

In Vitro Comparison of Modes of Failures among Titanium and One- and Two-piece Zirconia Abutment under Static Load

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Abstract

Objectives The objective was to assess modes of failures under static load (SL) among titanium (Ti) and one- and two-piece zirconia abutment (ZA) *in vitro*.

Materials and Methods The Ti abutments were digitally scanned for the fabrication of the one- and two-piece zirconia abutment specimens. This was done to standardize the design of the one-piece abutment and make it the blueprint of the Ti abutment. Twenty-one implant abutments and 21 implant replicas were categorized into three groups as follows: group 1 (Titanium group), group 2 (one-piece ZA group), and group 3 (two-piece ZA group). A 250K-cycle, linear fatigue-load, reaching 10 to 210 Newton (N), was put on all specimens using an all-electric dynamic test instrument and the specimens were loaded until fracture.

Statistical Analysis Assessment of mode of fracture among the groups was done visually. Significance was based below 0.05.

Results Screw fracture ($n = 7$) and abutment bending at the apical part ($n = 7$) occurred in the Ti group. In the one-piece zirconia group, screw and abutment fractures occurred in seven and seven cases, respectively. In the two-piece zirconia group, screw fracture ($n = 7$) above the Ti zirconia junction (transgingival segment) and abutment fracture ($n = 7$) were determined as the failure modes.

Conclusion In conclusion, all abutments underwent failures under SL *in vitro*; and the mode of failure modes varied among the different abutment designs used.

Keywords

- ▶ fracture resistance
- ▶ mode of fracture
- ▶ static load
- ▶ titanium
- ▶ zirconia

Introduction

Abutment for titanium (Ti) implants are usually fixed using an internal or external connection.^{1,2} With advancements in clinical implant dentistry and related research, zirconia implants were introduced, in which the internal connection can be achieved by the one- or two-piece zirconia abutments (ZAs).¹ Studies^{3–5} have assessed the load-to-fracture (LTF) values regarding the one-piece and 2-piece ZAs. *In vitro* results by Gehrke et al³ showed that the one-piece ZA has a lower fracture load than two-piece ZAs. These results are comparable to those reported by Chun et al⁴ Nevertheless, controversial results have also been reported.⁶ Kim and

coworkers assessed⁷ the fracture load of one-piece and two-piece ZA under static load (SL). The study⁷ results showed no difference in maximum-load-capacity for one-piece and two-piece ZAs.

In the study by Brodbeck U,⁸ destructive impact of zirconia on implants' external hexagon were reported. Moreover, a pilot study by Klotz and associates⁹ assessed the wear of Ti and ZAs under a cyclic load. According to the results of this investigation, implants with zirconia-abutments demonstrate a higher wear rate as compared with Ti-based implant abutments.⁹ Damages of this sort at the region of the junction between the abutment and implant can potentially

cause implant prosthesis fracture. Although enough evidence exists in indexed literature regarding the fracture strength of Ti and zirconia implants¹⁰⁻¹², there is a dearth of published data regarding the mode of fracture of one- and two-piece zirconia implants. Kammermeier et al¹² experimentally measured fracture resistance (FR) of two-piece-zirconia implant systems and observed that the FR of 2-piece zirconia implant systems was poorer as compared with one-piece zirconia implants. Nevertheless, the precise mode of fracture of zirconia implants remained unclear in this study.¹² In a recent scanning electron microscopy (SEM) based in-vitro study, Moris et al¹³ investigated the fracture modes of TI and customized and noncustomized ZAs. The SEM results showed that the Ti abutments underwent a plastic deformation, whereas the ZAs fractured following application of SL. Moreover, in ZAs, the fracture occurred underneath the platform of the implant in the zone between the abutment and implant, which propagated to the abutments' internal surface.¹³ Furthermore, in the study by Kim et al,⁷ modes of failure of three types of ZAs were assessed. The results showed that there was a variation in the modes of fracture of the 3 ZAs used.⁷ There is no published literature that has compared the mode of fracture among Ti and one- and two-piece ZAs under SL. Our hypothesis is that the modes of fracture under SL are comparable among the Ti and one-piece and two-piece ZAs.

The objective of this comparative in-vitro experiment was to assess the modes of failures among Ti and one- and two-piece ZAs under SL.

Materials and Methods

Fabrication of Test Specimens

The one- and two-piece ZA specimens were fabricated via scanning the Titanium abutment using a scanner (NobelPro-cera 2G Scanner; CH-8058 Zürich-Flughafen, Switzerland). This was done to standardize the design of the one-piece abutment and make it as a blueprint of the Ti abutment.

Grouping

Twenty-one implant abutments and 21 implant replicas (NobleReplace) were equally divided into three groups as follows: group 1 (Titanium group), group 2 (one-piece ZA group), and group 3 (two-piece ZA group).

Specimen Preparation for Fatigue Test

The implant replicas were mounted on a metal jig, which was machined from stainless steel (SS) into two-part with engraved pins to receive one implant replica. A metal base

was fabricated to hold the metal jig with secure screws to fix the position of specimen. The top of the base had a 135° inclination to the load application axis and the bottom was attached to a machine table. The load applicator was fabricated of SS and shaped to simulate the lower central incisor edge. The abutment was screwed into the implant replica at 35 Ncm using an implant motor console (Digital Torque; W&H implantMED, Bürmoos, Austria). Retightening of the screw of the abutment was done again after 10 minutes.¹⁴ The implant abutment (1) Titanium, (2) one-piece zirconia, and (3) two-piece zirconia were mounted on the metal jig. A 250K-cycle linear fatigue load, reaching from 10 to 210 N, was enforced on all specimens using an all-electric-dynamic-test instrument, and the specimens were loaded until fracture.

