

Effect of Implant Platform Connection and Abutment Material on Removal Torque and Implant Hexagon Plastic Deformation

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Eur J Dent 2019;13:349–353

Abstract

Objectives The aim of this study was to evaluate the plastic deformation of the hexagonal connection, and the removal torque of the implant-abutment joint of two dental implants combined with internal or external hexagonal connection implants after mechanical cycling.

Materials and Methods Twenty-four dental implants were used in the study. Half of the implants had internal hexagonal connections (IH; Titamax II Plus) and the other half had external hexagonal connections (EH; Titamax Ti Ex). Four groups of two types of dental implant abutments (titanium: Ti, UCLA II Plus and zirconia: Zr, fabricated by CAD/CAM; $n = 6$) were investigated. The abutments received a metallic crown and the settings were submitted to mechanical cycling (MC; 10^6 cycles, axial load, 120N). The connection surface area was measured by scanning electron microscope (SEM) images. The removal torque was evaluated and the plastic deformation of the hexagonal surface of the implant was measured by comparing the images before and after MC.

Statistical Analysis Paired-*t* test was used to analyze the data statistically at a significance level of $\alpha = 0.05$.

Results The torque values decreased for all groups after MC, and the hexagonal surface area decreased due to plastic deformation for IH and EH associated with Zr abutments.

Conclusions Zirconia abutments showed the worst plastic deformation of the implant connection surface and torque loosening when associated with IH implant.

Keywords

- ▶ internal hexagonal implant
- ▶ zirconia abutment
- ▶ connection wear

Introduction

The replacement of lost teeth by osseointegrated implants is an established therapy, with long-term reports of success.^{1,2} Titanium (Ti) was the first material to be applied in the fabrication of implants and abutments for the installation of prosthetic restoration. However, such material may present esthetic limitations when the thickness of peri-implant soft tissue is lower than 2 mm.³

Esthetic abutments have been applied as an alternative to Ti abutments.⁴ Ceramics may be used for the fabrication of

components and also solve the esthetic issue; however, function should be ensured, without compromising the bone-implant-restoration system.⁵ Some options for the fabrication of ceramic implant components are alumina and zirconia.⁶ Partially stabilized zirconia possesses high-mechanical strength and is a good alternative for Ti abutments in the maxillary anterior region.⁷

However, the clinical behavior of zirconia as implant abutment is still controversial. Mechanical characteristics of zirconia ceramic, such as the hardness,⁸ are very different from those of the titanium.⁹ Also, the elastic modulus of

both materials is very different.¹⁰ This may lead to different behaviors in terms of bending and deformation when a load is applied to the system.¹⁰ In this scenario, the implant-abutment joint may get compromised.

Literature reports significant difference in the wear of the hexagon surface of Ti implants when associated with Zr or Ti abutments.^{11,12} The wear of the connection may lead to loosening of the abutment screw torque, and is associated with loosening of the restoration as well as the dental implant. The wear of the implant-abutment joint may also cause misfit and a space in the subgingival zone, thus favoring bacterial microleakage and proliferation.^{4,5,13,14}

The design of the implant connection may also influence the implant-abutment interface, since this is the area of higher stress concentration in the system.¹⁵⁻¹⁷ External connections (EH) have the lowest torque loosening, when compared with the internal hexagonal connection (IH),^{18,19} and better stress distribution, since they present a higher contact area between the abutment and implant platforms than IH.²⁰

Thus, the aim of this study was to evaluate the removal torque and plastic deformation of the hexagonal implant connection after mechanical cycling when Zr and Ti abutments are associated with Ti implants. The tested hypothesis was that Zr abutments would present greater hexagonal implant deformation, and lower values of removal torque than Ti abutments in both internal and external hexagonal implant connections.

