The Precision of Fit of Cast and Milled Full-Arch Implant-Supported Restorations

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Purpose: *The purpose of this study was to investigate the marginal precision of computer numeric control–milled frameworks fabricated of grade 4 commercially pure titanium or cobalt-chrome alloy through digital technology and to compare them with conventional cast frameworks.* ***Material and Methods:*** *A titanium cast of a mandibular arch with six implant analogs was used as a master. The master cast was measured with a coordinate measuring machine. Fifteen rigid anatomic frameworks were created on the master cast in cast gold alloy and milled in titanium or cobalt-chrome material. The fifteen anatomic frameworks were measured in the same manner as the master cast. While the milled frameworks were measured once, at the end of the milling process, the cast anatomic frameworks were measured twice: immediately after the casting and divesting procedures and again after a technical adaptation procedure. Each anatomic framework was weighed. To compare the measurements obtained from each group of frameworks, descriptive statistics were calculated and one-way analysis of variance was performed, with values considered statistically significant at* $P < .05$. ***Results:*** *The mean weight of the cast frameworks was 33.41 g, the cobalt-chrome frameworks weighed 18.12 g on average, and the titanium frameworks averaged 8.7 g. The mean values for three-dimensional deviation of the center point position for each group of frameworks were 261 μm (cast frameworks before adaptation), 49 μm (cast frameworks after adaptation), 26 μm (milled frameworks in cobalt-chrome), and 26 μm (milled frameworks in titanium).* ***Conclusions:*** *Within the limitations of this in vitro study, absolute passive fit cannot be achieved, regardless of material and fabrication technique. Anatomic milled frameworks fabricated in titanium or cobalt-chrome presented reduced center point deviation compared to cast frameworks. Titanium frameworks weighed less than cobalt-chrome and cast gold alloy frameworks.* INT J ORAL MAXILLOFAC IMPLANTS 2013;28:687–693. doi: 10.11607/jomi.2990

Key words: *computer-aided design/computer-assisted manufacture, cobalt-chrome, dental implant, edentulous jaw, passive fit, prosthesis framework, titanium*

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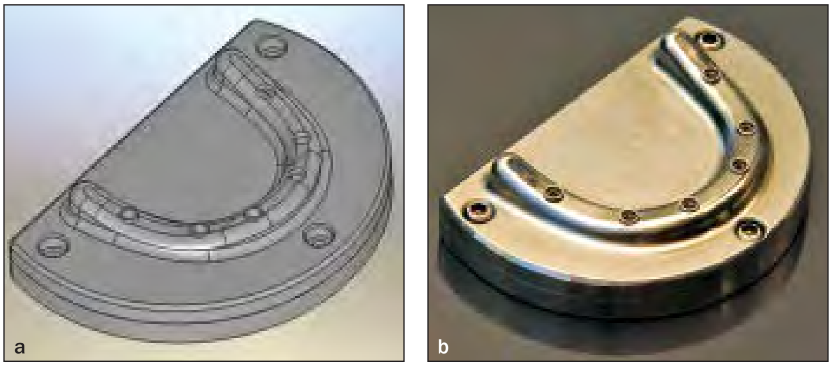
As a consequence of the absence of the periodontal ligament around dental implants, implant-supported restorations necessitate greater marginal precision than conventional tooth-supported restorations.[1] Biologic complications, which can range from minimal peri-implant bone remodeling to loss of osseointegration, are related to the presence of strain in the interface between the implant and the bone.[2–7] Similarly, mechanical complications, such as screw loosening or fracture and prosthesis deformation, are related to the presence of a prosthetic framework that does not sit firmly on the implant head, causing tension.[8–12]

Even though the literature provides extensive evidence of possible complications, a clear definition of the amount of misfit allowed is not described.[13] It has been shown that misfit of about 400 to 500 μm could contribute to bone remodeling at the implant level.[14,15] To limit mechanical and biologic complications, recent reports have recommended misfit limits of 50 μm and even less than 25 μm.[10,16,17]



Figs 1a to 1b Master model with six dental implant analogs in specific teeth positions. *(a)* The CAD model in 3D; *(b)* cast made of titanium.

