# EFFECT OF CYCLIC LOADING ON ZIRCONIUM ABUTMENT SCREW LOOSENING

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## INTRODUCTION

Although metal implant abutments have esthetic inherent disadvantages, they are most widely considered a standard treatment option for implant supported restorations. Improved material characteristics, complying with clinician's and patient's increased demands for highly esthetic results, have contributed significantly to the development of a new generation of ceramic abutments. Yttrium-oxide stabilized zirconium-dioxide (Y-TZP) has been noted for their tooth-like color, high load strength, tissue tolerability and intra-sulcular design enhancement. The phenomenon of transformation toughening of zirconium-dioxide results in extremely high component strength, extraordinary bending and tensile strength, fracture and chemical resistance. To be considered a true alternative, the mechanical and biological qualities of ceramic implant abutments must be equal to or better than those of widely used titanium abutments. These requirements can only be met by high-performance and biocompatible oxide ceramics. Oxide ceramics are equal to metals from a mechanical standpoint, but biologically stronger. However, one exception is the high brittleness of ceramics, and the risk for crack propagation. So far, the use of full ceramic implant abutments for implant restorations has been limited due to this feature. Abutment and prosthetic loosening of single and multiple screw-retained, implant-supported fixed partial dentures is a concern in general. The purpose of this study was to determine the fracture strength of zirconium-dioxide implant abutments and the torque required to unfasten the retaining screw prior to and after applying cyclic loading to the implant-abutment assembly. In addition, the dynamic behavior and stress distribution pattern of zirconium abutments, using the transient dynamic analysis of Finite Element Modeling (FEM), was evaluated.

## MATERIAL AND METHODS

A laboratory study according to the International Standards (DIN ISO/ WD 14801 Rev (F), International Organization for Standardization) was carried out, simulating the functional loading of an endosseous dental implant body and its abutment components under worst case conditions. Straight CERCON® zirconium-dioxide implant abutments were assembled to seven internally hexed XiVE® implants, 4.5 mm in diameter and 18 mm in length (DENTSPLY Friadent, Mannheim, Germany). All implants were embedded into an elastic material (EpoFix, Stuers, Ballerup, Denmark) with a Young's modulus of 4100 MPa, being similar to that of bone. The top of the implant extended three millimeters above the level of the surrounding material in order to create a worst case situation of crestal bone resorption. Spherical caps were fabricated and cemented (TempBond®, Kerr, California, USA) on each zirconium-dioxide abutment and adjusted to the same 8 mm length in order to create defined lever forces. During testing, the spherical cap rested on a flat plate. The load was applied via a stainless steel rod (pin-loaded using a small center drill point) to withstand external forces and to avoid undefined lateral forces in the set-up. Cyclic loading tests (CLT) were carried out by means of a servo hydraulic dynamic testing machine (Instron 8872, Instron, Canton, MA, USA) at loads between 100 and 450 Newton up to five million loading cycles, at 15 Hz. The tests were performed by applying a compression load 30° off the axis of the implant. This resulted in a combination of compression, bending, and shear loads in the device. The tests were performed both statically for single overload conditions, and in repeated loading to provide fatigue curves of load versus cycles required to cause failure. The same implant type (XiVE®) was used for both the static load tests (0.05 inches/ minute crosshead speed) and the fatigue tests (15 Hz). The torque values required to unfasten the retaining screws were determined with a Tohnichi torque gauge (Tohnichi America Corporation, Northbrook, IL, USA). In addition, the dynamic behavior of the zirconium-dioxide implant abutments was analyzed by transient dynamic analysis of the Finite Element Modeling (FEM); a software optimization method based on a CAD drawing (Computer Aided Design) of the implant-abutment assembly. A mathematical mesh was superimposed to the drawings of the implant-abutment assembly. Subsequently, a virtual load was chosen according to clinical conditions in the oral cavity. An identical set-up was selected for the computer analysis with straight abutments. External loads of 100 and 250 Newton were applied to the assembly at a 30° inclination towards the axis of the implant. FEM was carried out by Pro/MECHANICA software (Parametric Technology Corporation, Needham, MA, USA) comparing van-der-Mises and maximum stresses levels obtained from the calculation.

## RESULTS

The CERCON® zirconium-dioxide-ceramic abutments investigated in the current study exhibited a maximum fracture strength of 672 N during static loading, and during cyclic loading 269 N at 800,000 to 5,000,000 cycles run-out point, and respectively, 403 N at 10,000 cycles run-out point. The mean torque value required to unfasten the abutment retaining screws after (initial) tightening was 21 Ncm ± 1 and respectively 20 Ncm ± 1 (measurement accuracy ± 2 Ncm) after loading with up to five million cycles i.e. screw loosening did not occur. Within the limited number of test specimens (7), the difference was statistically not significant. The FEM analysis revealed a pattern of low, well-distributed stresses along the entire implant-abutment assembly at an external load of 100 N. However, higher stress peaks up to 800 MPa have been shown at the cervical aspect of the zirconium-dioxide abutment and at the apical third of its retaining screw at an external load of 250 N.

## CONCLUSION

Restorations in the esthetically demanding anterior region present significant challenges in both the surgical and prosthetic stages of implant dentistry. Titanium has been established as the material of choice for endosseous implants, resulting in a high degree of predictability. Zirconium-dioxide ceramics appears to be a suitable material for manufacturing implant abutments. Within the limitations of this study zirconium-dioxide implant abutments exceeded the established values of up to 300 N for maximum incisal bite forces reported in the literature, and tightly fit into the titanium implant after several millions of loading cycles. Ceramic abutments show a low bacterial colonization potential and minimize the gray color associated with metal components shining through the peri-implant tissues. Their durability and color conformity are prerequisites for highly esthetic implant restorations.

