Zirconium Oxide Three-Unit Fixed Partial Denture Frameworks Supported by Dental Implants in Acceptable and Reduced Interocclusal Space Possibilities: Pilot In Vitro Fracture Strength and Fractographic Analyses

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Purpose: *This study investigated the effect of fracture strength and fracture mode characteristics related to reduced interocclusal space on computer-aided design/computer-aided manufacturing (CAD/CAM).* ZrO_2 *fixed partial denture (FPD) frameworks subjected to quasi-static loads.* ***Materials and Methods:*** *First, two dental implants (4 × 10 mm) were positioned simulating a three-unit FPD (second premolar and second molar abutments). The implants were distributed into two groups: control group (n = 10), positioned at the same level; and the test group (n = 10), where the interocclusal space corresponding to the second molar was reduced by 3 mm in relation to the second premolar to simulate a clinical situation. After FPD wax-up (25-mm long; connector height = 5 mm; connector width = 3 mm, proximal and lingual collar reinforcement), casting was made in a Co-Cr alloy to serve as a prototype. Upon scanning, screw-retained CAD/CAM* ZrO_2 *FPDs were fabricated for each group. Then, FPDs were subjected to quasi-static axial loading until fracture in the mid-occlusal pontic area using a universal testing machine at the crosshead speed of 0.5 mm/min. Next, the samples were analyzed by scanning electronic microscopy (SEM) to describe the fracture characteristics.* ***Results:*** *The mean fracture strength values for the control group (1,747.4 ± 122.3 N) and test group (1,817.7 ± 158.9 N) showed no significant difference (Student t test,* $P < .124$*). The SEM images of the fracture sites revealed two cleavage areas in the test group, providing representative sites with increased fracture energy storage in this group compared with the control group.* ***Conclusion:*** *Within the limitations of this study, the results showed that reduced interocclusal space and reduced length did not decrease the fracture strength of the* ZrO_2 *FPD frameworks.* Int J Oral Maxillofac Implants 2019;34:337–342. doi: 10.11607/jomi.7009

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In implant dentistry, most prosthetic parts (screws, abutments) are made of metallic components/alloys, and, depending on implant location, inclination, and mucosal thickness, this can lead to esthetic complications. For example, gray gingival discoloration is a common clinical finding attributed to a thin peri-implant gingival tissue reflecting light from the metallic abutment surface.[1] Even when the metallic parts are positioned at the submucosal level, a dull gray background may give the soft tissue an unnatural bluish appearance. Thus, metal-free restorations can be a tool providing a more favorable esthetic outcome.[2,3]

On the other hand, mechanical complications are present in dental implant rehabilitations, including framework/abutment screw fracture or loosening.[4,5] Metallic materials present different properties than

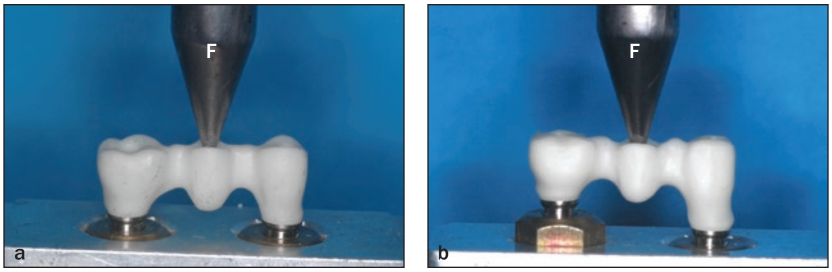

Fig 1 Images of the three-unit CAD/CAM monolithic zirconium oxide FPD positioned in the universal testing machine for load application at the central fossa of the pontic. *(a)* Control group. *(b)* Test group.

ceramics. However, short-term clinical data suggest that zirconium oxide fixed partial dentures (FPDs) may serve as an alternative to posterior dentition restorations.[6] Nevertheless, laboratory tests are fundamental in such adverse biomechanical scenarios before definitive clinical recommendations can be made.[7]

For unilateral or bilateral partially edentulous patients (Kennedy's Class I or II) and long-term wearers of removable partial dentures (RPDs), variations on the vertical dental implant levels are possible due to bone resorption and anatomical factors,[8] with migration of the antagonist teeth (overeruption) in this area reducing the interocclusal space and, consequently, demanding shorter clinical crowns over these implants.[9,10] Nevertheless, this has not prevented many patients from being treated with porcelain-fused-to-metal designs, demonstrating low failure rates for the veneering esthetic materials.[11]

In addition, before definitive recommendations are made over new therapies, laboratory investigations must provide a solid foundation for clinical decisions. Traditionally, strength tests and fractographic analysis, a technique that can determine the cause of failure in structures and materials and can give quantitative and qualitative information about failures,[12] have been on the scope of metals and ceramics.

