Evaluation of Vertical Misfit of CAD/CAM Implant-Supported Titanium and Zirconia Frameworks

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**Purpose:** This study compared the vertical misfit of fixed implant-supported titanium (Ti6Al4V) and yttria-stabilized tetragonal zirconia frameworks milled using the computer-aided design/computer-aided manufacturing (CAD/CAM) Zirkonzahn system. **Materials and Methods:** An aluminum mandibular master cast was used, and four analogs of the Regular CrossFit implant for straight multibase titanium alloy abutments (Institut Straumann) were fixed with self-curing acrylic resin in mandibular canine and second premolar tooth locations with the aid of a parallelometer. Scan abutments were placed over the four straight multibase Regular CrossFit abutments to determine their correct three-dimensional (3D) positioning in the virtual model. Implant frameworks were designed virtually, and five frameworks of each material (titanium alloy or yttria-stabilized tetragonal zirconia) were milled using the CAD/CAM system. Scanning electron microscope (SEM) images, with magnifications of 50×, 250×, and 1,000×, were obtained from three points on the buccal surface, three points on the lingual surface, and three points on the mesial surface of each abutment. The measurements were performed in the center of each of the thirds, thus defining points one, two, and three. The degree of vertical misfit at the framework-abutment interface was determined using ImageJ software and analyzed using the Student t test (P = .05). **Results:** The mean misalignment value was 6.011 ± 0.750 µm for the titanium group and 9.055 ± 3.692 µm for the zirconia group. **Conclusion:** Within the limitations of this study, there was no significant difference in vertical misfit between the titanium and zirconia implant frameworks produced using the CAD/CAM system. Regardless of the material used, the CAD/CAM frameworks achieved an adequate vertical fit. INT J ORAL MAXILLOFAC IMPLANTS 2018;33:1027–1032. doi: 10.11607/jomi.6320

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The passive fit of implant frameworks is a mechanical parameter that can interfere with the longevity of the restorative treatment.1 The long-term failure of restorative treatment with osseointegrated implants can be caused by the lack of adequate passive fit of implant structures and is aggravated by the absence of periodontal ligament.2 Clinically, fracture of prosthetic components or screws, pain, marginal bone loss, and osseointegration failure may indicate poor passive fit.3,4

However, the correlation between poor passive fit of implant frameworks and mechanical and biologic consequences is not entirely understood. Therefore, the techniques and materials used in clinical and laboratory settings can be improved to achieve a desirable level of passive fit.5

Several techniques have been proposed to improve passive fit. The first category is based on the inclusion of steps to refine the fit of prosthetic components and includes sectioning and soldering frameworks, electroerosion, and fusing prefabricated cylinders to the metal framework. The second category includes reducing manufacturing steps, particularly with the use...
of computer-aided design/computer-aided manufacturing (CAD/CAM) technologies and other prototyping methods.6

Studies have used CAD/CAM and rapid prototyping methods to manufacture implant-supported frameworks. Such technologies have provided significant improvements in the cervical adaptation of implant frameworks compared with traditional laboratory procedures, including waxing, investing, and casting. This progress was achieved primarily by eliminating several laboratory steps that caused overlapping errors inherent to the lost-wax casting technique. Even with the progress made, further studies are needed to improve this technique and achieve optimal vertical fit of frameworks and probably greater longevity of the restorative treatment.7

Absolute passive fit between implants and implant frameworks might be impossible to achieve clinically. Thus, prosthesis misfit is a clinical reality as the result of several factors involved in its fabrication. Therefore, the aim of this study was to evaluate the vertical misfit of screw-retained implant frameworks made of titanium alloy grade 5 (ASTM) (Ti6Al4V) or yttria-stabilized tetragonal zirconia using the CAD/CAM system. The null hypothesis tested in this study was the lack of a difference in misfit between the two framework groups tested.

MATERIALS AND METHODS

Four equidistant perforations corresponding to mandibular canine and second premolar tooth locations8 were made in an aluminum mandibular master cast.3,9

Four analogs for straight multibase Regular CrossFit titanium alloy abutments (Institut Straumann) were positioned in these perforations. They were positioned perpendicularly to the surface (90 degrees) and parallel to each other with the aid of a BIOART B2 parallelogram (Bioart). Then, they were fixed with self-curing Duralay acrylic resin (Reliance Dental). Considering mean misfit of a titanium and a zirconia specimen observed in the pilot study, the sample size was calculated using Lehr’s equation,10 a simplified method of sample size calculation from difference between two means. This calculation yielded a size of five specimens per group to be tested.

