A Pilot Study of Joint Stability at the Zirconium or Titanium Abutment/Titanium Implant Interface

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Purpose: *To compare the interfaces of loaded and unloaded zirconium and titanium abutments with titanium implants using scanning electron microscopy (SEM).* ***Materials and Methods:*** *Zirconium and titanium abutments (n = 5 per group; four test and one control) were torque-tightened into titanium implants secured into metal blocks, and computer-aided design/computer-assisted manufacture–based zirconium oxide copings were fabricated and cemented to the abutments with temporary resin-based cement. Specimens of each restoration were subjected to cyclic axial and lateral loading of 30 N at 2 Hz for 500,000 cycles using a servohydraulic test system; control specimens were left unloaded. Then, the abutment/implant assemblies were embedded in acrylic resin, sectioned longitudinally along the midline, and inspected under SEM with x-ray microanalysis.* ***Results:*** *Loosening or fracture of the copings and implant components was not observed after dynamic loading in both groups. SEM and x-ray microanalysis revealed unexpected microleakage of acrylic resin at the interface. Acrylic resin in the implants tightened to the titanium abutments was limited to the cervical part, and the components displayed scratched and smashed regions, suggesting slight deformation of the implant neck. Microleakage and pooling of acrylic resin were observed approaching the screw joint in loaded implants tightened to zirconia abutments, and the amount of microleakage was greater than in the unloaded control specimens, which had a larger microgap than the titanium abutment/titanium implant interface. Loaded zirconia abutments were associated with wear, scratches, and, in one sample, chipping.* ***Conclusions:*** *Zirconium abutment/titanium implant interface may be susceptible to wear of the abutment coupled with deformation of the implant neck greater than that associated with the conventional titanium abutment/titanium implant interface under dynamic loading.* Int J Oral Maxillofac Implants 2014;29:338–343. doi: 10.11607/jomi.3116

Key words: *abutment, dynamic loading, implant-abutment interface, dynamic loading, scanning electron microscopy, titanium, zirconia*

Since the introduction of ceramic implant abutments, many advances have been made to solve mechanical failures associated with the use of early alumina ceramic–based abutments.[1–3] Because the use of ceramic abutments is a prerequisite for patients with a thin gingival biotype in the esthetic region, high-strength yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) is currently being used.[4,5] The most prominent advantage of Y-TZP is transformation of tetragonal grains into monoclinic grains at room temperature to inhibit crack propagation, which in turn substantially increases its Young's modulus (215 GPa) (so that it is comparable to that of stainless steel), flexural strength, and consequently, fracture toughness so that it exceeds the limits of human bite force.[6–9] Nevertheless, zirconia abutments may still suffer fractures because the material cannot be used in thin sections.[9] In addition, the increased marginal gap between zirconia abutments in comparison to conventional titanium abutments[10] and over-tightening of abutment screws leading to wedging forces and high Hoop stresses in

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the internal part of the abutments could induce crack propagation and fracture.[11] A reasonable way to increase the mechanical strength of zirconia abutments, particularly under static bending forces, might be to amend the design of the abutment.[12,13] However, zirconia abutments are more prone to wear than titanium abutments,[14] and the impact of design changes on fatigue-induced failure remains unexplored.[15]

Because the Young's modulus of zirconia is greater than that of titanium[8,16] and the machining tolerance at the zirconium abutment–titanium implant interface is lower than that of a titanium abutment–titanium implant interface, it might be hypothesized that zirconia abutments, while experiencing greater wear than titanium abutments,[15] could also contribute to deformation of the implant neck under cyclic loading. Therefore, the purpose of this study was to explore possible signs of implant deformation and wear at the interface between titanium implants and zirconia and titanium abutments using scanning electron microscopy (SEM).

