RESEARCH AND EDUCATION

Mechanical behavior of zirconia and titanium abutments before and after cyclic load application

Sergio Alexandre Gehrke, DDS, PhD,[a] Pablo Mateus Poncio da Silva, MS,[b]
José Luiz Calvo Guirado, DDS, PhD,[c] Rafael Arcesio Delgado-Ruiz, DDS, PhD,[d]
Berenice Anina Dedavid, PhD,[e] Magda Aline Nagasawa, DDS,[f] and Jamil Awad Shibli, DDS, PhD[g]

Demand for esthetically ideal results from implant-supported restorations have increased significantly. Titanium abutments are commonly used to restore implants because of their excellent biocompatibility and mechanical properties.[1,2] However, the gray color of titanium may lead to esthetic problems.[2,3] In some situations, soft tissue height above the implant level may be insufficient at the time of definitive restoration or may occur after marginal periimplant bone loss and soft tissue recession. The resulting display of metal components could be unesthetic.[4]

Just as titanium, zirconia is a biocompatible material that promotes the health of the surrounding soft tissues.[5-7] Zirconia is radiopaque and clearly visible on radiographs. Its ivory color is similar to that of natural teeth.[8] This factor is particularly critical for the esthetic nature of implants, especially in patients with high lip lines, as it allows for light transmission at the critical interfaces between the marginal gingival tissue and the prosthetic components.[9,10]

Mechanically, zirconia exhibits good properties, such as flexural strength and fracture toughness.[11,12] In addition to these favorable properties, zirconia is believed to form less dental biofilm than does titanium.[5,13,14]

ABSTRACT

Statement of problem. Esthetic factors influence the decision to use titanium or zirconia abutments in anterior regions. Clinicians may have concerns about the durability and behavior of these zirconia abutments.

Purpose. The purpose of this in vitro study was to evaluate the longitudinal and transverse long axes of the implant-abutment interface before and after the cyclic loading of titanium and zirconia abutments with an external hexagon.

Material and methods. Forty dental implants with an external hexagon and 40 corresponding abutments made of titanium (Ti) and zirconia (Zr) were subjected to cyclic load (c1) versus no load (c2). The longitudinal and transverse axes of 4 experimental groups (Tic1, Tic2, Zrc1, and Zrc2) were analyzed (vertical/horizontal adjustment) using a scanning electron microscope at ×1000 magnification. The differences among the groups were determined by 1-way analysis of variance (ANOVA) and post hoc Tukey tests (α=.05). T tests were used to identify the statistically significant differences between each group and each condition (α=.05).

Results. Significant differences were found among the groups with respect to the misfits analyzed in the 2 sections (longitudinal and transverse) before and after load application (P<.05). The behaviors of the groups differed particularly with regard to the accommodation of sets (abutment/implant) after the application of cyclic loads (P<.05).

Conclusion. The use of zirconia abutments in titanium implants can cause changes to and/or permanent deformation of the implant hexagon. (J Prosthet Dent 2016;116:529-535)

[a]Researcher, Department of Research, Biotecnos Research Center, Santa Maria, Brazil.
[b]Graduate student, Department of Engineering, Industrial Technique College of the Federal University of Santa Maria, Santa Maria, Brazil.
[c]Full Professor, Department of Research, Faculty of Medicine and Dentistry San Antonio Catholic University of Murcia, Murcia, Spain.
[d]Associate Professor, Department of Prosthodontics and Digital Technology, Stony Brook University School of Dental Medicine, Stony Brook, New York.
[e]Full Professor, Department of Materials Engineering, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil.
[f]Graduate student, Department of Periodontology and Oral Implantology, Dental Research Division, University of Guarulhos, Guarulhos, Brazil.
[g]Titular Professor, Department of Periodontology and Oral Implantology, Dental Research Division, University of Guarulhos, Guarulhos, Brazil.

Clinical Implications

The use of zirconia abutments can cause damage to the implant hexagon because of the micromotions produced by mastication and the higher hardness of zirconia relative to titanium.

Furthermore, a short-term clinical study observed that the biologic, esthetic, and mechanical properties of zirconia are favorable and that this material can be used in various prosthetic indications on the teeth or in implants.[14]

The clinical consequences of poor fit between implants and prosthetic abutments has been reported extensively.[15-19] Discrepancies greater than 10 μm can have biologic effects (bacterial microfiltration)[15,16] and can produce inappropriate biomechanics (the loosening and rotation of screws),[17] which may lead to complete treatment failure.