The aluminum master model was scanned using an S600 ARTI scanner (Zirkonzahn). Because of the excess brightness of the metallic model, a powder (SKD-S2 SPOTCHECK, Magnaflux) was used to improve the image contrast. Scan abutments were placed over the four straight multibase Regular CrossFit abutments to determine their correct three-dimensional (3D) positioning in the virtual model. According to the positioning and format of the scan abutment, the software (Zirkonzahn.Modellier, Zirkonzahn) identified the 3D position of the abutments in the virtual model by image superimposition (Fig 1) so that no positioning errors occurred even after milling. Subsequently, the same software was used to perform the 3D virtual design of the frameworks, thereby completing the graphics development phase.

For the next stage of milling, titanium grade 5 (ASTM) (Ti6Al4V) and yttria-stabilized tetragonal zirconia blocks were selected and positioned virtually on the drawing of the frameworks, and the milling slopes and routes were defined.

The titanium grade 5 (ASTM) (Ti6Al4V) and yttria-stabilized tetragonal zirconia blocks were milled using an M5 heavy milling machine (Zirkonzahn). After completion of the milling process, the blocks (Ti and Zir) were removed from the milling unit and cut using a no. 7 diamond disc (Talmax, Curitiba) to remove the frameworks.

To measure the vertical misfit between the prosthetic frameworks and their respective abutments, a focused ion beam (FIB) Quanta FEG 3D scanning electron microscope (SEM) (FEI) was used, with magnifications of $50\times$, $250\times$, and $1,000\times$, in different areas of the specimens, as detailed in a recent study.11,12 Readings were performed at three points on the buccal

<table>
<thead>
<tr>
<th>Group</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Median</th>
<th>Mean</th>
<th>SD</th>
<th>P</th>
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<tr>
<td>Zirconia</td>
<td>3.000</td>
<td>12.860</td>
<td>9.527</td>
<td>9.055</td>
<td>3.692</td>
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Table 1 Descriptive Measurements (μm) and P value for Student t Test
surface, three points on the lingual surface, and three points on the mesial surface of each abutment. Torque values were determined using a Straumann manual wrench to simulate a clinical situation. The 15-N torque values were measured in the following sequence: left mandibular canine, right mandibular canine, left mandibular second premolar, and right mandibular second premolar.

To measure the degree of vertical misfit, the free and public software ImageJ version 1.48 (http://imagej.nih.gov/ij/download.html) (National Institutes of Health) was used. The measurement scale was calibrated using the scale supplied in the images acquired by SEM, drawing a line between two points of known distance and typing the known distance and units of measure in the appropriate boxes. The images were divided into three equal parts to determine the measuring points. The measurements were performed in the center of each of the thirds, thus defining points one, two, and three. Using a measure tool, a line was drawn between the edges of the prosthetic frameworks and their respective abutments in these three points. The distance of these points was determined in micrometers (µm).

The data were tabulated and analyzed using SPSS version 20.0. The mean vertical misfit values at the abutment/framework interface for the titanium and zirconia groups were subjected to the Shapiro-Wilk test to assess the assumptions of normality in the distribution curves. The homogeneity of variance was attested by Levene’s test. Considering the normal distribution and the homogeneity of variance, the Student t test for independent samples was used to compare the mean values of titanium and zirconia groups. The results of the Student t test for independent samples revealed no significant difference between the groups tested (P = .108) (Table 1).

Therefore, the misfit of the titanium frameworks (6.011 ± 0.750 µm) was similar to that of the zirconia frameworks (9.055 ± 3.692 µm). The coefficient of variation, calculated using the ratio between the SD and mean of the data, was 0.12 for the titanium specimens and 0.40 for the zirconia specimens, demonstrating the greater variability of vertical misfit in the zirconia specimens (Fig 2).

**RESULTS**

A total of 120 images were selected for analysis in ImageJ version 1.48. The mean/SD misfit values for each framework were calculated from 36 measurements, and these mean values were used in the statistical analysis.

The results of the Shapiro-Wilk test indicated that the data were normally distributed for titanium (P = .620) and zirconia (P = .379) groups. The homogeneity of variance was attested by Levene’s test (P = .134). Considering the normal distribution and the homogeneity of variance, the Student t test for independent samples was used to compare the mean values of titanium and zirconia groups. The results of the Student t test for independent samples revealed no significant difference between the groups tested (P = .108) (Table 1).

