Vertical Marginal Gap Evaluation of Conventional Cast and Computer Numeric Controlled–Milled Titanium Full-Arch Implant-Supported Frameworks

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Purpose: To use a novel approach to measure the amount of vertical marginal gap in computer numeric controlled (CNC)-milled titanium frameworks and conventional cast frameworks. ***Materials and Methods:*** Ten cast frameworks were fabricated on the mandibular master casts of 10 patients. Then, 10 CNC-milled titanium frameworks were fabricated by laser scanning the cast frameworks. The vertical marginal gap was measured and analyzed using the Contura-G2 coordinate measuring machine and special computer software. ***Results:*** The CNC-milled titanium frameworks showed an overall reduced mean vertical gap compared with the cast frameworks in all five analogs. This difference was highly statistically significant in the distal analogs. The largest mean gap in the cast framework was recorded in the most distal analogs, and the least amount was in the middle analog. ***Conclusions:*** Neither of the two types of frameworks provided a completely gap-free superstructure. The CNC-milled titanium frameworks showed a significantly smaller vertical marginal gap than the cast frameworks. *Int J Prosthodont 2014;27:517–522. doi: 10.11607/ijp.4134*

A primary objective in fabricating an osseointegrated implant superstructure is to achieve a passively fitting prosthesis.[1–6] Current clinical and laboratory techniques introduce errors that make it impossible to obtain a dental implant superstructure with a complete passive fit.[3,7–10] Attempts to optimize the fit between the implant abutments and the superstructure have led to recommendations for impression procedures, master-cast fabrication, spruing, casting, and soldering.[11–14] In addition, numerous computer-aided industrial manufacturing protocols have emerged in an attempt to overcome some of the many misfit factors related to manual fabrication of the conventional cast frameworks.

The computer numeric controlled (CNC)-milled titanium framework (Nobel Biocare) was developed more than 10 years ago. It offers the advantages of a light weight, lower cost for the titanium metal, and the potential for a lower risk of oral corrosion. It is also claimed to improve the superstructure fit to the implant by avoiding some of the inherent problems associated with the lost wax casting technique.[15,16] Furthermore, the technique has been reported to provide superior three-dimensional (3D) internal fit compared with conventional casting techniques.[3,15,16] Clinical trials have shown that the performance of such titanium frameworks is clinically and radiographically similar or superior to conventional cast frameworks.[17–19] However, to date, no studies have measured the amount of vertical marginal gap in CNC-milled titanium frameworks compared with conventional cast frameworks. Therefore, the aim of the current study was to use a novel approach to measure and compare the amount of marginal gap in CNC-milled titanium frameworks and conventional cast frameworks.

This study sought to address the following hypothesis: The vertical marginal gap of laser-scanned CNC-milled titanium frameworks relative to the implant analog is superior to that of conventional cast frameworks, comprising 50% silver (Ag), 30% palladium (Pd), 3% gold (Au), 15.9% copper (Cu), 1% zinc (Zn), and < 1% iridium (Ir).

Materials and Methods

Ten mandibular master casts of a completely edentulous patient with five Brånemark implants (Nobel Biocare) with multi-unit abutment analogs (Brånemark, Nobel Biocare) were used to fabricate the frameworks. Two sets of frameworks were fabricated on each of the master casts. The conventional cast framework was fabricated first followed by the CNC-milled titanium framework (grade 2 titanium, Nobel Biocare).

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The same technician fabricated all 10 cast frameworks using the same materials. This was performed to ensure standardization among the frameworks. Five multi-unit gold cylinders (DCA 072-0 Brånemark, Nobel Biocare) were screwed onto the abutment analogs in the master cast at 10 Ncm using gold alloy screws (DCA 075, Nobel Biocare). Then, the frameworks were waxed up (Thowax, YETI Dental) on the gold cylinders. To determine the dimensions of the framework, the silicone index of the teeth setup was used.