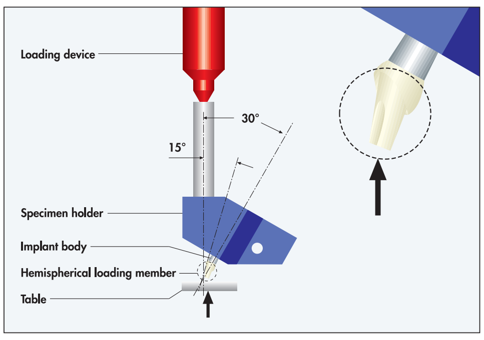


Fig. 1: Test set-up for cyclic loading by means of servo hydraulic dynamic testing. Compression load 30° off the axis of the implant.

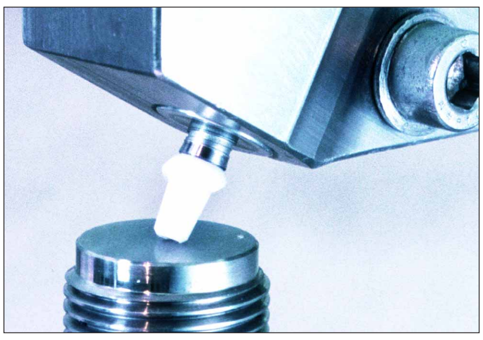

Fig. 2: Close-up of dynamic strength testing of implant-zirconium-dioxide-abutment assembly.

| Specimen | Cercon® Abutment | Dynamic load | Loading cycles [n] | Removal torque [Ncm] Retaining screw | |
|---|---|---|---|---|---|
| | Percentage of static fracture load (average 672 N) | | | Initial | After |
| **1** | 40% | 268.8 | 811,930 | 23 | 21 |
| **2** | 40% | 268.8 | 818,023 | 20 | 18 |
| **3** | 40% | 268.8 | 905,645 | 21 | 20 |
| **4** | 40% | 268.8 | 5,000,000 | 20 | 19 |
| **5** | 60% | 403.2 | 10,000 | 21 | 19 |
| **6** | 60% | 403.2 | 10,000 | 21 | 21 |
| **7** | 60% | 403.2 | 10,000 | 20 | 20 |

Fig. 3: Fatigue testing of zirconium-dioxide abutments and mean torque value required to unfasten abutment retaining screw

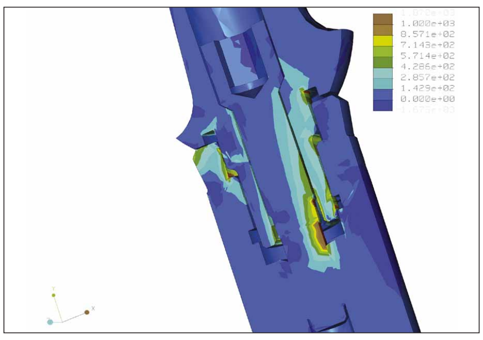

Fig. 4: FEM of implant-zirconium-dioxide-abutment-assembly at an external load of 100 N.

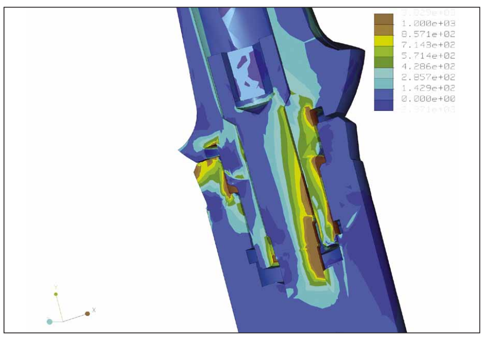


Fig. 5: FEM of implant-zirconium-dioxide-abutment-assembly at an external load of 250 N.

Fig. 6: FRIADENT® CERCON® abutment with hexagonal implant-abutment connection.

Fig. 7: Situation after flapless implant insertion. Pre-mounted XiVE® TempBase abutment is used as temporary abutment.

Fig.8: Non-functional provisional acrylic resin restoration immediately after implant insertion.

Fig. 9: Postoperative labial view after 4 months with CERCON® abutment *in situ*.

Fig. 10: Postoperative labial view at time of full-ceramic crown delivery.

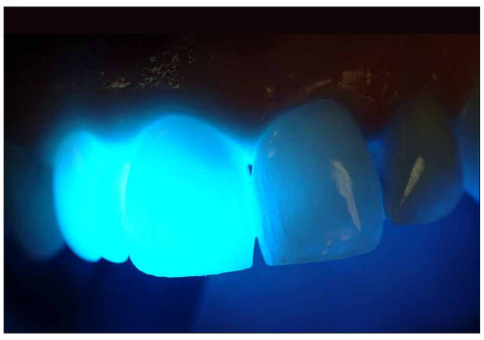

Fig. 11: Labial view with polymerization light of full ceramic restoration *in situ*. Note identical translucency of ceramic restoration and adjacent natural dentition.

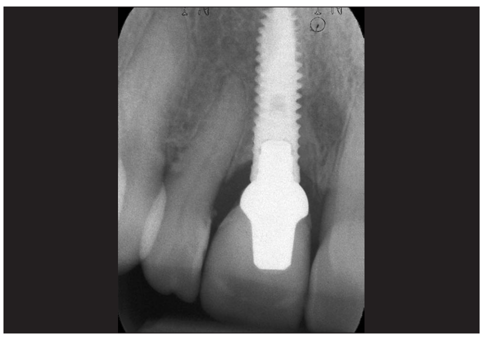

Fig. 12: Postoperative radiograph with final restoration.

## Literature

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