Values of 10 μm or less do not seem to have consequences for hard or soft periimplant tissues.[19] The long-term success of implant-supported restorations is directly related to the precision of the fit of the prosthetic components with the material from which the prosthetic components are made.[19] This factor dictates the stability of the implant-abutment interface and the strength of the interface when subjected to the loads produced by mastication.[15,20] The micromotions between the pieces are always present in the application of the occlusal forces produced during clenching, mastication, and jiggling movements (intermittent forces in two different directions), which might originate wear and fracture.[21-23]

The use of zirconia abutments in the esthetic region has increased significantly during the past 10 years.[24] Therefore, different studies have been developed to compare zirconia abutments with conventional titanium abutments. These studies on the behaviors and wear of titanium implants with zirconia and titanium abutments have indicated greater wear at the implant interface after cyclic loading in implants connected to zirconia abutments.[25-29] Similarly, the present study evaluated and compared the mechanical behaviors of titanium and zirconia abutments under different loading conditions using metallographic sections in 2 directions (longitudinal and transverse long axes).

MATERIAL AND METHODS

Forty dental implants (4.1 mm in diameter, external hexagon; Conexão Implants) and 40 prefabricated prosthetic abutments with external hexagon for cement-retained implant-supported restorations were used in the present study (Fig. 1). Twenty abutments were made of titanium, and another 20 were made of tetragonal
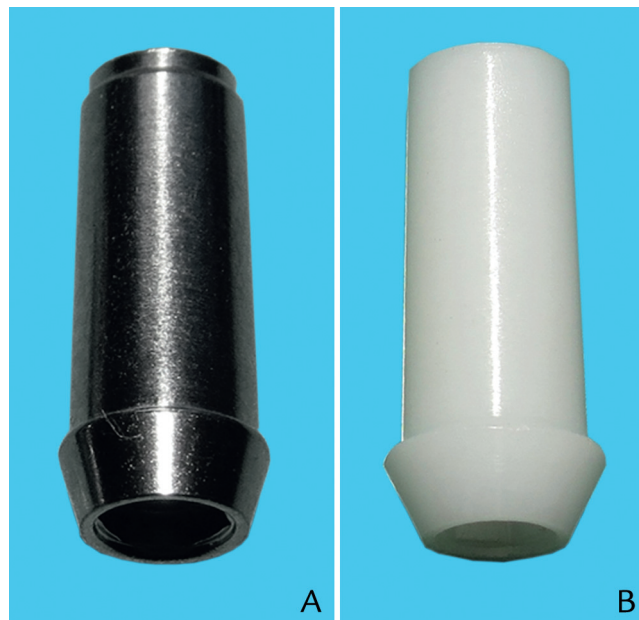

Figure 1. Images of abutments for external hexagon connection. A, Titanium. B, Zirconia.

zirconia polycrystal (Y-TZP). Two conditions were used in the test: the implants were (c2) or were not (c1) submitted to cyclic loads. Thus, the following experimental groups were examined: titanium (Ti) abutments (groups Tic1 and Tic2) and zirconia (Zr) abutments (groups Zrc1 and Zrc2).

The 40 specimens were exposed to 20 Ncm of torque on a computerized torque testing machine (CME 30 nm; Técnica Industrial Oswaldo) according to the manufacturer's instructions. To limit the effect of settling of the screws, which could reduce the preload, the components were retightened to their respective torque values 10 minutes after the initial torque.[30]

For cyclic load application, a cylindrical acrylic resin tube (20 mm in diameter) was used to prepare 20 blocks of 22 mm in height using an epoxy resin (GIV; Polipox) with a Young modulus similar to that of cortical bone. An appropriate drill sequence (recommended for the implant model) was used to insert the implant/abutment into the blocks. A semicircular metallic crown was cemented onto each set. The cyclic loading tests were performed following previous guidelines which recommend that the position of the sets (implant/abutment) should be at an angle of 30 ±2 degrees with respect to the applied load and that 3 mm of the implant should be exposed to reproduce bone loss.[31] The 20 specimens from the c2 groups were placed on a mechanical cycler (Biopdi) for the application of 360 000 cycles with 150 N of controlled axial force at 4 Hz frequency. During mechanical cycling, the specimens were immersed in water at 37°C.

All of the 20 specimens in the c1 groups and all of the 20 specimens in the c2 groups were embedded in resin
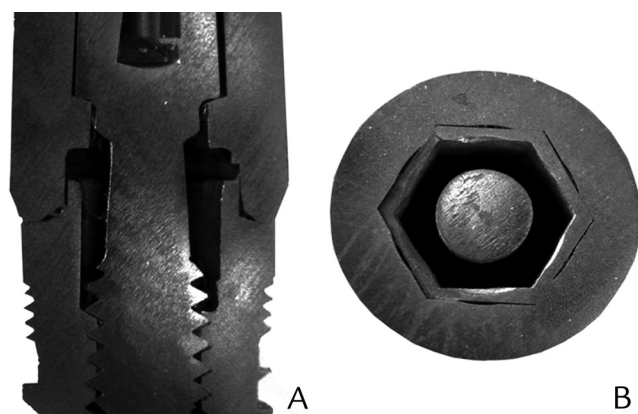
Figure 2. Sections of implant abutment assembly. A, Longitudinal section. B, Transverse section.