Screw-retained prostheses have a well-documented history of successful application in completely edentulous patients.[18–20] In these situations, marginal precision is even more critical, as multiple implants are involved and quite often the occlusal load is outside of the screw axis.[21]

The achievement of passive fit requires many precise clinical and laboratory procedures. Researchers agree that absolute precision is extremely difficult to achieve, as distortion occurs during most of the clinical and laboratory steps.[22,23] Impression procedures, implant component positioning, master cast fabrication, wax pattern fabrication, investment and casting procedures, porcelain firing, prosthesis try-in, and prosthesis delivery are all procedures during which inaccuracies might be introduced. It can be assumed that the distortion caused by each of the mentioned factors is probably very small and therefore clinically insignificant; however, the summation of all distortions can cause significant internal stresses within the implant-prosthesis complex.[21]

With respect to the specific step of prosthesis fabrication, many improvements have been introduced to the widely utilized casting techniques to reduce distortion.[24,25] Sectioning and soldering, laser welding (horizontally or vertically), bonding gold cylinders to cast frameworks, and cementation on conical abutments have provided significant improvement to the precision of frameworks in the short and long term.[26–28]

Because of the high demand for accuracy and the cost of precious alloys, interest has shifted toward different materials, such as titanium (Ti), cobalt-chromium (Co-Cr), and zirconia.[29] Furthermore, the development of computerized technology has significantly influenced the technical possibilities for the fabrication of full-arch implant-supported restorations.[30,31] Several studies have investigated the precision of implant frameworks fabricated through laser-welded or premachined commercially pure Ti components.[32,33] More recently, with the introduction of computer numeric controlled (CNC) milling techniques, a stronger framework fabricated from one piece of solid material can be produced with an excellent fit.[34–36] However, significant framework distortion has been observed versus the master casts, with larger discrepancies in the horizontal plane (*x*- and *y*-axes) rather than in the vertical direction (*z*-axis).[37]

The purpose of this study was to investigate the marginal precision of CNC-milled frameworks fabricated from commercially pure grade 4 Ti or Co-Cr alloy through digital technology and to compare them with the precision of conventional cast frameworks.

MATERIALS AND METHODS

A Ti cast of a mandibular arch with six implant analogs was used as the master cast. Following a reference model of the natural dentition, a virtual model was created with implant analogs secured with self-curing resin (Eco Cryl Cold, Central Protechno) (Figs 1a and 1b). The six implant analogs (Analogue Friadent D3.8, Friadent) were positioned symmetrically to correspond to the mandibular first molars, first premolars, and lateral incisors bilaterally, all parallel to each other and at different heights (laterals, 0 mm; premolars, -1.2 mm; molars, -1.0 mm) (Fig 2). The master cast was measured with a coordinate measuring machine (SmartScope Flash, CNC 300 Optical Gauging Products), an optomechanical system that is capable of moving a measuring probe to determine the spatial coordinates of points on a workpiece surface. All measurements were performed at the Department of Civil, Environmental, and Architectural Engineering of the University of Padova. The coordinates of the probed points were transferred into a three-dimensional (3D) computer-aided design (CAD) geometric modeling software program (Rhinoceros 5.0 Beta, Robert McNeel & Associates) and analyzed with a task-specific evaluation protocol, programmed in IronPython programming language, to estimate the position and orientation of each analog. The measuring system is capable of a maximum per-

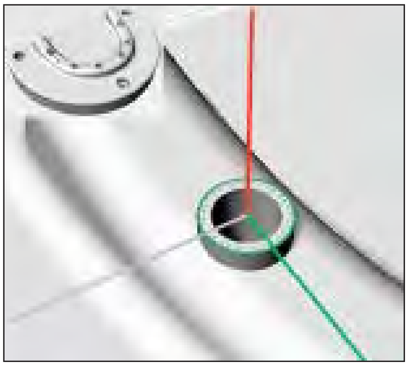


Fig 2 Measured points relevant to the determination of center point deviation of the analog's upper surface and the deviation axis. Blue = x-axis; green = y-axis; red = z-axis.

missible error (E, in microns) that is 10 times lower than both the performance of scanners commonly used in framework digital manufacturing and the expected position errors of the implant analog surfaces: E1(z) = 2.5 + 5L/1,000 µm, E2(xy) = 1.8 + 5L/1,000 µm, E3(xyz) = 2.8 + 5L/1,000 µm (with L, in millimeters, equal to the measured distance, according to International Organization for Standardization norm 10360). Uncertainty in experimental measurements was lower than 5 µm and was mainly influenced by the implant analogs' upper surface form error and by the system calibration method.