The aim of the present study was to analyze the behavior of a zirconium oxide framework regarding its resistance and fracture characteristics in a simulated condition with a reduced interocclusal space for oral rehabilitation.

The null hypothesis was to test that there are no differences in the fracture strength of a three-unit FPD supported by two implants in cases of "acceptable" and "reduced" interocclusal spaces.

MATERIALS AND METHODS

Sample Prototype Preparation

Two models with two titanium dental implants with an external hexagonal connection (4 mm in diameter and 10 mm in length, Implacil De Bortoli) were positioned in a stainless-steel adjustable matrix at a distance of 18 mm between its centers, simulating an area for an FPD (second premolar and second molar as abutments, with a pontic representing the first molar). In the control group (n = 10), the implants were positioned at the same level and the average length of a natural crown described in the literature for this area (8.5 mm),[13] which was used as reference to design the zirconium oxide framework. In the test group (n = 10), the interocclusal space corresponding to the second molar was reduced by 3 mm in relation to the other elements of the ZrO_2 framework (Fig 1). Then, corresponding prosthetic cylinders were attached, and a full wax-up crown contour was obtained. Silicone indexes were prepared in the buccal and lingual aspects. The waxed-up teeth were reduced to an FPD (connector height of 5 mm, width of 3 mm, and total length of 25 mm). After investing and casting in a Co-Cr alloy according to the manufacturer's instructions, these Co-Cr frameworks were used as a prototype for scanning and fabrication of the computer-aided design/computer-aided manufacturing (CAD/CAM) ZrO_2 FPDs.

CAD/CAM Zirconium Oxide Restoration Fabrication

New silicone indexes were obtained for the buccal and lingual aspects of the metallic fixed dental prosthesis. Then, new prefabricated prosthetic cylinders were attached, and a full contour was developed at the laboratory using a pattern resin (GC America). A full crown contour was scanned at the laboratory, and the virtual STL files were obtained for possible modifications. Then, a 4% to 6% yttrium-doped zirconia blank with flexural strength between 1,000 and 1,200 MPa (Zirconia Prettau, Zirkonzahn) was selected, and the restoration was milled according to the manufacturer's instructions. The definitive version was positioned, screwed in, and torqued to 20 Ncm on the correspondent matrix.

Fracture Strength Tests

All groups were subjected to quasi-static loading until fracture, using a properly calibrated universal testing machine (model AME-5kN, Técnica Industrial Oswaldo Filizola Ltda). Tests were conducted at the Laboratory of Biomechanics (Biotecnos). In both groups, the 5kN load (crosshead speed rate of 0.5 mm/min)

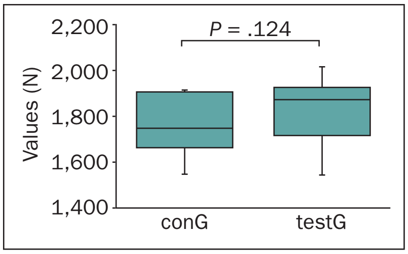

Fig 2 Box plot of the values measured in the quasi-static test. The statistical analysis showed no difference between the groups. conG = control group; testG = test group.

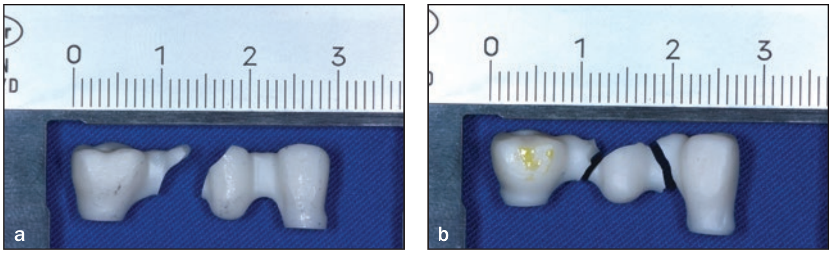

Fig 3 Representative fractured samples. *(a)* Control group. *(b)* Test group.