(EMbed 812; Electron Microscopy Sciences) for sectioning and for metallographic analyses of the interfaces. A cutter (Model 1000; IsoMet) equipped with a diamond disk was used for cuts in 2 directions (implant/abutment): at the center of the longitudinal joint (n=5 per group) and transverse (n=5 per group) to the long axis in the center of the length of the connection (Fig. 2). Thereafter, the specimens were polished using a sequence of papers 240-, 320-, 400-, 600-, and 1200-grit abrasive (Polipox) plus a rag wheel to provide appropriate surface smoothness. Subsequently, the specimens were ultrasonically cleaned in 96% isopropanol, and a strong air jet was used. The specimens were analyzed by scanning electron microscopy (XL30; Philips), which was used to record a series of images based on secondary electrons (SE).

The longitudinal sections were examined at ×1000 magnification. The following 3 positions were identified and measured on both sides (right and left) of the image: (p1) on the most external border, (p2) in the center, and (p3) on the inner border (Fig. 3A). An overall average was then obtained for each specimen. For the transverse sections, ×500 magnification was used to measure each of the 6 interfaces of the hexagon in 3 positions at each angle (on the right and left of the image) and at the center (p1, p2, p3), as illustrated in Figure 3B.

For the analyses, an overall average was calculated for each specimen. The measurements were made with software (Image Tool v5.02, for Windows; UT Health Science Center School of Dentistry) (Fig. 4).

The results obtained from the measurements of the fits of each abutment were statistically analyzed by 1-way analysis of variance (ANOVA) to identify the differences among the groups, and subsequent analyses were performed with post hoc Tukey tests. The t test was applied to determine the significance of the differences between the groups before and after fatigue (α=.05). The statistical analysis was performed using software (SPSS Statistics v21.0; IBM Corp).

RESULTS

In all specimens, loosening of the sets (abutment/implant) occurred after the programmed cyclic loads. Table 1 shows the contact measurements between the walls before and after the mechanical loading cycles in the 2 directions (longitudinal and transverse). The 1-way ANOVA for the analysis of the transverse section did not reveal any significant differences (P=.479) among the 4 groups. Tic1 and Tic2 specimens showed no significant differences (P=.358) and exhibited gaps in positions p2 and p3 before and after load application to the sets (implant/abutment). Contact was present in all specimens in position p1 (Fig. 5). The Zrc1 and Zrc2 specimens did not exhibit any significant differences (P=.403); they had greater contact at the angle of each face of the hexagon, and none of the specimens demonstrated contact in any of the other areas before or after cyclic load application. The Zrc2 specimens exhibited rounding of the angles in the implant hexagon, which was probably caused by the micromotion of the sets during cyclic loading (Fig. 6). Comparisons of the data between the groups in the same condition with t tests (Tic1 versus Zrc1, P=.105 and Tic2 versus Zrc2, P=.098) revealed no significant differences.

Regarding the longitudinal sections, significant differences were observed among the 4 groups according to 1-way ANOVA (P<.001). Before cyclic loading, the groups had exhibited gaps between the sets (abutment/implant) and contacts in different positions (Fig. 7). However, after the application of cyclic loads, the interfaces in the Tic2 group were in full contact, with significantly lower values than those of the Tic1 group (P=.002). The zirconia abutment (Zrc2 group) specimens exhibited microfractures in the region between abutment and implant (Fig. 8), but no significant differences in misfit values were observed compared with the Zrc1 group (P=.479). The t tests used to compare the groups in the same condition revealed significant differences (Tic1 versus Zrc1, P=.002; Tic2 versus Zrc2, P<.001).