Materials and Methods

The sample size calculation was performed using the Bioestat 5.0 software to offer results with 0.9 power and 0.05 significance. Calculation was based on data from previous literature,¹⁶ and resulted in $n = 5$. Extra sample was added to each group, resulting in $n = 6$. Samples were evaluated before and after mechanical cycling. Thus, the study was conducted using 24 dental implants ($n = 6$) (3.75×13 mm) with a 4.1-mm platform connection. Half of the implants had internal hexagonal connections (IH; Titamax II Plus, Neodent, Curitiba, PR, Brazil) and the other half had external hexagonal connections (EH; Titamax Ti Ex, Neodent, Curitiba, PR, Brazil).

The implants were embedded into epoxy resin (TCR-550/XR-451; Triepox, Sao Paulo, SP, Brazil) with a parallel surveyor (B2; Bioart, Sao Carlos, SP, Brazil). The initial images of the hexagons from the implant connection were obtained using a scanning electron microscope (SEM; InspectF50, FEI, Hillsboro, Oregon, USA) with 70X magnification. The surface areas of the hexagons were measured with digital software (Image Proplus 6.0, Media Cybernetics, Rockville, MD, USA).

The prosthetic abutments were selected according to the implant connection, using two different materials: titanium (UCLA II Plus; Neodent, Curitiba, PR, Brazil) and zirconia (fabricated by CAD/CAM, Zirkonzahn System, Gays, Bolzano, Italy). The abutments were attached to the implants by titanium screws with a square head. The following four groups were considered: IH/Ti, IH/Zr, EH/Ti, and EH/Zr.

The Ti abutments were 10 mm high with an axial convergence of 30 degrees. The Zr abutments were fabricated from

the scans of the Ti abutments and milled in CAD/CAM unity (Zirkonzahn System; Gays, Bolzano, Italy). The abutments were screwed on each implant with manual torque meter (BTG; Tohnichi, Buffalo Grove, IL, USA), as recommended by the manufacturer: 30 N.cm (Ti abutments) and 20 N.cm (Zr abutments). The torque was checked and applied again after 10 minutes.

Subsequently, simplified metallic crowns were waxed on each abutment, 2 mm away from the implant-abutment joint, and fabricated into chrome-cobalt alloy (Degudent, Dentsply, York, PA, USA) by lost-wax casting process. The metallic crown was 8 mm high with a flat occlusal surface to avoid oblique loads during mechanical cycling, and had a hole in the central area for assessment of the abutment fixation screw and measurement of torque after mechanical cycling. The crown was cemented to the abutments with zinc-phosphate cement (SS-White, Sao Paulo, SP, Brazil).

Then, the samples were subjected to mechanical cycling (MC) in a universal testing machine (8801, INSTRON Fatigue Testing Systems, Norwood, MA, USA). The mechanical cycles (10^6) were applied with 120 N axial load and 10 Hz frequency. The axial load was applied at the center of the metallic crown by a tungsten piston with a spherical tip (diameter: 4 mm).

After MC, the removal torque was measured by removing the abutment screw with a manual torque meter. The surfaces of the implant hexagon were observed using a scanning electron microscope (SEM). The wear/plastic deformation of the surface of the implant hexagon was evaluated by calculating the difference between the measurement of the surface area of each hexagon before and after MC.

The obtained data were subjected to paired-t test at the significance level of $\alpha = 0.05$. The factors were combined and tested for correlation.

Results

After MC, small fractures at the margins of the Zr abutments were observed. Regarding the values of the removal torque of abutments, all groups showed a decrease in the values after MC (►Table 1). This decrease was statistically significant different ($p < 0.05$). IH/Zr showed significant decrease in removal torque compared with the other groups. Two Zr abutments associated to internal hexagon implants presented transversal fractures.

After the removal of the abutment/crown, all groups showed statistically significant decrease in the implant hexagon surface area ($p < 0.05$) except for the IH/Ti group ($p > 0.05$). The greatest decrease in the implant hexagon surface area was observed for IH/Zr (►Table 2). ►Fig. 1 shows a SEM image (60X magnification) of the implant hexagon surface from one representative sample of each tested group, before and after MC. After MC, it is possible to observe rounding of hexagon corners and deformation of the hexagon edges.