MATERIALS AND METHODS

Two bone-level Regular Crossfit (RC) (4.1 × 12-mm) titanium implants (021:4112, Institut Straumann) were secured into a geometric ridge, 7 mm high and 6.5 mm wide, prepared in a machined block (50 × 50 × 60 mm) of type IV aluminum (EN-AW-AlMg1SiCu) after stepwise preparation of sockets using 2.2- and 2.8-mm pilot drills and a 3.5-mm twist drill followed by a 4.1-mm tapping drill with ratchet. The purpose of rigid mounting of implants was to ensure that any possible loosening occurred only at the implant-abutment interface.[17] A total of five models (four for testing and one for a control) were prepared of each abutment. Straumann RC Anatomic IPS e.max abutments (022.4812, Institut Straumann) and Straumann RC Anatomic titanium abutments (022.4102, Institut Straumann) were torque-tightened to the implants using a ratchet (046:119, Institut Straumann) at 35 Ncm in each model. Computer-aided design/computer-assisted manufacture–based zirconium oxide copings (40/19 inCorisZr, Sirona Dental Systems) were fabricated using an inEOS scanner, inLab 3D software, and an inLab MC XL milling machine (Sirona Dental Systems) on each implant abutment. The copings were designed buccolingually along the nonanatomic metallic ridge as the abutments were secured. The thickness of the material was approximately 1 mm, 1.25 mm, and 1.5 mm at the cervical, middle, and occlusal, respectively. The flat occlusal surface was heightened by 1.25 mm on the buccal half to simulate lateral axial loading from the implant axis. The copings were secured with

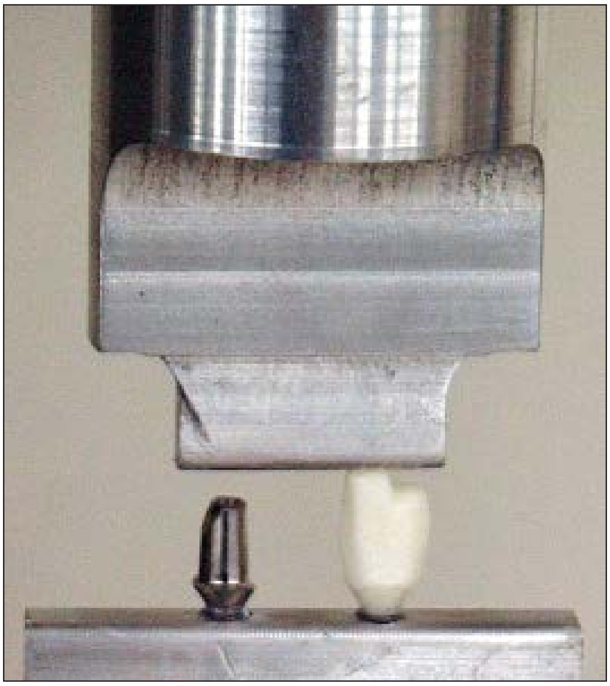

Fig 1 The zirconia and titanium abutments after being torque-tightened to titanium implants in the metal block. A custom-made loading jig was fabricated to apply dynamic loads to the implants. Note the zirconium coping on the zirconium abutment.

resin-based temporary cement (TempBond Clear, Kerr Sybron Dental Specialities).

Specimens of each restoration complex were subjected to cyclic axial and lateral loading of 30 N at 2 Hz for 500,000 cycles using a Servohydraulic Test System (MTS Landmark, MTS Testing Solutions) in a dry environment (Fig 1). After loading, the copings were removed by hand and each abutment was indexed to its counterpart implant with a thin stick of graphite. After the abutments were removed with the ratchet (Institut Straumann), the implants were removed from the metal blocks using the explantation device for bone-level RC implants (026.4048, Institut Straumann). Half the length of each implant was embedded apically into an autopolymerizing polymethyl methacrylate acrylic resin. Then, the abutments were placed onto the implants according to the graphite index and torque-tightened to 35 Ncm using the ratchet (Institut Straumann). The implant-abutment complex was embedded in an autopolymerized methylmethacrylate resin (Orthoacryl 2000, Dentaurum) and sectioned longitudinally along the midline using a precision saw (Isomet 4000, Buehler) resulting in two sections, each comprising half an implant-abutment complex (Fig 2). The sectioned abutments were removed from the implants for evaluation of the mating surfaces. Thus, two surfaces of each abutment and implant were obtained from one test sample.

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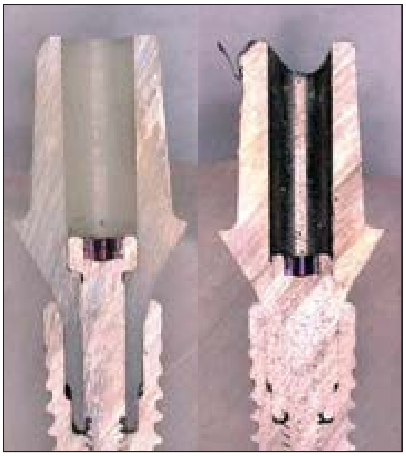

Fig 2 Longitudinally sectioned zirconium abutment/titanium implant and titanium abutment/titanium implant complexes.