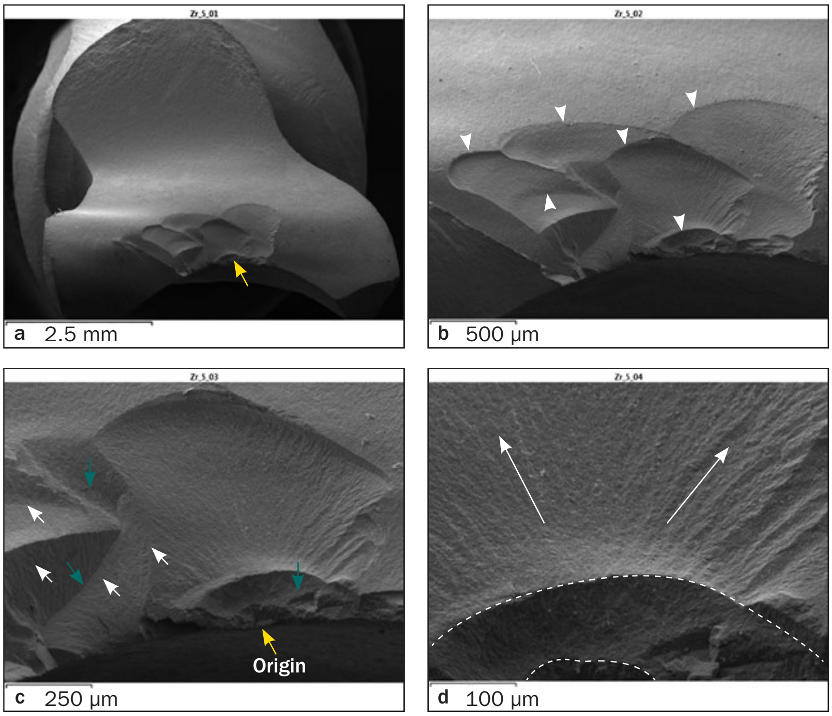

Fig 4 SEM fracture images in a control group sample. *(a)* Entire fracture surface. The yellow arrow shows the origin of the fracture. *(b)* Detailed view of arrest and hacker lines associated with stress cycles indicated by white arrow heads. *(c)* Several secondary cracks occurred during the fracture propagation indicated by the green arrows. Notice that, in this case, crack propagation is first downward and then upward *(white arrows)*. *(d)* Detail showing arrest lines *(dashed lines)* and fatigue striations relative to fracture propagation. The arrest line is the intersection between the rapid and the slow crack growth regions. Note that the rough surface aspect indicates brittle failure.

was applied at the center of the occlusal fossa (midportion) of the pontic (Fig 1). Strength values were recorded in Newtons (N).

Fractographic Analysis

All 20 samples from both groups were inspected under SEM (Philips XL30, Philips) using different magnifications. Also, the morphologic and fractographic characteristics were described.[14] The fractured portions were examined in the plane where separation/fracture occurred.

Statistical Analysis

Normality and equal variance tests were applied to determine homoscedasticity and verify the need of parametric or nonparametric tests to compare the mean strength values between groups. The statistical analyses were performed using the SPSS 21.0 package (SPSS). Statistical significance was set at alpha = .05.

RESULTS

All groups passed on normality (Shapiro-Wilk, $P = .344$) and equal variance (Brown-Forsythe, $P = .634$) tests. Mean and SD values for the control and test groups were 1,747.4 ± 122.3 N and 1,817.7 ± 158.9 N, respectively. The Student *t* test did not identify significant differences ($P = .124$). The box plots with the data distribution and the statistical analysis are presented in Fig 2. All samples of the control group showed oblique fractures in one location corresponding to the distal region. On the other hand, samples in the test group showed oblique fractures in both connectors (mesial and distal regions). Figure 3 shows the separation characteristics for both groups after fracture. The SEM analysis revealed common fractographic ceramic patterns in the control group samples (Fig 4). However, different cleavage patterns (inverted V-shape) were only seen in pontics of the test group samples (Fig 5),