To reduce stresses, allow for passive fit of each cylinder to its related abutment, and minimize lifting torque,[20] the waxed-up frameworks were allowed to set for at least 12 hours at room temperature (25°C) prior to investment. Then, they were tested for passivity using the one-screw test.[21]

Five 8-gauge round wax sprues (Kewax, Keystone) originating from a central sprue form that was placed in the middle of the casting ring were attached to each of the wax patterns. The sprued patterns were left screwed onto the master cast for at least 30 minutes and were tested for possible warpage prior to investing. The pattern was then invested immediately (Micro-Fine 1700 Casting Investment, Talladium) in a 2.5-inch-diameter ringless mold (Proven Ringless Casting System, Talladium). The sprued pattern was oriented so that it was approximately 12 mm from the top end of the ring and horizontally separated from the ring walls by 6 mm. The weight ratio of the expansion liquid to distilled water for the Ag-Pd-Au alloy used was 60:40.

Prior to casting the alloys, the invested wax-up had gone through a gradual (2 hours) 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 hour. The casting-ring orientation was held constant in relation to the ring holder for each casting by a mark in the investment.

The frameworks were cast using a centrifuge (TSI, Degussa). All frameworks were cast in silver-palladium alloy (50% Ag, 30% Pd, 3% Au, 15.9% Cu, 1% Zn, < 1% Ir; Maestro, Jelenko).

Following casting, the rings were bench cooled prior to divesting. Then, the frameworks were separated from the sprues and polished per the manufacturer's instructions.

The 10 CNC-milled titanium frameworks were fabricated at the Nobel Biocare laboratories. To avoid any possible provider bias, the technicians involved in the fabrication process were not aware that these frameworks were to be used as part of the study.

To control for some of the factors that may contribute to distortion, such as framework contour, span length, and cantilever extension, the conventional cast frameworks were used instead of the acrylic resin jig to fabricate the CNC-milled titanium frameworks. First, the conventional cast frameworks were coated with a special paint to facilitate their scanning. A laser scanner scanned the frameworks, and the positions of the implant replicas in the master cast were measured using a contact-type coordinate measuring machine (CMM). 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 one piece of titanium. The CNC-milled frameworks were then polished per the manufacturer's instructions. Special care was taken to avoid the cylinder platforms and their inner conical surfaces. The paint on the conventional cast frameworks was removed using acetone-free nail polish remover prior to the measurement session.

Measuring the Vertical Marginal Gap

To measure the size of the vertical gap between the frameworks and their respective abutments, a CMM (Contura-G2, Carl Zeiss Industrial Metrology) was used. The ball diameter of the stylus was 1.0 mm for the frameworks and 0.3 mm for the implant analogs. The frameworks and implant analogs were measured with 50 points in a circular pattern. The coordinate system (base alignment) for the implant analogs was established as follows: *(1)* Flat 3 constrains spatial rotation (ie, pitch and roll) setting +Z axis. It also constrains the Z translation setting Z = 0. *(2)* The line segment joining the intersection of Cone1 – Flat 1 and the intersection of Cone5 – Flat 5 constrains planar rotation (ie, yaw) setting the +X axis. And, finally, *(3)* the intersection of Cone3 – Flat 3 constrains X and Y translation setting X = 0 and Y = 0. The base alignment for the frameworks was established as follows: *(1)* Flat 3 constrains spatial rotation (ie, pitch and roll) setting –Z axis. It also constrains the Z translation setting Z = 0. *(2)* The line segment joining the intersection of Cone1 – Flat 1 and the intersection of Cone5 – Flat 5, constrains planar rotation (ie, yaw) setting the +X axis. And, finally, *(3)* the intersection of Cone3 – Flat 3 constrains X and Y translation setting X = 0 and Y = 0.

To evaluate the profile of the framework points onto the implant analogs, a tolerance of 0.03 mm was set. The profile actual value was calculated by taking the maximum value of the high point on one side of the implant (positive side) and the high point on the other side of the implant (negative side) and multiplying by 2. The inward to infinity method was performed to measure and analyze the amount of vertical gap between the implant analog and the framework using special computer software (Calypso, Carl Zeiss Industrial Metrology; Fig 1).