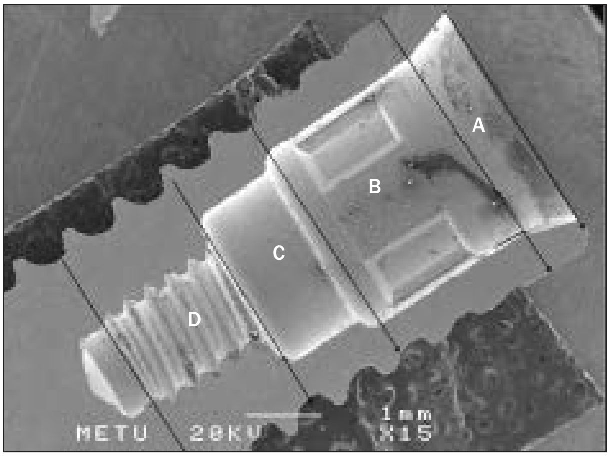

Fig 3 SEM assessments were performed at region A (cervical), region B (upper middle), region C (lower middle), and region D (apical) portions of each complex (original magnification ×15).

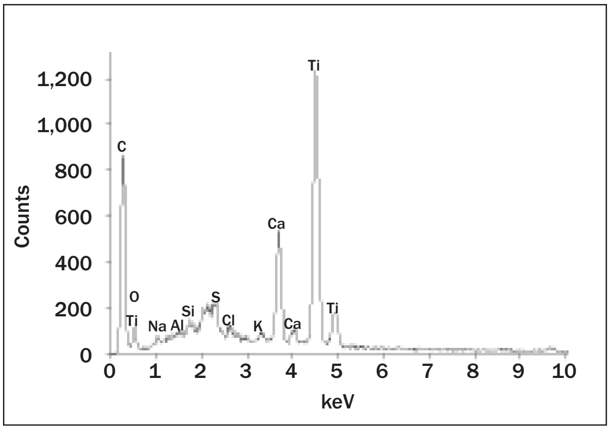

Fig 4 X-ray microanalysis of the substances observed at the interface. The analysis revealed microleakage of acrylic resin through the interface.

Table 1 Presence (+) and Absence (–) of Acrylic Resin at the Interface of Loaded and Unloaded Zirconia and Titanium Abutments with the Titanium Implant

	Titanium-titanium interface		Zirconium-titanium interface	
Region	Abutment	Implant	Abutment	Implant
Loaded specimens				
A	–	+	–	+
B	–	–	–	+
C	–	–	–	+
D	–	–	–	+
Unloaded specimens				
A	–	–	–	+
B	–	–	–	+
C	–	–	–	+
D	–	–	–	+

Each pair of surfaces (the abutment and implant) was inspected under an SEM (JSM-6400 Electron Microscope, JEOL Ltd) equipped with an x-ray microanalysis system and semaphore digitizer (NORAN System SIX, Thermo Electron Scientific Instruments) to explore signs of wear, fracture, and clarity. Each surface was inspected at four regions: region A = cervical; region B = upper middle; region C = lower middle; region D = apical) (Fig 3).

RESULTS

During mechanical loading, no loosening of the abutments or fracture of the copings, abutments, or implants were observed in any of the specimens. One important finding observed at the very beginning of the SEM analysis was that the interface of both types of abutments was unexpectedly filled to a certain extent with the autopolymerizing acrylic resin, as detected by x-ray microanalysis (Fig 4). The level (from regions A to D) to which microleakage of the resin extended was therefore used to categorize the joint stability. The presence of this unexpected acrylic resin compared to the unloaded control specimen suggested that the interface of the titanium abutment/titanium implant interface was slightly deformed by dynamic loading (Table 1) (Figs 5a and 5b). The titanium abutments and implants were associated with small regions of scratching and crushing, respectively, after dynamic loading, confirming that the interface deformation at region A was minimal. In contrast, the zirconia abutment/titanium implant interface was dramatically affected after dynamic loading. Microleakage of acrylic resin was ob-

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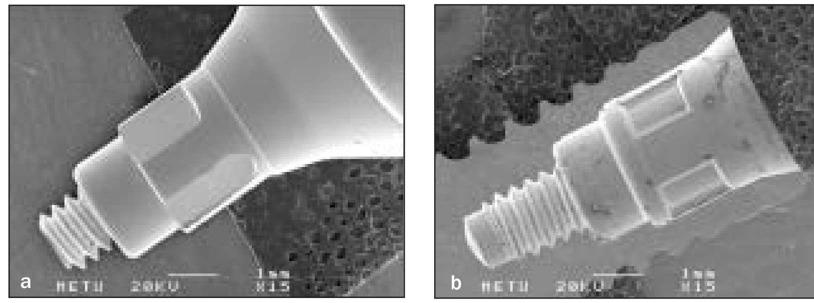

Fig 5 SEM images of *(a)* the titanium abutment and *(b)* implant (original magnification ×15). Note the presence of acrylic resin, particularly in region A.