DISCUSSION

This in vitro study evaluated the fit accuracy between external hexagon implants and abutments made of titanium and zirconia before and after the application of cyclic loads. Sections were made in 2 directions (longitudinal and transverse) relative to the long axis of the set (abutment/implant). The misfits and structural changes were measured using a scanning electron microscope. While most studies have evaluated the wear of abutments and implants separately,[25-29] the present study assesses the behaviors of the sets together. In this manner, the internal behavior of traditional abutments made of titanium and esthetic abutments made of zirconia could be demonstrated. After load application,
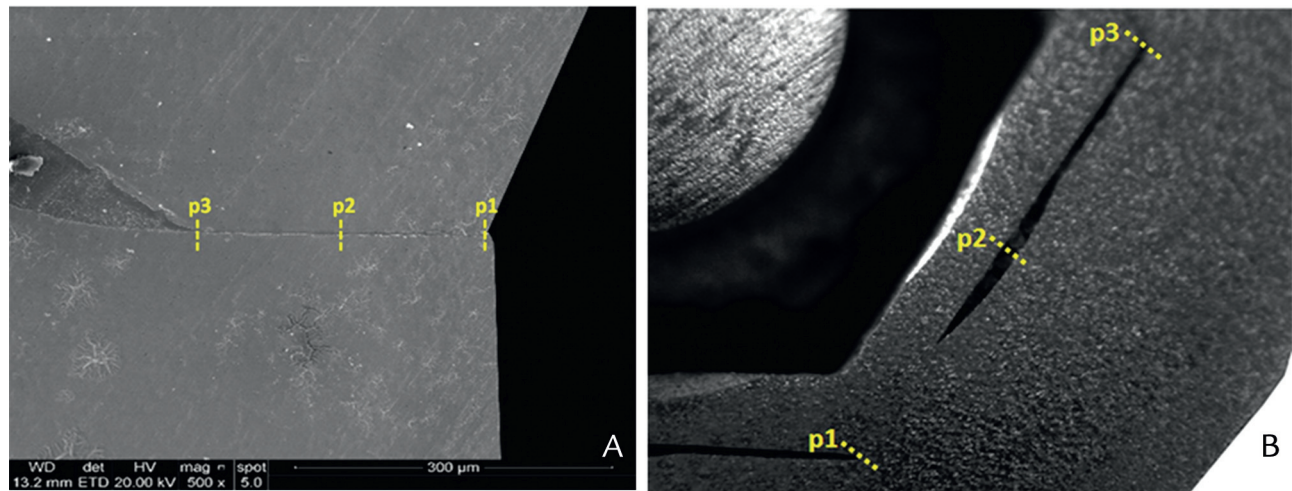
Figure 3. A, Longitudinal section with landmarks p1 (most external area), p2 (central region), and p3 (internal region) used for evaluation of misfit. B, Horizontal section showing 1 side of hexagon with landmarks p1, p2, and p3 used to misfit measurement (×500 magnification).
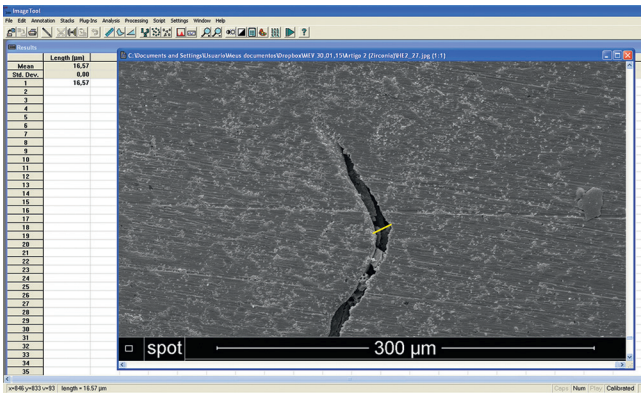

Figure 4. Image of measurement performed with software (yellow line).

Table 1. Contact measurements (mean ±SD) between walls of sets (abutment/implant) before and after mechanical load cycles in 2 sections (longitudinal and transverse)

Group	Longitudinal Section (μm)	Transverse Section (μm)
Tic1	3.8 ±1.9	13.4 ±7.0
Tic2	0	13.5 ±7.3
Zrc1	8.2 ±3.3	21.1 ±14.5
Zrc2	9.1 ±3.5	22.1 ±17.4

titanium abutments accommodated to the implant without changing their structure. Unlike zirconia abutments, in which structural changes were found in both the abutment and implant, a previous study found that the implants with zirconia abutments showed a greater initial rate of wear and more total wear than the implants with titanium abutments after cyclic loading.[26]

Although in vitro testing has limitations because of the difficulty in simulating all the clinical variables, an ISO standard was created in order to standardize dental implants assays using mechanical cycling.[31] However, the results produced by such a method should be interpreted with caution. A wide range of testing parameters is specified in ISO 14801:2007, including testing frequency (2 to 15 Hz), environment (water or dry when testing above 15 Hz), and number of cycles (2 or 5 million, depending on the chosen frequency). The present study used low frequency (4 Hz) in water at 37°C, and there may be differences in the results when testing at the highest end of the speed scale allowed by the standard. Further investigation is needed.

Based on the results obtained in this study, titanium abutments performed better, especially with regard to damage to the implants. Regarding the adjustment of both implant abutments tested, the values were within the range reported in the literature; however, higher precision was found in the titanium abutments. This probably results from the difficulties in the production process (machining) of zirconia, which quickly wears the cutting tools used.

Zirconia-based ceramic is a high-strength material.[11,12] The strength and toughness of zirconia are attributable to its toughening mechanisms, which include crack deflection, zone shielding, contact shielding, and crack bridging.[12] The prevention of crack propagation is critically important in high fatigue situations, such as those encountered during mastication and parafunction.[4] However, in this study, after the application of cyclic loading at a low frequency (4 Hz) and of a relatively low force (150 N), zirconia abutments exhibited cracks and microfractures that most likely occurred during the shift of the abutment accommodation against the implant platform. Nevertheless, titanium abutments allow for easier accommodation because of their excellent mechanical properties.

