Fracture Resistance and Analysis of Stress Distribution of Implant-Supported Single Zirconium Ceramic Coping Combination with Abutments Made of Different Materials

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The purpose of this study was to compare the fracture resistance and fracture mode of single implant-zirconium coping combinations using zirconium and titanium abutments and to analyze the stress distribution pattern using three-dimensional finite elements analysis. Twenty implants with titanium and zirconium abutments were randomly divided into two groups (n = 10) and into resin blocks. Zirconium copings were cemented onto the abutments. The specimens were loaded with 135° angles to the long axis and the load values at the moment of failure were recorded using a universal test machine. Stress levels were calculated according to the maximum Von Mises criteria. The fracture resistances for titanium and zirconium abutment groups were 525.65 N and 514.05 N, respectively. No significant differences were observed between two groups regarding the fracture resistance levels. The maximum Von Mises equivalent stress concentrated on zirconium copings in both of the groups. Implant-abutment-ZrO₂ coping combination has the potential to withstand physiological occlusal forces in the anterior region. Three-dimensional finite elements analysis results of the implant-abutment-ZrO₂ coping combination is compatible with the results of fracture resistance.

Keywords: ceramic abutment, all-ceramic crown, titanium abutment, fracture resistance, stress analysis

Implant-supported single tooth restorations in the anterior segment demand a high degree of natural appearance and individuality. Dental implants and abutments are usually manufactured using pure titanium due to its well-documented biocompatibility and mechanical properties (Adell et al., 1981; Marinello et al., 1997). Although there have been several modifications in fabrication and design of metal abutments, there is still a risk of metallic components showing through when such abutments are used (Jemt, 1986). A grayish background may result with an unnatural bluish appearance in soft tissue even when placed subgingivally (Glauser et al., 2004). The presence of a gray gingival discoloration may be attributed to a thin gingiva that is incapable of blocking reflective light from the metallic abutment surface (Canullo, 2007; Jung et al., 2008). This is a major disadvantage for patients with gummy smile. Ceramic abutments are being used in dentistry to overcome this aesthetic disadvantage (Kollar et al., 2008; Kohal et al., 2008).

Dental implants have been restored with all-ceramic crowns hoping that a superior aesthetic outcome will result compared with metal ceramic crowns (Kollar et al., 2008; Kohal et al., 2008). However this may not be the case if a highly translucent restoration is placed on a metal abutment. Today ceramic abutments are fabricated using two different high-strength ceramic materials: a densely sintered high-purity alumina (Al₂O₃) ceramic and a yttrium-partially stabilized zirconium dioxide ceramic (Yıldırım et al., 2000). Although ceramic abutments are aesthetic, some questions exist as to their capacity to withstand functional loading (Att et al., 2006a, 2006b).

Furthermore, there is a lack of research on the fracture resistance of ceramic abutment in the dental literature. Biomechanical aspects of implant-supported restorations are currently under investigation and a number of in vitro, clinical studies have attempted to predict the clinical behavior of dental materials and techniques associated with implant-supported prostheses (Ormianer & Schiroli, 2006; Kohal et al., 2002)

In vitro methods include conventional in vitro laboratory test and finite elements analysis. Finite elements analysis (FEA) has been used for many years in industry to provide analytical solutions to problems involving complex geometric forms and a popular numerical

Note. In this article, the figures are in color in the online PDF.
method in stress analysis (Ho et al., 1994). It shows the internal stresses, and on that basis, predictions can be made about failure (Verdonschot et al., 2001).

The purpose of this study was to compare fracture resistance and fracture location of single implant-supported zirconium oxide (ZrO2) coping combinations with different abutments (titanium vs. ZrO2) and to analyze stress distribution patterns for the same combinations using 3-dimensional FEA. The null hypothesis tested in this study was as follows: both the single implant-titanium abutment-ZrO2 coping and single implant-ZrO2 abutment-ZrO2 coping combinations would exhibit the same fracture resistance and stress distribution patterns.