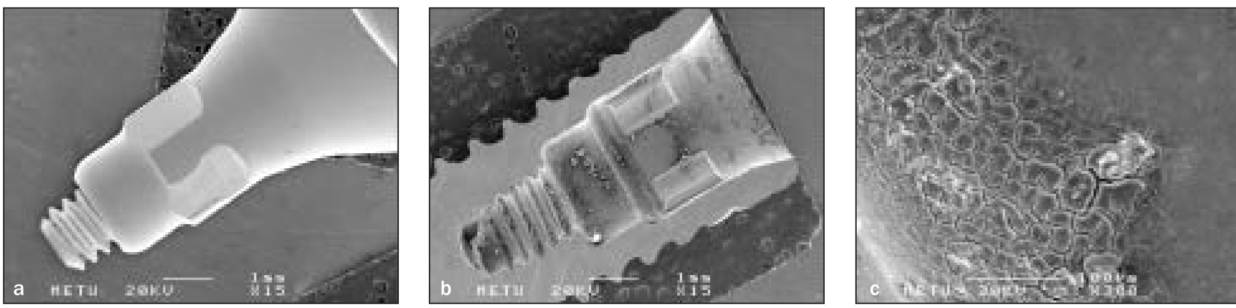

Fig 6 SEM images (×15) of the *(a)* zirconia abutment and *(b)* its titanium implant counterpart. *(c)* Excessive amounts of microleakage and pooling are apparent around the loaded implant (×300).

served from regions A to D in the loaded specimens, and the amount of microleakage and pooling of the acrylic resin was much greater than that observed in the unloaded control specimens (Table 1) (Fig 6). Owing to the fact that microleakage of the resin was also observed from regions A to D in the unloaded zirconia abutment/titanium implant interface, it was concluded that the machining tolerance of these components was already lower than that of the titanium abutment/titanium implant group. Loaded zirconia abutments were frequently associated with many regions of wear, scratches, and, in one sample, chipping (Fig 7).

DISCUSSION

Except for a few dental implant systems, eg, Bicon dental implants (Bicon), it appears to be impossible to eliminate the retaining screw mechanism, which joins the two dental implant components to each other. In the context of zirconia abutments, the screw joint interface as well as the size of the microgap could affect the mechanical fate of the loaded interface. A study on the effectiveness of unloaded zirconia abutments with or without platform switching showed that the abutment material and design influence the static bending fracture toughness, although the maximum forces achieved were lower than those of the titanium abutment/implant group.[12] In the present study, the zirconia and titanium abutments used had a platform-switched two-piece design with an internal cone interface, which is generally agreed to have greater stability.[18–20] In truth, a two-piece internal-cone zirconia abutment with an internal notched surface reduces the total interface contact area in comparison to one-piece conventional titanium abutments[21] (eg, a standard solid abutment with its retaining screw component as an apical extension of the cone part of the abutment itself) and does not ensure cold welding to achieve mechanical joint stability approaching that of one-piece designs.[22] In addition, a two-piece zirconia abutment with an internal antirotational design[12] and/or associated with a large preexisting microgap at the zirconia abutment/titanium implant interface[10] has an inherently weak design, which will presumably lead to excessive wear of the abutment[14] and deformation of the implant neck, as observed in the present study. Several zirconia implant abutments provided by other manufacturers have metal inserts that potentially shield the zirconia/titanium interface. Although these were not studied herein, it should be taken into account that an interface between materials with very different Young's moduli could lead to microseparations and, consequently, mechanical failure.