Measurements consisted of the acquisition of a set of 30 points on the upper surface and a second set of more than 200 points on the external profile of each analog. To evaluate both position and orientation, the first set of points was used to construct the upper plane of the analogs, while the second set of points was used to obtain fitting circles that were constrained to lie on those planes; thus, the spatial (x, y, z) coordinates of the center of the fitting circles estimate the positions of analogs (Fig 2). The fitting algorithm relevance in relation to the mentioned constructed geometries was assessed in a previous study, and its contribution to the experimental measurement uncertainty is negligible.[38]

Fifteen rigid anatomic frameworks were created on the master cast. Prior to the fabrication of the bars, their anatomic design was developed in resin (soft violet inlay wax, dental inlay casting wax, GC) via the use of silicon keys following the data of the mandibular reference model. The same design was followed for the anatomic cast frameworks and for the anatomic milled frameworks.

The five anatomic cast frameworks were fabricated through conventional technology by the same dental technician. Each implant component (Aurobase, Friadent) was screwed to the model and cut according to the silicon key, and the anatomic framework was completed with the use of adhesive wax (Virab Special, Virab) and modeling wax (soft violet inlay wax, GC). Prior to casting procedures, the customized wax structure was separated between each implant analog and joined with low-shrinkage wax (Erkodent Thiel, Erich Kopp). The wax pattern was then merged in the refractory die (Deguvest F, DeguDent), which had been prepared with a vacuum mixer (Twister Evolution 230V, Renfert) following the manufacturer's instructions. After the refractory materials were completed, the recommended boil-out sequence was followed prior to casting procedures (ASM Tecno Gaz 20Plus) with gold alloy (Orion WX, Elephant Dental).

All 10 anatomic milled frameworks were fabricated with the same protocol. Five frameworks were made of Co-Cr and five were made of grade 4 commercially pure Ti (Dentsply, Compartis ISUS International). After six scan flags were placed on each implant analog, the master model was scanned to accurately identify the implant analog positions (Hint-Els System). The same procedure was used to scan the master cast itself and the resin duplicate of the anatomic frameworks. The three scans were merged into a single digital model to reproduce as accurately as possible the position of the analogs and the geometry of the bar (ISUSsoft version 2.4, ES Healthcare). The digital data were transformed into the anatomic frameworks through a five-axis milling machine (Willemin Macodel).

The 15 fabricated anatomic frameworks were measured in the same manner of the master model with the optomechanical coordinate measuring machine (SmartScope Flash CNC 300, Optical Gaging Products) and analyzed by means of the aforementioned 3D CAD geometric modeling software (Rhinoceros 5.0 Beta, Robert McNeel & Associates). Each anatomic framework was weighed to determine possible differences between the materials in terms of patient sensation. While the milled frameworks (groups C and D) were measured once, at the end of the milling process, the cast anatomic frameworks were measured twice. The first measurement was conducted immediately after the casting and divesting procedures (group A). After these measurements, the same dental technician who fabricated all the frameworks then performed the adaptation procedure. This

Table 1 Mean Deviations of the Central Point Position at Each Implant Analog

Framework group/ analog	Deviation (µm) x-axis Mean	(SD)	y-axis Mean	(SD)	z-axis Mean	(SD)	3D Mean	(SD)
Cast (before adaptation)								
A1	361	(111)	151	(76)	11	(12)	393	(128)
A2	240	(112)	41	(16)	10	(12)	245	(110)
A3	96	(40)	110	(62)	13	(7)	149	(68)
A4	95	(53)	113	(64)	10	(5)	149	(81)
A5	229	(106)	38	(16)	20	(16)	238	(94)
A6	359	(132)	151	(60)	13	(14)	391	(143)
Cast (after adaptation)								
A1	59	(65)	25	(11)	12	(11)	68	(64)
A2	26	(20)	15	(9)	14	(10)	35	(20)
A3	21	(10)	21	(15)	10	(7)	33	(14)
A4	16	(12)	28	(23)	7	(5)	36	(22)
A5	36	(19)	21	(25)	18	(18)	49	(29)
A6	53	(55)	36	(28)	14	(14)	71	(56)
Milled Co-Cr								
A1	35	(19)	10	(6)	3	(3)	37	(18)
A2	16	(8)	4	(1)	3	(2)	17	(7)
A3	19	(1)	11	(8)	5	(3)	23	(4)
A4	12	(4)	9	(6)	7	(3)	17	(2)
A5	28	(10)	2	(2)	2	(1)	28	(10)
A6	30	(19)	10	(5)	3	(2)	32	(19)
Milled Ti								
A1	26	(14)	6	(6)	1	(1)	36	(10)
A2	16	(6)	4	(2)	2	(1)	21	(3)
A3	15	(3)	7	(4)	4	(2)	21	(5)
A4	13	(4)	9	(6)	2	(3)	19	(5)
A5	20	(6)	4	(3)	3	(2)	24	(4)
A6	26	(12)	8	(5)	2	(2)	37	(11)