The occlusal forces produced during clenching, mastication, and jiggling movements (intermittent
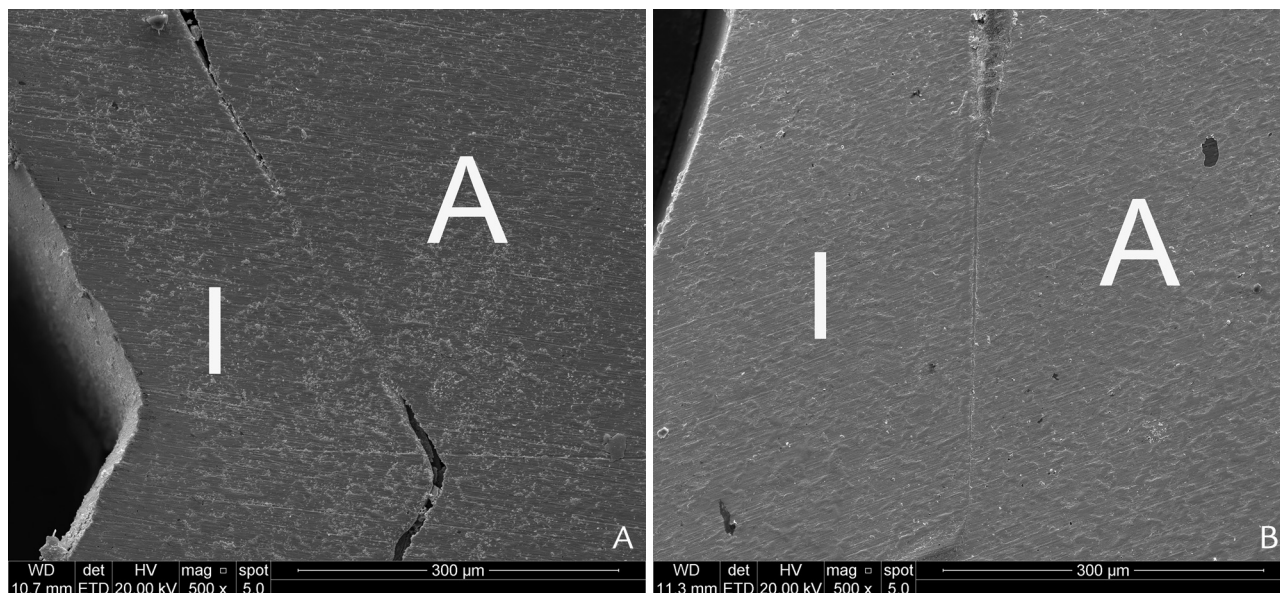
Figure 5. Horizontal sections of titanium abutments. A, Before cyclic loading. B, After cyclic loading. (×500 magnification). (I) implant, (A) abutment.
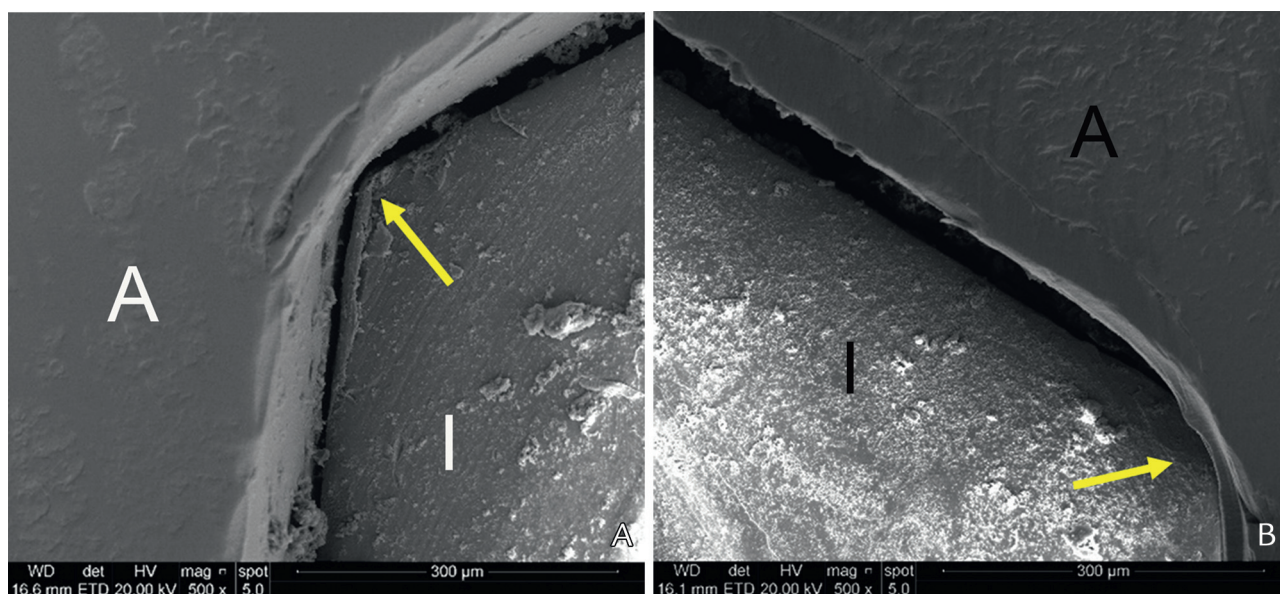