In the present study, loosening or fracture of the copings and implant components was not observed. Leutert and colleagues[12] observed a striking number of fractures of the crowns and presumed that the crowns, not the zirconia abutment, were the weakest link. In the present study, the copings were fabricated

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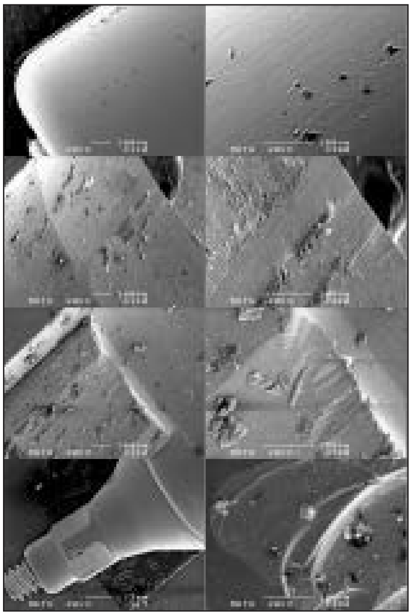

Fig 7 SEM images (original magnification: *left*, ×110; *right*: ×300) of the loaded zirconia abutments. Many regions were associated with scratches, wear, and even chipping in one incidence.

from zirconia, whereas glass-ceramic crowns, which have considerably lower fracture toughness, were used in the study by Leutert and colleagues.[12] A restorative material with a lower Young's modulus than zirconium might minimize catastrophic damage to the zirconia abutment/titanium implant interface to some extent, although the discrepancy in Young's modulus between the zirconia abutment and the titanium implant might lead to deformation of the implant neck under dynamic loading. Indeed, the built-in microgap, together with the discrepancy in Young's moduli between the abutment and implant materials, dramatically affected the specimens in the present study. Unlike the loaded titanium implants, which showed minimal signs of wear and deformation of the implant neck, the loaded zirconia implants were associated with excessive microleakage and pooling of acrylic resin beyond the screw joint. At the outset, microleakage of acrylic resin was not expected in the planning of the present study. It was identified through x-ray microanalyses after clusters of foreign material were seen at the interface. In addition, the zirconia abutments were associated with wear, scratches, and, in one case, fracture at the notched part, all of which could be attributed to poor seating of the interface under dynamic loading as well as dry test conditions, which might have affected the results. Indeed, testing in wet versus dry conditions can have an effect on the outcome of an experiment. In addition, the number of loading cycles (500,000) used in the present study is the lowest threshold for such mechanical experiments; more mechanical problems—probably frequent fractures of the zirconia abutment—would be observed with more cycles. Nguyen and colleagues[14] performed fatigue testing of different zirconia abutment systems on Replace Select and Brånemark implants with three different diameters up to failure and reported that the failure mode of zirconia abutments was particularly dependent on the diameter of abutment used. Of the 50 samples tested, 29 implant-abutment combinations failed and 18 fractured. The reason for the higher number of failures in the study of Nguyen and coworkers[14] versus the present study is that the number of fatigue cycles was much higher.

The findings obtained in the current study are in line with those of Klotz and colleagues,[15] who observed a wear area that was 8.3 times larger on zirconia abutments than on titanium abutments, especially during the first 250,000 loading cycles, and tended to reach a steady state toward 1,000,000 cycles. It was concluded that potential component loosening and subsequent fracture and/or release of particulate titanium debris might be of concern. In the present study, titanium debris was not found at the interface. However, the implant-abutment interface was not inspected in the assembled state, and titanium debris might have been swept away during dissembling of the components. SEM analysis also revealed circumferential machining lines around zirconia abutments that were more apparent than around titanium abutments. Zirconia abutments could benefit from better machining tolerance leading to an interface microgap comparable to that seen at the titanium abutment/titanium implant interface. The present results suggest that the larger microgap or poor seating of the zirconia abutments coupled with its high Young's modulus may have led to deformation of the implant body.

Another issue is the mechanical fate of the zirconium/titanium/zirconium alloy (TiZr1317) implant interface. Since narrow-diameter titanium implants are more prone to fracture, manufacturers have recently added to their strength with a novel titanium-zirconium alloy. The high-strength alloy consists of more than 99.6% Ti and zirconium, mainly in a monophasic α-structure, with up to 10% α/β permitted in the raw material.[23] Because the ultimate tensile strength of the alloy, according to ASTMF67 norms, is 50% higher than that of titanium, the potential use and mechanical fate of zirconia abutments on titanium-zirconium alloy implants needs to be investigated. Despite its relatively low Young's modulus in comparison to conventional titanium (100 versus 110 GPa), one could expect a higher resistance to bending of the implant neck because of the remarkably higher tensile strength of the new titanium-zirconium alloy.

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CONCLUSION

Differences in the materials of the implant-abutment complex (ie, titanium versus zirconia) may compromise the initial integrity of the interface and further weaken its mechanical stability under fatigue loading conditions. However, clinical studies reporting on mechanical/biologic outcome measures are needed to determine the importance of the discrepancies caused by different mechanical behavior at the implant-abutment interface.

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