time, the technician who fabricated the CNC-milled frameworks was blinded to the objective of the study.

The same CMM was used to measure all casts and frameworks, and the measurements were performed by the same technician. This way, if any measurement errors from the machine occurred, it would be considered a systematic error that equally affects all samples.

Although the present study suggests a general trend in the difference between the 2 types of frameworks, the findings were not always statistically significant because of the relatively small sample size. One reason for this variation between the present study and that of Ortorp et al[20] is the difference in the fabrication technique of the CNC-milled titanium frameworks. In the other study, all 20 CNC-milled titanium frameworks were fabricated using the same resin pattern framework and the same master cast. This means that 1 set of data from the scanning procedure was fed to the computer and used to fabricate all 20 frameworks. Using the same data could produce frameworks that are more or less duplicates of each other and do not include any operator errors. This is not the actual clinical scenario when fabricating this type of framework. On the other hand, all 5 conventional cast frameworks were fabricated following the conventional protocol, meaning they were not duplicates of each other, as was the case with the CNC-milled frameworks. This allows for possible continuous errors during their fabrication and represents a more realistic scenario.

The slight deviation from the normal protocol for fabricating the CNC-milled titanium frameworks was conducted to control for some of the factors that may contribute to distortion: framework contour, span length, and cantilever extension.[18,27–29]

Overall, the CNC-milled titanium frameworks showed a lower level of misfit in all measured axes compared to the conventional cast frameworks. However, the conventional frameworks presented distortion comparable to that seen in other studies.[18,20,28,31,32] The technician's experience and laboratory skills, the blind design of the study, and the difference in the number of frameworks used are reasonable explanations for the variation in the reported accuracy of fit between this study and previous studies. Furthermore, the difference in the evaluation methods used in each of these studies may also have contributed to the different levels of recorded accuracy.

It is important to note that the effect of misfit is determined by the amount of preload induced through screw tightening (preload). However, it was not the objective of the present study to measure the biologic effect of stress induced through screw tightening.

The orientation of dental implants and the curvature of the arch may affect the accuracy of fit of frameworks regardless of the fabrication technique. This can be seen in frameworks no. 4, 7, and 9, which showed more distortion in both types of frameworks. This can be attributed to the severe angulation of the dental implants in these 3 casts.

Distortion Patterns in the Different Axes

Although the difference in distortion in the y-axis was not statistically significant, the data show an overall trend of less distortion in the CNC-milled titanium frameworks compared to the conventional cast frameworks (Table 1). Similar findings were reported by Ortorp et al.[20] However, in that study, the difference in distortion in the y-axis between the 2 types of frameworks was statistically significant. This may be a result of the larger difference in distortion between the 2 types of frameworks in the latter study compared to the present study. Another possible explanation is the higher number of CNC-milled titanium frameworks used by Ortorp et al.

Table 2 Distortion Measurements of the CNC-Milled Titanium Frameworks and the Conventional Cast Frameworks (µm)

	CNC	Cast
x-axis		
1	7.8	21.4
2	20.8	34.6
3	3	27.1
4	71.5	68.1
5	3	32.5
6	22.5	22.4
7	99.2	134.8
8	4.1	29.3
9	71.6	72.3
Mean	33.7 ± 12.3	49.2 ± 12.41
y-axis		
1	7.1	11.1
2	14.6	57.1
3	10	57.7
4	65.8	78
5	2.3	18
6	17	19
7	33.7	21.4
8	3.1	20.1
9	47	38.2
Mean	22.3 ± 7.3	35.6 ± 7.8
z-axis		
1	3.4	4.4
2	5.3	101.7
3	1.5	272.1
4	28.4	31.3
5	1.8	4.3
6	5	7
7	5	3
8	1	6.7
9	68.3	102.8
Mean (±SE)	13.3 ± 7.4	59.2 ± 30

When measuring the amount of distortion in the horizontal plane (x + y), the difference between the 2 types of frameworks was statistically significant, with less distortion in the CNC-milled titanium group ($P = .012$) (Table 3, Fig 3).