Assessment of Mode of Fracture

Visual assessment of mode of fracture was done by an investigator whose intraexaminer kappa score was 0.92.

Statistical Analysis

Using a computer-based software (SPSS, Version 20, Chicago, I.L., USA), group comparisons were performed using utilizing Kolmogorov and Shapiro tests. Levene's test was performed to determine variances' homogeneity. *P*-values below the value of 0.05 were an indicator of statistical significance. Power-based calculations were done as recommended by Gehrke et al.³ Based on the results of a pilot investigation, it was estimated that with the use of seven abutments per group, the study would attain a power of 80% to notice differences among the mean with an α of 0.05.

Results

Modes of Fracture

Screw fracture ($n = 7$) and abutment bending at the apical part ($n = 7$) occurred in the Ti group. In the one-piece zirconia group, screw and abutment fractures occurred in seven and seven cases, respectively. In the two-piece zirconia group, screw fracture ($n = 7$) above the Ti zirconia junction (transgingival segment) and abutment fracture ($n = 7$) were determined as the failure modes (►Table 1). Modes of failure of Ti and one-piece and two-piece ZAs are illustrated in ►Fig. 1.

Discussion

The current *in vitro* results showed that Ti and one- and two-piece ZAs exhibit different modes of failure under SL. Our results clearly demonstrated that under a SL, screw fractures

Table 1 Failure mode for Titanium and 1- and 2-piece zirconia abutment groups

Study groups	Mode of failure			
	Screw fracture (<i>n</i>)	Screw bending (<i>n</i>)	Abutment fracture (<i>n</i>)	Abutment bending (<i>n</i>)
Titanium group	7	0	0	7
One-piece zirconia	7	0	7	0
Two-piece zirconia	0	7	7	0

Note: *n* = number of failures



Fig. 1 An illustration of various fracture modes observed in the titanium and 1- and 2-piece zirconia abutment groups.

and bending of abutment occurred in Ti abutments; whereas, screw bending and abutment fracture were the prevalent modes of fracture of two-piece ZAs. On the contrary, the modes of fracture of one-piece ZAs were fracture of screw and abutment. From these results, it is obvious that the proposed hypothesis is rejected. From a clinical perspective, the present *in vitro* results emphasize that the classical risk factors, such as bad oral hygiene status, use of tobacco containing products, and immunosuppression (as seen in patients with long-standing hyperglycemia), are not the only causes of failure of implants¹⁵⁻¹⁷, and high-end occlusal forces can also create complications (such as fracture induction at the implant abutment interface) which, if left untreated and not dealt with in a timely manner, may lead to peri-implant diseases and even implant failure. Nevertheless, it is clinically exigent to determine a minimum threshold value of biting force, which may stringently reflect the occlusal masticatory forces. It has been reported that habits such as bruxism are risk factors of abutment fracture in patients with dental implants.¹⁸ In this regard, there is a possibility that Ti, and one- and two-piece ZAs are more susceptible to display modes of fractures comparable to the patterns reported in the present *in-vitro* investigation. It is speculated that individuals demonstrating high-biting forces and simultaneously exposed to risk factors of implant failure (such as those mentioned above) more often display Ti and one- and two-piece ZA fractures compared with unexposed patients with normal biting forces. To the best of our knowledge, this hypothesis is yet to be assessed.

In our experimental study, a 250K cyclic load was utilized to expose specimens to fatigue, using forces which ranged from 10 to 210 N to simulate a 1-year human chewing

function.¹⁹ The specimens were mounted on a heavy SS jig with 135° inclination to the load application axis to simulate the clinical inclination between the upper and lower central incisor. The load applicator was especially shaped to simulate the shape of the edge of central incisors located in the mandible. Fatigue and load fracture tests were performed purely on abutments and all other parameters, such as porcelain-based ceramic crowns that are clinically related with the assembly, were eliminated. This was done to minimize confounding factors. In case, crowns were placed in the abutments, then crown-cement interface might have tolerated higher forces before failure due to its stress shielding mechanism, thereby biasing the recorded LTF values.⁶ Implant analogues were made from SS, instead of Ti, and were used in our experimental study. The replica made from SS bears higher forces before failure than titanium-fabricated implants. Furthermore, the replica made from SS eradicates the confounding variable that could have influenced our outcomes.²⁰ The SS-based implant does not have the same resilience as bone and this could have dissipated a portion of the loading stress.

It is also pertinent to mention that variations in the mode of fracture among the Ti and one- and two-piece ZAs could be credited to varying abutment systems, direction of the load, and preceding the LTF test without conducting the fatigue test. Alqahtani and Flinton⁶ tested fracture loads of zirconia implant abutments with varying planes of preparation. Although modes of fracture remained unaddressed in their study, there is a likelihood that mode of failures varied between the study groups. It can be speculated that the difference in mean of the LTF load is due to different implant systems and abutment thicknesses.

One limitation of our experimental study is that the results were based on *in-vitro* observation of modes of fracture of various implant abutment connections under SL. For instance, nocturnal bruxism induces high occlusal forces²¹, and is therefore a risk factor of prosthesis fracture. It seems challenging to determine the minimum SL value required to induce fracture of the various abutments used in the present study. Further studies are needed in this context. There is a likelihood that the mode of fracture of one- and two-piece zirconia abutments varies among patients with bruxism. Further studies are required to test this hypothesis.

Conclusion

All abutments underwent failures under SL *in vitro*, and the mode of failure varied according to the different abutment designs used.

Authors' Contributions

Fawaz Alqahtani designed and supervised the study and wrote the manuscript. Mohammed AlAmar performed the experiments and wrote the results. Mohammed AlAmar and Fawaz Alqahtani read and revised the manuscript prior to submission.

Conflict of Interest

None declared.

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