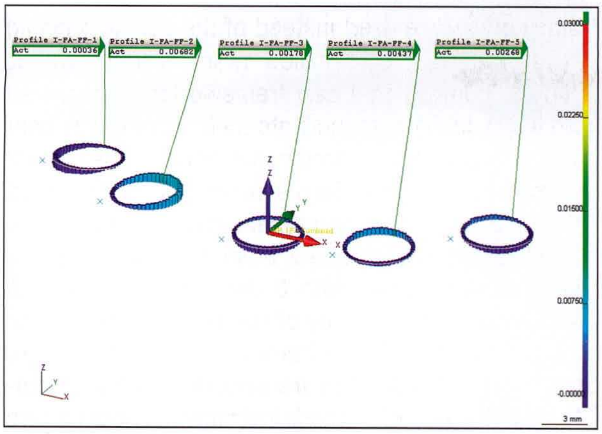

Fig 1 Isometric view of vertical gap measurements in the Calypso software indicating the maximum amount of gap at each implant analog.

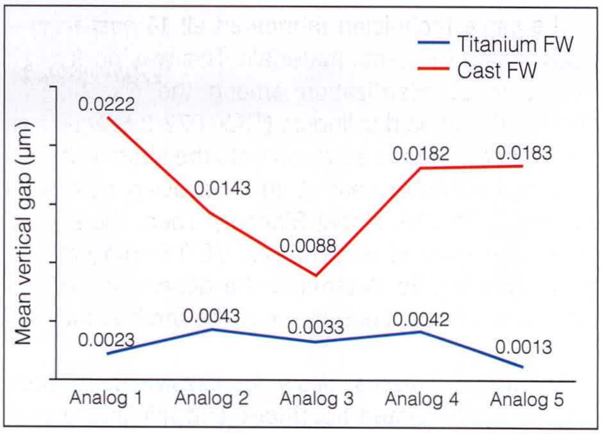

Fig 2 Mean values of vertical marginal gap for the cast and CNC-milled titanium frameworks at the five implant analogs. FW = framework.

Table 1 Mean Vertical Marginal Gap for the Cast and CNC-Milled Titanium Frameworks at the 5 Implant Analogs*

Analog no.	Framework	Mean (µm)	N	SD	*P* value
1	Titanium Cast	0.0023 0.0222	10 10	0.00123 0.00726	**.0000**
2	Titanium Cast	0.0043 0.0143	10 10	0.00180 0.01072	.0158
3	Titanium Cast	0.0033 0.0088	10 10	0.00256 0.00609	.0434
4	Titanium Cast	0.0042 0.0182	10 10	0.00229 0.00944	**.0017**
5	Titanium Cast	0.0013 0.0183	10 10	0.00080 0.00715	**.0000**

*Statistical significance set at $P < .001$ ($\alpha = .001$).

A series of paired *t* tests were used to test for the difference in marginal gap in the cast frameworks and CNC-milled frameworks. Statistical significance was set at $\alpha = .001$.

Results

The data showed an overall smaller mean vertical marginal gap in the CNC-milled titanium frameworks compared with the cast frameworks in all five analogs (Fig 2). This difference was highly statistically significant at analog numbers 1, 4, and 5 (Table 1, in bold).

The CNC-milled framework showed more consistent values of measured gap at all five analogs compared with the cast framework. Furthermore, in the cast framework, the largest mean gap was found in the most distal analogs, and the least amount was reported in the middle analog (see Fig 2). The maximum mean marginal gap was reported in analog 1 in the cast framework (0.0222 µm), and the minimum gap reported was in analog 5 in the CNC-milled framework (0.0013 µm; see Table 1).

Discussion

Given the nature of the rigid support provided by osseointegrated dental implants, a controlled mechanical environment is necessary to ensure adequate remodeling stimulus for maintenance of integration.[1,2,22] As a result, passive fit of implant-prosthodontic frameworks is believed to be one of the factors that affects the mechanical load on implants and possibly the longevity of osseointegration.