process involved cutting and soldering on the master cast to improve the marginal adaptation. After this procedure, the cast anatomic frameworks were measured for a second time (group B).

To evaluate the positional accuracy of each anatomic framework, the estimated centers of the elements were aligned, using a least-square best fitting algorithm, to the corresponding analogs on the master cast; the algorithm "optimizes" the position and orientation of the frameworks while considering the 3D distances between each abutment and the relative analog. Three-dimensional distances between centers and their components along the *x*-, *y*-, and *z*-axes were calculated at each position for all frameworks.

To compare the measurements obtained for each group of frameworks, descriptive statistics for the discrepancies (means, standard deviations [SDs], maxima, minima) were calculated. Furthermore, a paired *t* test was applied to the cast frameworks, before and after adaptation, to determine whether the adaptation process had a significant effect on the measurement results. Finally, a one-way analysis of variance (ANOVA) was calculated to evaluate the differences in the framework sample population, with the exception of cast frameworks before adaptation, with statistical significance considered at $P < .05$.

RESULTS

The mean weights of the frameworks were 33.41 g (SD 2.19) for the cast frameworks, 18.12 g (SD 0.25) for the Co-Cr frameworks, and 8.7 g (SD 0.04) for the Ti frameworks.

Table 2 Mean Deviations of the Center Point for Each Group of Frameworks

Group	Deviation (µm) Mean	SD
Cast (before adaptation)		
x-axis	230	142
y-axis	101	68
z-axis	13	11
3D	261	141
Cast (after adaptation)		
x-axis	35	37
y-axis	24	19
z-axis	12	11
3D	49	39
Milled Co-Cr		
x-axis	23	14
y-axis	8	6
z-axis	4	3
3D	26	13
Milled Ti		
x-axis	19	10
y-axis	6	5
z-axis	2	2
3D	26	10

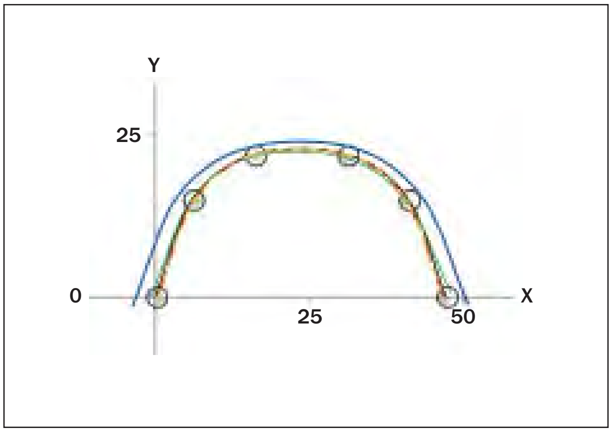


Fig 3 Graphic representation of the mean deviation of the center point position for each group of frameworks in the x-y plane (in millimeters). Circles represent nominal positions of the implant analogs. Each framework and the master model are represented by a specific color. Blue = Cast before adaptation; green = cast after adaptation; red = Co-Cr; orange = Ti; black = master model.

Table 3 Summary of One-Way ANOVA

	SQ	df	Mean square	*P* value	F
Between groups	0.010053	2	0.005026	.0004	8.48
Within groups	0.051545	87	0.000592		
Total	0.061598	89			

SQ = sum of squares; df = degrees of freedom.

Table 4 Summary of Statistically Significant Differences

	Cast (after adaptation)	Milled Co-Cr	Milled Ti
Cast (after adaptation)	–	.0036	.0037
Milled Co-Cr		–	.8854
Milled Ti			–

The deviations in the center point position at each implant analog level are described in Table 1. The mean values are reported along the *x*-, *y*-, and *z*-axes as well as on the resultant 3D levels. Each group deviation, with specifications on the three different axes and on their resultant 3D levels, is summarized in Table 2. A graphic representation in the x-y plane is shown in Fig 3. The mean 3D deviation values of the center point position were 261 µm (SD 141 µm) for the anatomic cast frameworks before adaptation, 49 µm (SD 39 µm) for the anatomic cast frameworks after adaptation, 26 µm (SD 13µm) for the Co-Cr frameworks, and 26 µm (SD 10 µm) for the Ti ones.