There was no correlation (Pearson's correlation test) between the results of the reversal torque and plastic deformation ($p = 0.118$).

Discussion

The present study showed that the Zr abutments had the lowest reverse torque values when associated with IH implants, accepting the proposed hypotheses. The decrease in removal torque after MC was significant in all the groups tested. The possible causes for torque loosening in all the groups may be the occurrence of micromovements between the involved components when a load was applied at the metallic crown. The initial torque promotes friction between the interfaces of the abutment, screw, and implant platform. When micromovements are present due to the loading of the metallic crown during MC, there is wear of these interfaces, and the retention of the screw may decrease.²¹

The greatest torque decrease was recorded for IH/Zr. The differences in hardness and elastic modulus of Zn and Ti may lead to unequal stress distribution at the interface of components during load application, with plastic deformation of the Ti screw (lowest hardness) and loss of abutment torque.¹⁵

The group that had Zr abutment associated with IH showed 40% decrease in the removal torque values. Besides the effect of the material discussed above, the IH abutment was slightly longer than the abutment for EH, considering the portion that was attached to the internal hexagon inside the implant. It was already reported that a greater height of the abutment was related to a decrease in the reverse torque values due to changes in force moment.¹¹ The moment formed by high abutments increased the stress from MC at the screw (lever fulcrum), leading to wear, torque loss, and/or fracture of the abutment. Two Zr abutments associated with IH exhibited transverse fractures after reverse torque application. In the study of Fabbri et al, 2017, they found that Zr abutments associated with IH implants had the highest fracture incidence after 6 years of clinical follow-up.²² Considering the internal part, high and thin abutments were more prone to fracture and torque loss when compared with large and short abutments.²³ EH implants associated with Ti abutments were the only group that did not exhibit a decrease in the torque values after MC.

The decrease in the hexagonal surface after MC was significant for EH implants, with both Ti and Zr abutments