Figure 6. Horizontal sections of zirconia abutments. A, Before cyclic loading. B, After cyclic loading. Yellow arrows indicate angles of implant hexagon. (×500 magnification). (I) implant, (A) abutment.

forces in two different directions) are typically transferred through dental implant systems, causing movement between implants and abutments.[21,22] The positional stability of the mated surfaces has been found to be inversely proportional to rotational freedom.[23] In the present study, zirconia abutments exhibited the greatest contact between the parts (abutment and implant) against the angle of the hexagon. This contact produced micromotion during the application of cyclic loads, and, because the zirconia abutments were harder than the titanium implants, the angles of the implant hexagon were rounded, but there was no loosening of the abutment screws. However, this deformation can derail the use of this implant especially in single crowns.

Statistically significant results were obtained from this study. A possible limitation of the results, however, is related to the number of specimens included, the load value used, and the number of tests for each abutment. Including different load values and other evaluation methods, such as with regard to loosening of the abutment screws, would be important. Although studies have
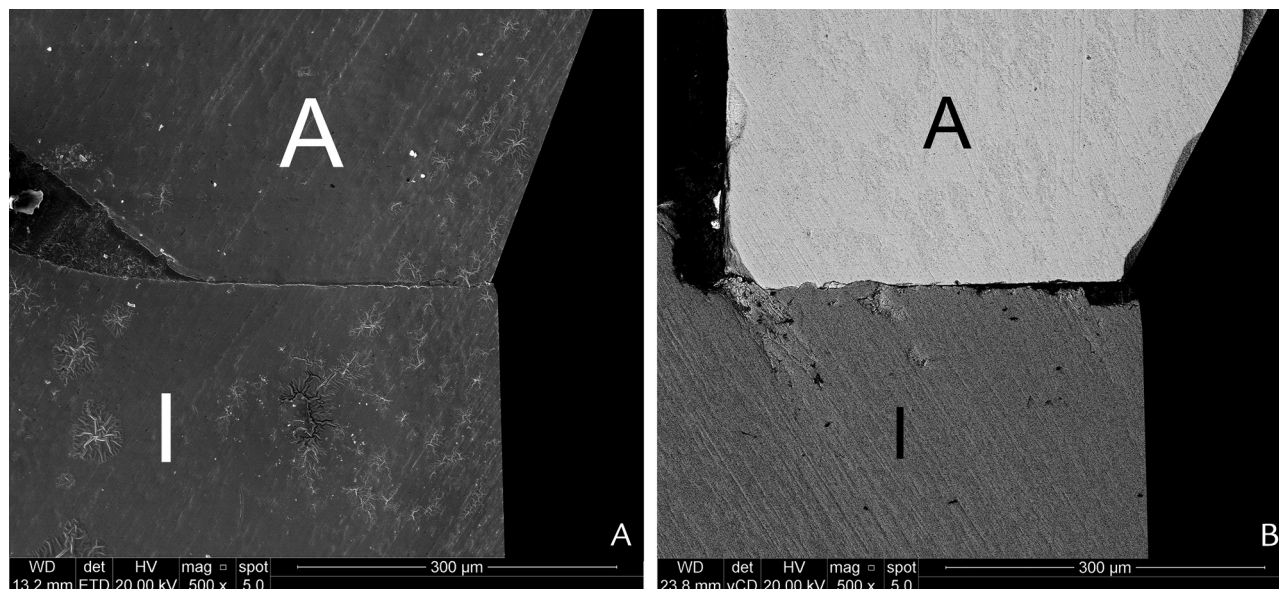
Figure 7. Longitudinal sections of specimens before application of load cycles. A, Tic1. B, Zrc1. (×500 magnification). (I) implant, (A) abutment.
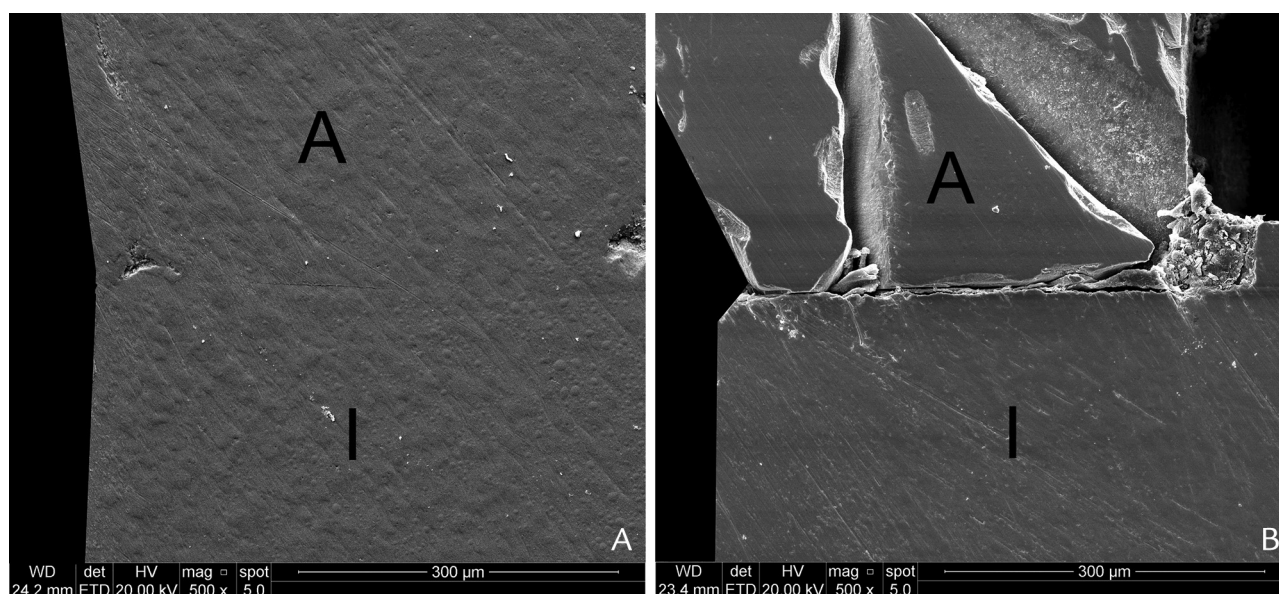