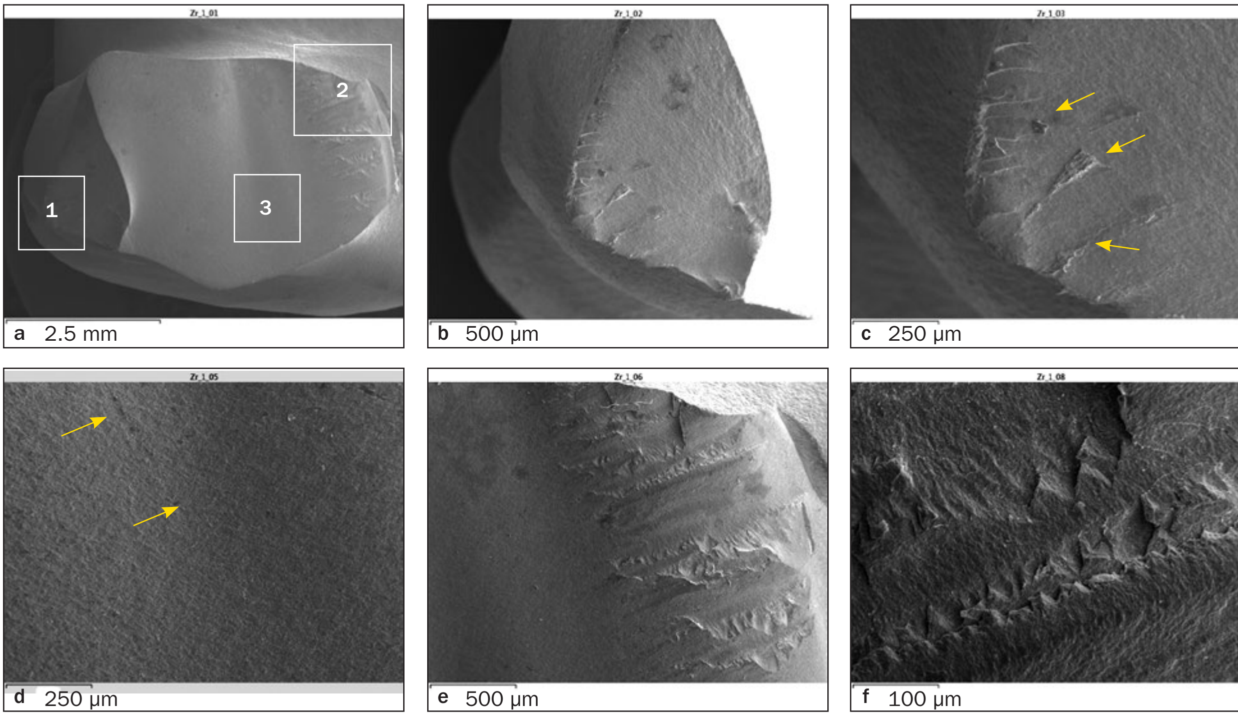

Fig 5 SEM fracture images in a test group sample. *(a)* Typically brittle fractured surface broken by bending. *(b, c)* Detail in greater magnification of twist hackle on the surface of zone 1. The yellow arrows show fragmentation typical of excessive stored elastic energy during fracture. *(d)* Detail view of zone 3 in greater magnification. Notice that the yellow arrows show a transversal crack at the center of the sample. *(e, f)* Detail in greater magnification of zone 2 showing a jagged twist hackle.

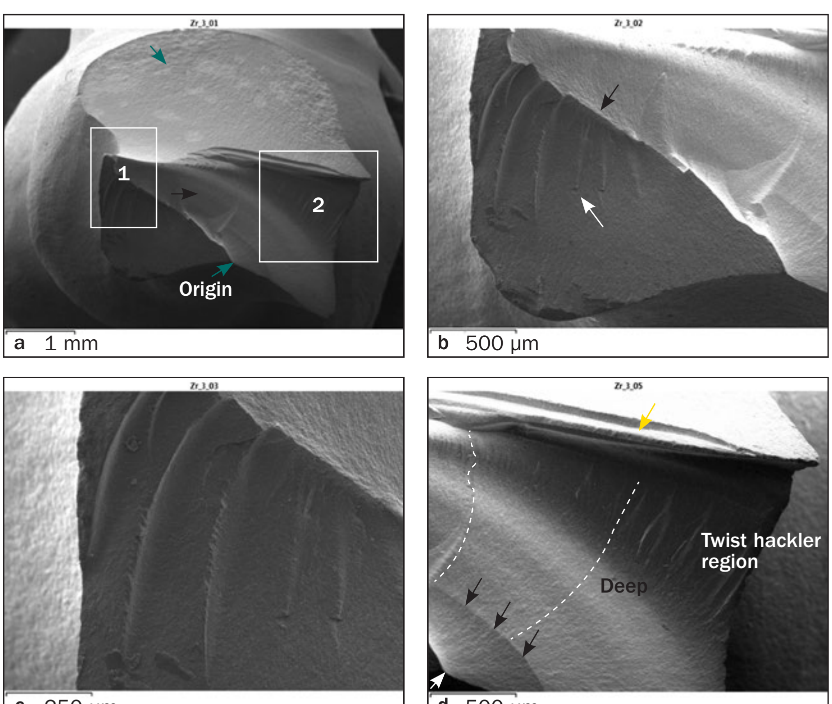

Fig 6 SEM image of typical helical fracture surface in a test group sample. *(a)* The green arrows indicate ceramic microstructure defects, and the black arrow shows the twist hackle associated with the variation in fracture propagation speed. *(b)* The short white arrow shows the origin of fracture, and the black arrow indicates a well-defined arrest line. Detail of zone 1, showing the steps in the arrest line *(black arrow)* and the twist hackle toward fracture propagation. *(c)* Detail in greater magnification of twist hackle on the surface of zone 1. *(d)* Detail of zone 2, where the dashed lines show fracture direction. Notice that, in this case, crack propagation is first downward, then upward, ending in a big rise. The yellow arrow shows the crack region.

with areas suggesting increased elastic energy storage (Fig 6).