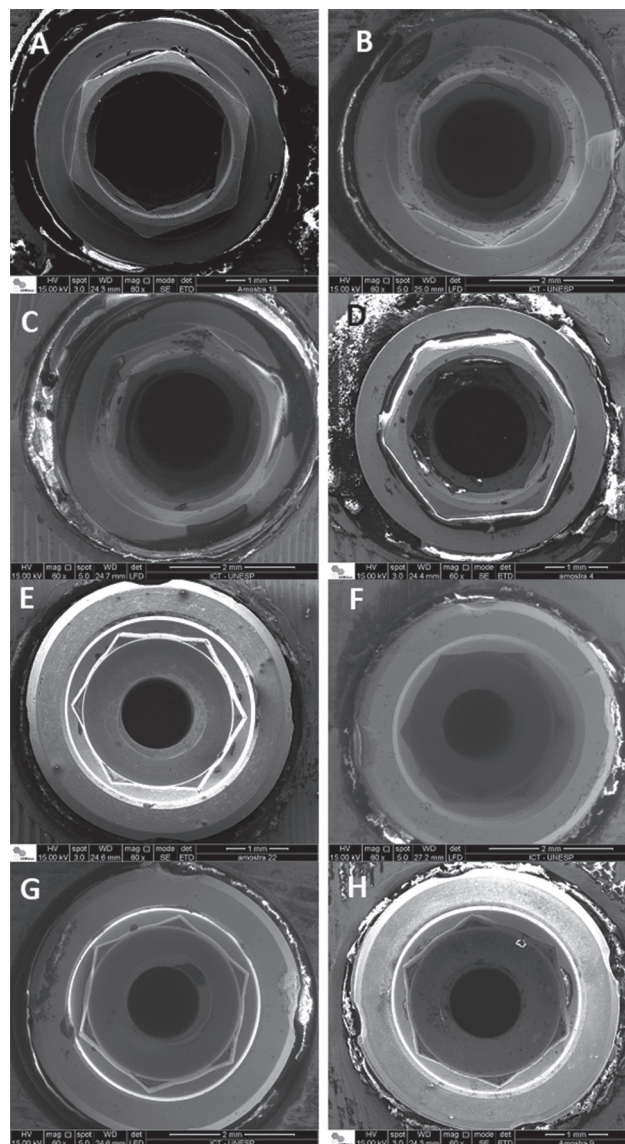


Fig. 1 SEM images of the implant hexagon surface of one sample from each group. (A) EH/Zr before mechanical cycling, (B) EH/Zr after mechanical cycling, (C) EH/Ti before mechanical cycling, (D) EH/Ti after mechanical cycling, (E) IH/Zr before mechanical cycling, (F) IH/Zr after mechanical cycling, (G) IH/Ti before mechanical cycling, (H) IH/Ti after mechanical cycling. SEM, scanning electron microscope.

Table 1 Reverse torque values of each group

Groups tested	Initial torque (N.cm)	Reverse torque (N.cm) after mechanical cycling	% of torque loosening	p-Value
EH/Zr	20.00	17.33 (2.27)	13.3	0.035
EH/Ti	32.00	29.83 (1.29)	6.8	0.009
IH/Zr	20.00	12.00 (2.25)	40.0	0.000
IH/Ti	32.00	27.58 (1.53)	13.8	0.001

Table 2 Area of implant hexagon surfaces before and after mechanical cycling (MC)

Groups tested	Before MC (mm ²)	After MC (mm ²)	% of decrease in area	p-Value
EH/Zr	73.66 (3.21)	69.44 (2.56)	5.7	0.037
EH/Ti	73.41 (2.99)	69.33 (2.10)	5.5	0.013
IH/Zr	129.2 (8.34)	116.97 (1.16)	9.5	0.014
IH/Ti	118.4 (6.95) A	115.1 (3.69)	2.7	0.077

(►Fig. 1A–D); however, hexagons associated with Zr abutments had the greatest decrease in area. Besides the implications of combination between Ti and Zr mentioned above, the material with lower elastic modulus, Ti in this case, tended to suffer deformation when stresses were concentrated at the interface of both materials. Alterations at implant abutment joint are reported to be related to the shape of the milled abutment hexagon.²⁴ The plastic deformation of connection hexagons (►Fig. 1B, 1D, 1H) may lead to loss of retention of the screw and thus create a misfit between the abutment and implant platform, leading to clinical failure.^{25,26}

The region of the implant-Zr abutment connection was reported as the weakest part in internal connections.²⁷ Torque (20 N.cm) was applied, as recommended by the manufacturer and as already tested in other studies²⁸; however, torque application in cases of nonpassive fit might have created cracks at the cervical regions of the Zr abutments,¹³ which were propagated during MC, thereby resulting in the fracture of two abutments. The loss of specimens, manufactured with one-piece zirconia abutments during chewing simulation, was already reported in literature and they also present lower fracture loads than noncycled specimens.²⁹ Titanium abutments present 30 to 40% higher strength than zirconia abutment, limiting the indication of the ceramic abutment to regions of low-chewing forces (anterior region).³⁰

Besides that, the higher space between abutment and implant may have contributed to the micromovements in the implant abutment joint during MC, resulting in torque loosening and wear of implant connection when the Zr abutment was used.³¹

The present research evaluated only one commercial brand of implant and abutment, in addition to fabricated Zr abutments based on Ti abutments. Other implant-abutment assemblies and commercial brands, like other Zr abutment dimensions, may present different outcomes. Moreover, the use of titanium base in zirconia abutments may enhance the strength of these abutments.²⁹

Conclusions

Within the limitations of the present research, negative results were observed for Zr abutments in terms of plastic deformation of implant connection surface. The association of internal hexagonal connection and zirconia abutment was the worst situation in terms of torque removal.

Conflict of Interest

None declared.

Acknowledgments

Authors thank Neodent (JJGC Ind & Com. Of Dental Materials S.A.) for donating the materials for this research.

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