Figure 8. Longitudinal sections of specimens before application of load cycles. A, Tic2 B, Zrc2. In Zrc2 group (B), microfractures can be observed on border of abutment in contact with implant. (×500 magnification). (I) implant, (A) abutment.

shown no statistical or clinically relevant differences between survival rates and the technical and biologic complication rates of zirconia and titanium abutments,[24] other clinical trials could assess possible damage to the implants after loosening of the abutment.

CONCLUSION

Despite the limitations of this in vitro study, it was concluded that the use of zirconia abutments in titanium implants can cause changes and/or permanent deformations of the implant hexagon. Furthermore, the stress that tended to accumulate at the vertices of the abutments led to microfractures and subsequent microgap formation in zirconia abutments.

REFERENCES

1. Smith DC. Dental implant: materials and design considerations. Int J Prosthodont 1993;6:106-17.
2. Depprich R, Zipprich H, Ommerborn M, Naujoks C, Wiesmann HP, Kiattavorncharoen S, et al. Osseointegration of zirconia implants compared with titanium: an in vivo study. Head Face Med 2008;4:30.
3. Kohal RJ, Weng D, Bachle M, Strub J. Loaded custom-made zirconia and titanium implants show similar osseointegration: an animal experiment. J Periodontol 2004;75:1262-8.