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**DISCUSSION**

The null hypothesis tested in this study was the lack of a difference in misfit between prosthetic frameworks made with titanium grade 5 (ASTM) (Ti6Al4V) and yttria-stabilized tetragonal zirconia. This hypothesis was confirmed based on the results obtained (Table 1).

This study was conducted to deepen knowledge of the passive fit of prosthesis frameworks because clinical rehabilitation using implant-supported prostheses is being used more frequently compared with the conventional tooth-supported system. The use of SEM in this study provided adequate-quality images at a magnification of 1,000× and resulted in high-consistency results with high intra-examiner reliability (intraclass correlation coefficient [ICC] = 98.6%).

Passive fit is a synonym for “ideal fit” and is considered one of the requirements for the maintenance of the bone-implant interface. The concept of passive fit establishes that, in the absence of the application of an external load, the prosthesis should not cause stress.
on the implant components or the bone around them. This requirement may be satisfied by simultaneous contact of the inner surfaces of all of the retainers with all of the abutments.\textsuperscript{14}

In this way, the ideal fit is a three-dimensional concept by nature, and its sophisticated evaluation methods\textsuperscript{13} are not readily available. The present study did not evaluate the fit three-dimensionally and seems to present a lack of consistency. Notwithstanding, when implants are placed parallel to each other, as was done in the present study, vertical misfit has been shown to create the highest levels of stress.\textsuperscript{11,15} In this way, clinicians should pay special attention to this type of ill-fitting and work to minimize it. Therefore, the present study prioritized the linear evaluation of vertical misfit, as described by others.\textsuperscript{5,16,17} The use of more conventional measuring methods is still able to indicate if there is ill-fitting while recognizing the fact that this is not as precise as three-dimensional techniques.\textsuperscript{18}

Considering the methods and costs involved, the pilot study used one specimen per group. The data of this pilot study resulted in a sample size of five specimens per group for the main study, a number similar to other studies.\textsuperscript{3,19} The authors recognized that the first manipulation of the CAD/CAM system in the pilot study possibly resulted in specimens with more pronounced misfit than the misfits observed in the main study. In this way, the ideal sample size possibly should be underestimated, and other studies with a great number of specimens are necessary to confirm the present results.

Good passive fit of implant-supported prostheses, achieved primarily by the absence of vertical alignment grooves and stress when applying torque to the abutments, is one of the parameters that supposedly can determine the longevity of a prosthetic rehabilitation. Mechanical and biologic failures related to the misfit of prosthetic structures can often be perceived by the dentist as fractures of the prosthetic components and/or screws, pain, marginal bone loss, and osseointegration failure.\textsuperscript{3,20}

The clinical implications of vertical misfit were demonstrated by Assunç\~ao et al.,\textsuperscript{21} who observed that the type of vertical misfit in implant-supported prostheses also influenced the stress generated on the implants and surrounding bone tissue and triggered distinct biomechanical reactions. Unilateral angular misfits are more harmful to the body of the implant and the retention screw; unilateral vertical misfits cause more stress on the prosthetic framework, whereas total vertical misfits cause stress on the implant hexagons.

Therefore, the type of misfit should be identified at the study site to predict what type of failure will occur in a given prosthetic framework. In this context, the importance of evaluating vertical misfits is justified because these misfits prevent the control of biofilms in the region and generate harmful stress on the prosthesis/implant/bone system.

Brånenmark\textsuperscript{22} reported that prosthesis frameworks are considered passively fit when the distance between the framework and abutment is equal to or less than 10 µm. Hecker and Eckert\textsuperscript{18} and Hecker et al.\textsuperscript{23} demonstrated better fit between the prosthodontic frameworks and the implant-supported abutment after simulated functional loading of the anterior portion of the prosthesis. At that time, those authors demonstrated more realistic misfit values of prosthetic frameworks, fabricated using gold cylinders and conventional casting techniques, ranging from 30 to 50 µm.

The results of this study revealed misalignment values of 6.011 ± 0.750 µm for titanium frameworks and 9.055 ± 3.692 µm for zirconia frameworks. Therefore, the tested groups were within the range considered optimal (Table 1). The present results, obtained with CAD/CAM for the production of prosthetic frameworks, overcame the best indexes obtained previously using lost-wax casting systems with noble metal alloys.\textsuperscript{6}

Previous studies, such as Jemt et al.\textsuperscript{12} reported the production of implant frameworks using computer-aided methods, which at the time were experimental. Their results indicated a degree of high vertical misfit but no significant differences in misfit between implant frameworks developed with computer-aided and lost-wax casting methods. However, Takahashi and Gunne\textsuperscript{24} observed that the production of prosthetic frameworks using CAD/CAM systems was significantly better at all points measured in comparison with the lost-wax casting method, even using gold alloy.