A summary of the ANOVA is given in Table 3 (between groups and within groups). A synthesis of the statistically significant differences between groups ($P < .05$) is given in Table 4.

DISCUSSION

As described in the literature, the achievement of passive fit of a full-arch implant-supported restoration, as a result of the many clinical and laboratory procedures involved, is extremely difficult to achieve, and marginal discrepancies are always present.[21–23] In the frameworks examined in the present study, distortion was always detected, and it is important to remember that this study examined only one step in the process (prosthesis fabrication). In agreement with previous studies,[29–37] a mean deviation of the center point of about 26 µm for the most accurate frameworks was detected. This deviation reached a mean of 261 µm for the anatomic cast frameworks before adaptation (Table 2).

Significant differences in center point deviation were noted between cast and milled frameworks. As described in previous reports, the use of digital technology has significantly reduced the inaccuracy of prosthesis fabrication, which nearly doubles for conventional cast frameworks (after adaptation) (Table 2). It is also important to note that the fabrication of cast frameworks is extremely technique sensitive. A comparison of cast frameworks before and after adaptation reveals major differences. Casting procedures, as a result of material deformation during the process, cause a major deviation of the center point that needs to be corrected with extremely technique-sensitive procedures, such as welding and soldering. Without these procedures, the center point deviations are not acceptable. In the present study, cutting and soldering procedures were performed for all but one framework in at least one position. In particular, two frameworks were cut and soldered in two different positions. The advantages of CAD/computer-assisted manufacture technology—ie, obtaining frameworks from a single block of Ti or Co-Cr—is that the final product is made up of one solid block of material that is milled into its final shape, with the required accuracy, without the need to perform any further procedures that might decrease its strength. For this reason, the present study did not investigate cut and soldered milled frameworks.

As described in Table 2 and in previous studies,[37] the most significant framework distortion is observed in the horizontal plane (*x*- and *y*-axes) rather than in the vertical direction (*z*-axis), regardless of the technique or material. Unquestionably, a limitation of the present study, together with a small sample size, is that all the implant analogs were positioned with the same spatial orientation. In the intraoral environment this is not possible, and increased discrepancies can be expected.

Analysis with the paired *t* test confirmed a statistically significant difference ($P < .05$) between cast frameworks before and after adaptation. Statistically significant differences between cast adapted frameworks, Co-Cr frameworks, and Ti frameworks are summarized in Table 3. On the other hand, a *P* value equal to .89 (for Ti versus Co-Cr frameworks) confirmed the absence of statistically significant difference between the two groups (Table 4). Hence, the decision regarding which material to choose for an implant-supported restoration must be related to aspects other than precision of fit. It is not the topic of the present investigation, but the biologic peri-implant tissue response and reaction to different layering procedures should be considered. Although this was not the purpose of the present study, it is interesting to note that these measurements allow further investigation, as they can be considered as input quantities for analysis focused on the prediction of the magnitude of static implant loading that will occur as a consequence of superstructure fixation.

Because implant-supported restorations are extremely extensive when they reconstruct an edentulous arch and are quite often associated with significantly resorbed bone, it was interesting to compare the weights of these type of prostheses. Anatomic cast frameworks weighed significantly more (mean 33.41 g) than milled frameworks. Moreover, the weight of Ti frameworks was less than half that of the Co-Cr frameworks (mean weights, 8.70 g and 18.12 g, respectively).

CONCLUSION

Within the limitations of this in vitro study, the following conclusions were drawn.

- Absolute passive fit cannot be achieved, regardless of the type of material and technique used.
- Anatomic cast frameworks showed significantly larger center point deviations compared to milled anatomic frameworks fabricated through digital technology. Anatomic cast framework accuracy was strictly related to adaptation of the framework through cutting and soldering.
- Anatomic milled frameworks fabricated in titanium or cobalt-chrome displayed reduced center point deviation compared to the cast frameworks. No statistically significant differences were present between the two milled materials.
- Titanium frameworks weighed less than cobalt-chrome frameworks and cast frameworks.

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