The conventional implant-prosthodontic framework fabrication technique was largely borrowed from conventional prosthodontics. Casting accuracy studies have reported errors in the range of 100 µm with the use of conventional techniques for fabrication of multi-unit fixed partial dentures.[23] Furthermore, it has been shown that the experienced clinician may not even be able to distinguish horizontal margin error in the range of 32 to 230 µm and vertical margin error of 43 to 196 µm.[24]

By extrapolating these data to the field of implant dentistry, it is reasonable to expect that the clinical

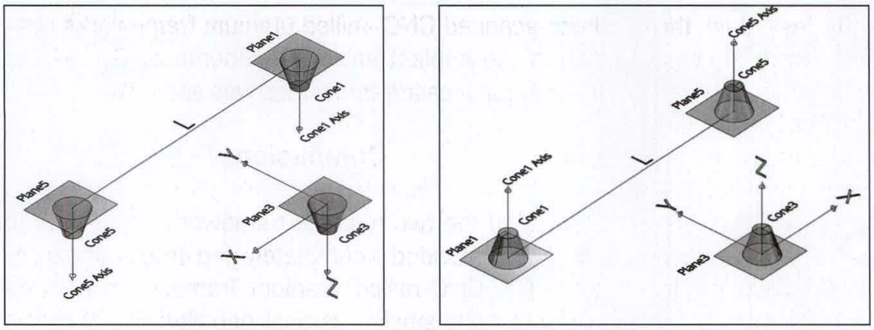

Fig 3 Framework and implants coordinate frames (base system).

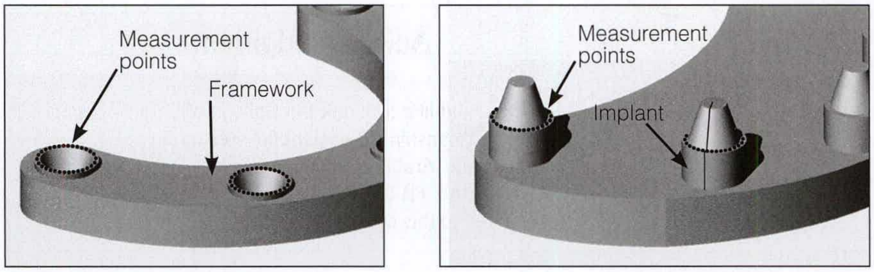

Fig 4 A large number of measurement points are determined along both the implant analog and the framework surfaces in a circular pattern to construct a flat surface to represent the framework and implant analog platforms.

evaluation of the implant frameworks' accuracy could not be accomplished at the 10-μm level, and, therefore, prostheses with nonpassive superstructure relationships are being screw-fastened to implants.

The novelty of the vertical gap assessment approach applied in the current study is threefold. First, to the author's knowledge, this is the first study to utilize the high precision offered by the CMM to directly assess the amount of vertical marginal gap between the implant frameworks and their corresponding analogs. In the literature, the most commonly used method for measuring the vertical gap is microscopic examination,[25–27] where few measurements are usually performed in the buccal and lingual surfaces of the implant analog. The overall gap is then calculated by averaging the measurements. In contrast, the CMM measures 50 or more points along both the analog and framework surfaces in a circular pattern (Fig 3). This extensive number of points results in a more detailed representation of the amount of vertical gap. Moreover, with most types of microscopes, measuring the amount of gap involves seating the framework on the master cast, which renders the interproximal areas inaccessible for evaluation. Since fixing the framework to the master cast is not a requisite for obtaining measurements with the CMM, critical information on the interproximal vertical gap is not overlooked; hence, the results are more representative of the real values. Moreover, the Contura-G2 CMM is equipped with a rotary dynamic sensor and an XXT probe with computer-aided accuracy, which enables the clinician to set the probe at various compound angles to gain "perpendicular" access to the implant analogs' narrow platforms—even in cases with severely tilted implants. This feature enabled the use of 10 patient models with various implant tilts and spatial orientations. Consequently, the amount of vertical gap discrepancies measured and the results obtained reflected real intraoral situations.

Second, a special set of mathematical algorithms were employed to mimic the implant-framework fitting process. This was carried out as follows: *(1)* Two coordinate frames were constructed for the measurement of the implant analogs and the framework, respectively (Fig 4). *(2)* A large number of points was measured on each implant analog's platform and used to construct a flat surface to represent each implant's platform, five in total. *(3)* A large number of points were measured on the corresponding platforms of the framework with respect to its coordinate system. *(4)* The framework points were aligned with the corresponding surfaces, constructed using the implant analogs' platforms. The alignment process minimizes the function of the deviation between the framework measurement points and their corresponding implant flat surfaces. *(5)* The deviations between these points, and their corresponding surfaces on the implant analogs, were calculated and reported to represent the framework-implant 3D vertical marginal gap.