Methods

Twenty pure titanium implants with a diameter of 4 mm and a length of 12 mm were used in the current study. The implants were classified into two groups (1 and 2) of 10 specimens each. In group 1 titanium abutments were used, whereas in group 2 ZrO2. All abutments were fixed on dental implants (Biolok; Biolok Precision Dental Implant System, Szombathely, Hungary) using titanium screws. Fixture and abutment combinations were stabilized on a fixator (Herbst) with vertically moving rods, from the most coronal tip of each abutment with sticky wax. These combinations were then embedded in autopolymerizing acrylic resin (Meliodent, Bayer Dental, Newbury, United Kingdom) surrounded by plastic mold. Twenty abutments were fixed onto the fixture. All abutments had standard dimensions; a chamfer finish line of 1 mm depth and a total height of 9 mm. A 2 mm incisal reduction was performed for abutments using diamond rotary cutting instruments under water cooling. All abutments were restored with 1 mm thickness ZrO2 coping (ICE Zirkon, ZirkonZahn GmbH, Bruneck, Italy) and were torqued to 32 Ncm according to the manufacturer’s instructions. In the part of FEA, stress distribution on implant-abutment-ZrO2 coping combination supported by different abutment (ZrO2 vs. titanium) was evaluated by using a 3-dimensional FEA model. In the modeling of the FEA, a Biolok implant fixture with a diameter of 4 mm and a length of 12 mm was scanned by a computerized tomography (LPX-60/600 3D laser scanner, Roland DGA Corporation, California, USA) and the solid model was created using 3D Doctor Software (Able Software Corp, Lexington, USA). Autodesk Inventor (Autodesk, Inc. San Rafael, USA) was used for creating the implant fixture-abutment-ZrO2 coping combination system assembly together with cortical bone, cancellous bone, abutment screw, and luting cement (Figure 1). Then the model was exported to the ANSYS 10.0 Workbench Software (Swanson Analysis Inc., Houston, PA, USA) (Figure 2). The model was meshed using ANSYS 10.0 Workbench. 3-D triangular elements were used for the mesh. The numbers of elements and nodes of the models were 8,953 and 17,344, respectively. The thickness of ZrO2 coping was 1 mm. Model included modeling for use of luting cement in a film thickness of 50 μm. The mechanical property values required for the analysis (modulus of elasticity, Poisson’s ratio) are listed in Table 1. For simplification purposes all materials were considered homogeneous, isotropic, and linearly elastic. All materials were assumed to be rigidly bound together. A 100 N force was applied at 45 degrees 2 mm below the incisal edge of the palatal surface of the modeled coping. The 100 N load was determined from the current literature establishing the normal chewing force as a third of the maximum biting force (Kohal et al., 2002). All nodes on the outline of the bone surface were constrained in the vertical and labiolingual directions. This study was conducted by considering the three-dimensional Von

![Figure 1 — Mid-labiolingual section of model. Ceramic coping (A), luting cement (B), abutment, (C), abutment screw (D), implant fixture (E), cortical bone (F), cancellous bone (G).](image-url)
Mises criteria. The Von Mises value formula is given below (Toksavul et al., 2006):

\[ V_m = \frac{1}{\sqrt{2}} \sqrt{(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2} \]

The terms \( S_1, S_2, \) and \( S_3 \) are known as the principal stresses. The Von Mises formula results in a value that is always positive. The results are presented in terms of Von Mises stress values. Because the tensile strength values of all of the materials concerned are not available for comparison, the likelihood of a failure is decided by accepting the fact that a higher Von Mises stress value is a strong indication of a greater possibility of failure. To analyze stress location and distribution, the fixture, abutment, luting cement and coping combination was isolated from the rest of the model.

**Results**

Mean fracture loads for two test groups are presented in Table 2. The fracture resistances data for group 1 (titanium abutment) and group 2 (ZrO₂ abutment) were recorded at 525.65 N and 514.05 N, respectively. One-way ANOVA detected no significant difference in fracture resistance between two groups (\( p = .604 \)). In the evaluation of fracture location, while 2 abutment screws were fractured, 8 fractures were located at ZrO₂ copings in group 1 (titanium abutment). None of the titanium abutment was fractured. In group 2 (ZrO₂ abutment), whereas 7 ZrO₂ copings were fractured, 3 ZrO₂ abutments at cervical region were fractured. No screw fracture occurred in ZrO₂ abutment group (group 2). The types of fracture were observed in Figure 3.

When the three-dimensional model was subjected to simulated masticatory loading, maximum Von Mises equivalent stress was concentrated on the ZrO₂ coping for both groups (Figure 4). Maximum Von Mises stress distributions for models 1 and 2 were 139.27 MPa and 146.3 MPa, respectively.
Discussion

This study compared the fracture resistance and fracture location of titanium implant fixture and ZrO₂ coping combination with different abutments (titanium vs. ZrO₂). In addition, stress distributions were evaluated for the same combinations when applied simulated masticatory loading using 3-dimensional FEA. The null hypothesis was not rejected.