Improvements have been observed in computer-aided methods for the production of implant frameworks because in the studies of Katsoulis et al.\textsuperscript{2} and de França et al.\textsuperscript{19} as well as in the present study, the degree of vertical misfit has been decreasing (14 µm, 1.2 µm, and 6.4 µm, respectively) compared with experimental methods such as the method of Jemt et al (37 µm)\textsuperscript{12} or Takahashi and Gunne (25 µm).\textsuperscript{24} This finding justifies the constant search for improved methods to obtain smaller vertical misfits. The vertical misfit values found in this study were similar to the values observed by de França et al.,\textsuperscript{19} who found lower values when using the CAD/CAM system to manufacture prosthetic frameworks of cobalt-chromium (1.2 ± 2.2 µm) and zirconia (5.9 ± 3.6 µm).

CAD/CAM systems have become a reality in the daily practice of dental surgeons, and touch and laser scanners facilitate the fabrication of highly accurate screwed structures in implant-supported prosthetic rehabilitation. The results of this study confirm that current CAD/CAM systems yield lower vertical misfit values than conventional lost-wax casting methods, as reported by Jemt et al.,\textsuperscript{12} Ortop et al.,\textsuperscript{25} and Takahashi and Gunne.\textsuperscript{24}
Previous studies compared CAD/CAM-based techniques involving different materials, including the studies of Katsoulis et al.⁵ and de França et al.,¹⁹ and demonstrated that titanium frameworks had more consistent precision and lower degrees of misfit than zirconia frameworks, although the differences between the groups were not significant. These results are similar to the results obtained in this study, where-in the misfit values of the titanium frameworks were lower (6.011 μm) than the values of the zirconia frameworks (9.055 μm). Moreover, a higher SD was found for the zirconia specimens (3.692 μm) compared with the titanium specimens (0.750 μm), indicating the presence of lower variability in the titanium specimens.

The present study found low vertical misfit values for zirconia frameworks, which present excellent biocompatibility, low bacterial adhesion, favorable chemical properties, high flexural strength, and better esthetics, and thus are suitable for the production of all-ceramic complete restorations with satisfactory results.¹⁹ Zirconia frameworks also exhibit high toughness and high flexural strength, and their surface is favorable for the application of porcelain veneers in the esthetic characterization phase of a rehabilitation treatment.⁵ This characteristic may be beneficial compared with the direct application of porcelain on frameworks made of titanium alloy. However, dimensional changes related to the sintering of zirconia should always be well controlled to minimize misfit resulting from the sintering process.¹⁹

During the sintering process, the zirconia structure contracts; therefore, the structure was designed to be approximately 20% to 25% larger to compensate for this expected contraction.²⁶ The dimensional variations that occur during the manufacturing of zirconia frameworks did not affect the results of this study. The overall mean of this group (9.055 ± 3.692 μm) showed excellent fit (Fig 3). The differences between the means and SDs found in this study can be explained by the occurrence of failures in specific regions during the milling process (Fig 4). During framework production, the zirconia blocks are milled with low pressure and low heat to avoid the development of microfractures and cracks at the edges of the interfaces.²⁷ However, at certain sites, it was observed that these small failures were not eliminated despite the high accuracy of the technique. The concept of interfacial abrasive wear, demonstrated by Hecker and Eckert,¹⁷ also deserves to be tested between zirconia frameworks and titanium abutments.

Even though titanium grade 5 (ASTM) (Ti6Al4V) prostheses have lower variability indexes (Fig 2), the analysis of some images (Fig 5) demonstrated the presence of irregularities in the milled surfaces associated with minor fit failures, which may indicate some degree of variation in the quality of the final finishing of titanium frameworks. The overall mean of this group (6.011 ± 0.750 μm) also showed excellent fit (Fig 6).
CONCLUSIONS

According to the method applied in this study, there was no significant difference in vertical misfit between titanium and zirconia frameworks produced using the CAD/CAM system, and SEM analysis revealed occasional failures in the milling process for the production of zirconia. The CAD/CAM frameworks achieved an adequate vertical fit, regardless of the material used.

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REFERENCES