Third, the algorithm used to calculate the framework-implant analog vertical gap considers only positive deviations; ie, no interference between the framework and the implant analog mating surfaces is allowed. This technique physically mimics the clinical process of fitting the framework into the underlying implants.

None of the frameworks evaluated in this study exhibited complete marginal adaptation. However, the amount of vertical gap in the CNC-milled titanium frameworks was mostly significantly less than the cast framework. Furthermore, in contrast to the cast framework, the recorded amount of vertical gap in the CNC-milled framework around all five implant analogs is consistent. This further emphasizes the fact that the use of computer-aided design/computer-assisted manufacture technology for framework fabrication significantly reduces the dentist's dependence on varying degrees of consistency in technician skills. Therefore, similar accuracy in casting protocols by methods that are less vulnerable to individual skills would appear to be a very progressive step in patients needing implant prosthodontics. Additional advantages also could include the actual laboratory cost of the prescribed protocol. While sectioning, soldering, and laser welding of an ill-fitting cast framework can significantly improve the marginal adaptation,[28-31] these procedures add to the laboratory cost, are technique sensitive, and might compromise the framework's durability.

Another interesting finding was the pattern of vertical gap distribution in the cast frameworks. In addition to the inconsistent amount of recorded gap among the five analogs in all 10 frameworks, the largest mean gap was found in the most distal analogs and the least amount was recorded in the middle analog (see Fig 2). There is no clear explanation for this pattern distribution. However, it could be attributed to the form of framework shrinkage and expansion associated with the various laboratory fabrication procedures (ie, wax pattern fabrication, investing, casting, and finishing).[32] It is important to emphasize that the accuracy of the frameworks appeared to be limited by the accuracy of the master cast whose accuracy was, in turn, affected by the impression technique and materials used. Consequently, future investigations should focus on developing techniques of optimizing the process of duplicating the intraoral situation with minimum distortion.

The results of this investigation support the notion of an alternative method for producing fixed prosthodontic frameworks. The significance of the observed differences in the marginal gap of the framework to the implant abutments may not be clinically significant. This interpretation is suggested by the very successful positive recorded results from numerous clinical reports of various loading protocols using the conventional cast framework.[33-35] It certainly appears that biologic tolerance of very slight casting inaccuracies permits such successful clinical experiences. However, the argument regarding optimal clinical fit and its long-term outcome significance can only be tested in vivo.

Based on the findings of the current study, the hypothesis, that the vertical marginal gap of laser-scanned CNC–milled titanium frameworks relative to the implant analog is superior to that of the conventional cast frameworks, was accepted.

Conclusions

Neither of the two types of frameworks measured in this study provided a completely gap-free superstructure. The CNC-milled titanium frameworks showed a significantly smaller vertical gap than did the cast frameworks.

Acknowledgments

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Literature Abstract

Association of aggressive periodontitis with reduced erythrocyte counts and reduced hemoglobin levels

The authors investigated effects of generalized aggressive periodontitis (GAP) on a variety of erythrocyte parameters. GAP is defined as probing depth and clinical attachment $\geq$ 5 mm on at least eight permanent teeth of which at least three are not the first molars or incisors. A total of 64 patients (32 men, 32 women) with GAP were compared with 58 periodontally healthy people (33 men, 25 women). A variety of confounding variables known to be associated with anemia and periodontal diseases were recorded. Gingival and plaque indices and periodontal statuses were measured. Fasting venous blood was analyzed for mean corpuscular volume, hematocrit, mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), red cell distribution width (RDW), and erythrocyte sedimentation rate (ESR). Results indicated that erythrocyte count, hemoglobin concentration, hematocrit, and MCH were significantly lower in the GAP group. ESR was higher. Erythrocyte count and hemoglobin concentration were negatively correlated with mean probing depth, mean clinical attachment level, and percentage of severe sites. After adjusting for the confounding variables, the GAP group still had significantly lower erythrocyte counts and hemoglobin levels. The authors concluded that GAP, like chronic periodontitis, may be associated with an increased risk of "anemia of chronic disease."

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