When analyzing the effect of the application of force on an implant-abutment-ZrO₂ coping combination, various experimental methods are used. Mechanical tests to analyze the fracture resistance of the implant-abutment-crown combination are used and mentioned in the literature (Att et al., 2006a; Cho et al., 2002). However, the use of biomechanical analyses, such as the finite elements method, have been used more frequently as they show the behavior and analysis of structure stress, which are not obtained in mechanical tests (Toksavul et al., 2006; Cho et al., 2002; Wang et al., 2009). The use of a combination of mechanical test and computational...
analyses would appear to be more suitable, as it facilitates an understanding of the real magnitude of resistance of implant-abutment-ZrO2 coping combination placed in the maxillary anterior region and is able to detail causative factors and the points of greatest influence in which such failures might occur. The association of the mechanical test (fracture resistance) and finite elements analysis methods (stress distribution) proved to be an efficient tool in complex structure analysis. To minimize the number of variables, all specimens were designed with similar dimensions only differing in the abutment type being used for both groups.

In the current study, the teeth were loaded palatinally at 135° to the long axis. This angle reflects the positions, contacts and loading characteristics of maxillary central incisors in Class I occlusion (Toksavul et al., 2005).

Ceramic abutments were fabricated using aluminum oxide (Al2O3) and ZrO2 ceramics (Yıldırım et al., 2000). Several studies evaluated the fracture resistance of ceramic abutments (Butz et al., 2005; Yıldırım et al., 2003). As a result of those studies, Al2O3 ceramic abutments exhibited significantly lower fracture resistance. In addition, Al2O3 ceramic abutment is not used in dental application. Therefore, ZrO2 abutment was used as ceramic abutment in the current study.

Although the fracture resistance of titanium abutment group (525.65 N) was lower than that of ZrO2 abutment group (514.05 N), there was no statistically significant difference under 135° angle oblique loading in the current study. In an in vitro study, Butz et al. compared the fracture resistance of ZrO2, aluminum oxide and titanium abutments (Butz et al., 2005). It was reported that fracture resistance of ZrO2, aluminum oxide and titanium abutments were 294 N, 239 N, and 324 N, respectively in that study. The results of that study were lower than the results of the current study. Application of thermomechanical cycling may be the reason of lower results for that study. In another in vitro study reported by Att et al., all specimens were received the thermomechanical cycling (Att et al., 2006b). According to that study, the group with titanium abutment (1,454 N) showed highest fracture resistance compared to groups with Al2O3 (422.5 N) and with ZrO2 (443.6 N).

The analysis of the fracture mode of the abutments revealed that no abutment fracture occurred in the titanium abutment group. Two abutment screws were fractured at the middle region of screws. On the other hand, no screw fracture occurred in the ZrO2 abutment group. Three abutments were fractured in the ZrO2 abutment group. From this point of view, this is an advantage for the ZrO2 abutment because when ZrO2 abutment was fractured it can be easily replaced. However, when a screw was fractured, it is almost impossible to replace the abutment. In an in vitro study, the abutment screw was identified as the weakest component for implant-titanium abutment–crown combination (Glauser et al., 2004).

The principal stresses are in fact normal stresses acting on principal planes on which the shearing stresses are zero. The reason for selecting Von Mises criteria, which apparently results in a tensile-type normal stress, lies in the fact that brittle materials fail primarily due to tensile-type normal stresses (Yaman et al., 1998). The stress levels and distributions were similar in spite of some notable differences between two groups. High stresses occurred in the ZrO2 coping where the loading originated. Low stress was associated with the facial region of the implant fixture for both groups. All units (implant fixture, abutment screw, and coping) except for the abutment were simulated as being made from the same material for both models, so that the ones revealing the highest stresses would indicate sites more prone to fracture. The probability toward fracture was primarily governed by amount and location of stress. Three-dimensional finite element stress analysis results for the maximum Von Mises stress were in harmony with the results of fracture resistance and location experiments in the current study. The fracture location in the fracture resistance experiment was predominantly at the palatal surface of the coping. In the FEA the palatal surface of coping was the maximum von Mises stress concentration area. There is no study to compare the FEA results of the current study in the dental literature. The results of this in vitro evaluation of all-ceramic prosthetic implant superstructures are promising. Long-term in vivo evaluation, however, is mandatory to provide a definitive prognosis of the clinical performance.

Within the limitations of this study, ZrO2 abutments can be safely used in the anterior region in respect to fracture resistance. No abutment screw was fractured in the ZrO2 abutment group. When ZrO2 abutment was fractured it can be easily replaced. Three-dimensional FEA results of implant-abutment-ZrO2 coping combinations are compatible with the results of fracture resistance. The results of three-dimensional FEA indicated that the use of different abutment did not affect the region of stress concentration in implant-abutment-ZrO2 coping.

References