DISCUSSION

The null hypothesis of this study was accepted. This in vitro study measured the fracture strength of zirconium oxide frameworks and analyzed their fractographic characteristics. Added to the problematic migration of the opposing teeth, Kennedy's Class I or II patients who have been long-term removable denture wearers can also present with varied alveolar ridge heights. Therefore, two situations were simulated with different interocclusal spaces (normal or reduced) in a ZrO_2 three-unit FPD for the posterior teeth.

Monolithic zirconia restorations have been recommended due to their improved strength and low wear rate,[15] but a simple different vertical implant positioning probably changed the biomechanical behavior (more elastic energy stored) of this material, as shown in the SEM images (Figs 4 to 6). However, there are limitations in this study, beginning with the quasi-static loading procedure, but it is necessary to produce starting load parameters to follow in a dynamic fatigue test. Although the mean fracture strength values found in this study were high, in the simulated oral clinical scenario, zirconia could not be the best material of choice. Only one ceramic material was manufactured using CAD/CAM technology. All cores were fabricated to the same shape and size for the purposes of standardization. All supporting structures were manufactured using a CNC milling machine for the same reason. Also, veneering material was not applied to the zirconia cores to eliminate co-factors because the use of veneering material could cause delamination and thus affect the aim of the investigation. Although not the purpose of this study, a metallic framework under the same conditions would generate higher fracture strength values since their mechanical properties are different from zirconium oxide.

In past years, there has been a shift proposal from metallic to all-ceramic prostheses, partially because of their improved strength and bio-inertness, but mainly due to their esthetic appeal.[1,2] Zirconium oxide ceramics are high-strength materials.[16,17] Also, they provide toughening mechanisms, which include crack deflection, zone shielding, contact shielding, and crack bridging.[17] This is crucial in high fatigue circumstances, such as those encountered during mastication and/or parafunction.[18] However, ceramics are brittle and susceptible to fatigue fracture in repetitive functions. The cracks tend to follow paths of highest tensile stresses. A ceramic prosthesis may fracture abruptly due to a single intense overload or cumulatively after an extended period of superficially innocuous but lower-load biting events.[14] This has been seen in standardized controlled conditions in the laboratory, but it is still difficult to predict long-term results in clinical cases such as the one simulated in this study.

Fracture strength is one of the most important criteria for the long-term success of dental restorations.[19] It is obvious, from the different studies on the fracture strength of all-ceramic systems, that the reported values are highly variable.[20–23] Fracture strength depends on the modulus of elasticity of the supporting substructure, luting agent, tooth preparation design, surface roughness, residual stress, and restoration thickness.[22,24–26] In a bench test, the present fracture strength results indicated that no difference exists between normal and reduced vertical spaces when zirconium oxide is milled using CAD/CAM process frameworks.

Several in vitro studies demonstrated that most of the loads applied to dental implants and dissipated in bone tissue are placed onto the bone crest.[27–29] The elastic modulus of the abutment material is a significant factor in determining fracture strength. Metal dies are very rigid and have a higher elastic modulus than that of dentin, so dies deform less, resulting in lower shear stress on the inner crown surface.[30] A previous finite element analysis study showed a more widespread stress distribution of zirconia frames on dentin dies than on brass and steel dies.[30] Therefore, the energy accumulation observed in test group samples in the present study should be considered and analyzed in order to verify where the tension will be released.

Finally, new clinical studies (eg, split-mouth design with two different materials) on the load distribution over dental implants inserted under these same conditions should be designed to check if there is any increase in the stress concentration. In addition, clinical studies should be performed to assess the behavior of bone tissue around implants receiving FPDs with implants positioned at different vertical levels, as the sign of excessive stress on a dental implant means bone loss around the implant crest.

CONCLUSIONS

Despite the limitations of this study, the results showed that reduced interocclusal space, resulting in a short crown, does not decrease the mechanical resistance of the FPD framework. However, the fractographic analysis showed that the short crown, due to the reduced interocclusal space, can generate more energy accumulation.

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The authors declare no conflicts of interest.

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