Vertical distortion has been shown to create higher stress levels than horizontal distortion when implants are placed parallel to each other.[14,31] This suggests that clinicians should pay special attention to this type of distortion and work to correct it. In the present study, the z-axis in both types of frameworks was the least affected by the fabrication technique and showed the least amount of distortion compared to the x- and y-axes (Tables 1 and 2). Moreover, the difference in distortion between the 2 types of frameworks in the z-axis was statistically insignificant and lower overall compared to other studies.[20] This may be a result of the smaller dimension of the frameworks in this axis compared to the x- and y- axes. On the other hand, the largest dimension of the frameworks is found in the x-axis, which in turn showed the highest amount of distortion and a statistically significant difference between the 2 framework types.

Table 3 Mean Distortion of the CNC-Milled Titanium Frameworks and Conventional Cast Frameworks in the Horizontal Plane (x + y) (μm)

	Mean distortion				
Dimension	Titanium (± SE)	Gold (± SE)	*t*	*df*	*P*
x-+ y-axes	56 ± 56.6	85 ± 46	3.231	8	.012

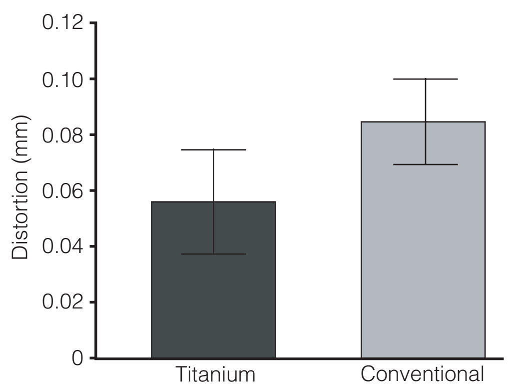

Fig 3 Distortion of CNC-milled titanium vs conventional cast frameworks in the horizontal plane (x + y) (mm).

Table 4 Differences in Arch Width Between the 2 Types of Frameworks and the Master Cast (μm)

Framework no.	CNC	Cast
1	20	–50
2	70	–100
3	0	–110
4	150	90
5	10	–100
6	–50	–20
7	–340	–520
8	10	–70
9	13	–40

*Minus sign indicates that the framework is smaller than the corresponding master cast.

Table 5 Differences in Arch Length Between the 2 Types of Frameworks and the Master Cast (μm)

Framework no.	CNC	Cast
1	20	–10
2	–1,210	–1,320
3	10	10
4	260	260
5	0	–20
6	30	20
7	100	30
8	0	–40
9	60	50

*Minus sign indicates that the framework is smaller than the corresponding master cast.

Translation Displacement Analysis

When analyzing the translational displacement of frameworks in the x-axis, the values for the conventional cast frameworks were negative, indicating an overall reduction in arch width (arch width = C5x master cast – C5x framework) (Table 4). These findings are in accordance with those reported elsewhere.[30] This distortion would have contributions from the wax/resin pattern stage[33] and the investing and casting processes.[30] The heat cycle used and the effects of the sprue design and reservoirs may also provide a significant contribution to the observed distortion pattern. The corresponding values for the CNC-milled titanium frameworks were mostly positive, thus indicating that the frameworks were slightly greater in width than the master cast (Table 4).

When analyzing the translational displacement in the y-axis (arch length = C3y master model – C3y framework), the values for the conventional cast frameworks did not show any significant patterns (Table 5). However, y-axis values for the CNC-milled frameworks were mostly positive, thus indicating that the frameworks were slightly larger than the master cast (Table 5). The reason for this is unknown; however, one possible explanation is the manufacturer's protocol.

Conclusion

1. Neither of the 2 types of frameworks provided a completely passive fit.
2. The laser-scanned CNC-milled titanium frameworks showed significantly less distortion along the x-axis and in the horizontal plane (x + y) than did the conventional cast frameworks.
3. Although the differences were not statistically significant, both the vertical plane (z-axis) and total 3D distortion measurements showed less distortion overall in the laser-scanned CNC-milled titanium frameworks.
4. The clinical perception of biologic tolerance to a certain degree of implant-frameworks misfit may not be clinically significant. However, in vivo prospective studies with a higher number of subjects are needed to investigate the possible clinical significance of this recorded difference in the context of a long-term treatment outcome.

Acknowledgments

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