4. Dunn DB. The use of a zirconia custom implant-supported fixed partial denture prosthesis to treat implant failure in the anterior maxilla: a clinical report. J Prosthet Dent 2008;100:415-21.
5. Stadlinger B, Hennig M, Echelt U. Comparison of zirconia and titanium implants after a short healing period. A pilot study in minipigs. Int J Oral Maxillofac Surg 2010;39:585-92.
6. Rimondini L, Cerroni L, Carrassi A, Toricelli P. Bacterial colonization of zirconia ceramic surfaces: an in vitro and in vivo study. Int J Oral Maxillofac Implants 2002;17:793-8.
7. Degidi M, Artese L, Scarano A. Inflammatory infiltrate, microvessel density, nitric oxide synthase expression, vascular endothelial growth factor expression, and proliferative activity in peri-implant soft tissues around Ti and Zr oxide healing caps. J Periodontol 2006;77:73-80.
8. Welander M, Abrahamsson I, Berglundh T. The mucosal barrier at implant abutments of different materials. Clin Oral Implant Res 2008;19:635-41.
9. Ahmad I. Yttrium-partially stabilized zirconium dioxide posts: an approach to restoring coronally compromised nonvital teeth. Int J Oral Maxillofac Surg 1998;18:454-65.
10. Gehrke P, Riekeberg U, Fackler O, Dhom G. Comparison of in vivo visual, spectrophotometric and colorimetric shade determination of teeth and implant-supported crowns. Int J Comput Dent 2009;12:247-63.
11. Yilmaz H, Aydin C, Gul BE. Flexural strength and fracture toughness of dental core ceramics. J Prost Dent 2007;98:120-8.
12. Chai J, Chu FC, Chow TW, Liang BM. Chemical solubility and flexural strength of zirconia-based ceramics. Int J Prosthodont 2007;20:587-95.
13. van Brakel R, Cune MS, van Winkelhoff AJ, de Putter C, Verhoeven JW, van der Reijden W. Early bacterial colonization and soft tissue health around zirconia and titanium abutments: an in vivo study in man. Clin Oral Implant Res 2011;22:571-7.
14. Kollar A, Huber S, Mericske E, Stern RM. Zirconia for teeth and implants: a case series. Int J Periodontics Restorative Dent 2008;28:479-87.
15. Jansen VK, Conrads G, Richter EJ. Microbial leakage and marginal fit of the implant-abutment interface. Int J Oral Maxillofac Implants 1997;12:527-40.
16. Vidigal GM Jr, Novaes AB Jr, Chevitarese O, de Avillez RR, Groisman M. Evaluation of the implant-connection interface using scanning electron microscopy. Braz Dental J 1995;6:17-23.
17. Al-Turki LE, Chai J, Lautenschlager EP, Hutten MC. Changes in prosthetic screw stability because of misfit of implant-supported prostheses. Int J Prosthodont 2002;15:38-42.
18. do Nascimento C, Ikeda LN, Pita MS, Pedroso E Silva RC, Pedrazzi V, de Albuquerque Junior RF, et al. Marginal fit and microbial leakage along the implant-abutment interface of fixed partial prostheses: an in vitro analysis using Checkerboard DNA-DNA hybridization. J Prosthet Dent 2015;114:831-8.
19. Jemt T, Book K. Prosthesis misfit and marginal bone loss in edentulous implant patients. Int J Oral Maxillofac Implants 1996;11:620-5.
20. Tenembaum H, Schaaf JF, Cruisinier FJ. Histological analysis of the Ankylos periimplant soft tissues in a dog model. Implant Dent 2003;12:259-65.
21. Eskitascioglu G, Usumez A, Sevimay M, Soykan E, Unsal E. The influence of occlusal loading location on stresses transferred to implant-supported prostheses and supporting bone: a three-dimensional finite element study. J Prost Dent 2004;91:144-50.
22. Clark GT, Tsukiyama Y, Baba K, Watanabe T. Sixty-eight years of experimental occlusal interference studies: what have we learned? J Prost Dent 1999;82:704-13.
23. Semper W, Kraft S, Krüger T, Nelson K. Theoretical considerations: implant positional index design. J Dental Res 2009;88:725-30.
24. Zembic A, Bösch A, Jung RE, Hämmerle CH, Sailer I. Five-year results of randomized controlled clinical trial comparing zirconia and titanium abutments supporting single-implant crowns in canine and posterior regions. Clin Oral Implants Res 2013;24:384-90.
25. Stimmelmayr M, Edelhoff D, Güth JF, Erdelt K, Happe A, Beuer F. Wear at the titanium-titanium and the titanium-zirconia implant-abutment interface: a comparative in vitro study. Dent Mater 2012;28:1215-20.
26. Klotz MW, Taylor TD, Goldberg AJ. Wear at the titanium-zirconia implant-abutment interface: a pilot study. Int J Oral Maxillofac Implants 2011;26:970-5.
27. Yilmaz B, Salaita LG, Seidt JD, Clelland NL, McGlumphy EA. Load to failure of different titanium abutments for an internal hexagon implant. J Prosthet Dent 2015;114:513-6.
28. Yilmaz B, Salaita LG, Seidt JD, McGlumphy EA, Clelland NL. Load to failure of different zirconia abutments for an internal hexagon implant. J Prosthet Dent 2015;114:373-7.
29. Chang JS, Ji W, Choi CH, Kim S. Catastrophic failure of a monolithic zirconia prosthesis. J Prosthet Dent 2015;113:86-90.
30. Breeding LC, Dixon DL, Nelson EW, Tietge JD. Torque required to loosen single-tooth implant abutment screws before and after simulated function. Int J Prosthodont 1993;6:435-9.
31. International Organization for Standardization (ISO). ISO 14801/2007: Dentistry-implants – dynamic fatigue test for endosseous dental implants. Geneva: The Organization, Document published Nov. 2007.

Corresponding author:
Dr Sergio Alexandre Gehrke
Rua Dr Bozano, 571-97015-001
Santa Maria, RS
BRAZIL
Email: sergio.gehrke@hotmail.com