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The role of prosthetic abutment material on the stress distribution in a maxillary single implant-supported fixed prosthesis

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ABSTRACT

Purpose: Evaluate the influence of abutment's material and geometry on stress distribution in a single implant-supported prosthesis.
Materials and Methods: Three-dimensional models were made based on tomographic slices of the upper middle incisor area, in which a morse taper implant was positioned and a titanium (Ti) or zirconia (ZrN) universal abutments was installed. The commercially available geometry of titanium (T) and zirconia (Z) abutments were used to draw two models, TM1 and ZM1 respectively, which served as control groups. These models were compared with 2 experimental groups were the mechanical properties of Z were applied to the titanium abutment (TM2) and vice versa for the zirconia abutment (ZM2). Subsequently, loading was simulated in two steps, starting with a preload phase, calculated with the respective friction coefficients of each materials, followed by a combined preload and chewing force. The maximum von Mises stress was described. Data were analyzed by two-way ANOVA that considered material composition, geometry and loading ($p < 0.05$).
Results: Titanium and zirconia abutments showed similar von Mises stresses in the mechanical part of the four models. The area with the highest concentration of stress was the screw thread, following by the screw body. The highest stress levels occurred in screw thread was observed during the preloading phase in the ZM1 model (931 MPa); and during the combined loading in the TM1 model (965 MPa). Statistically significant differences were observed for loading, the material × loading interaction, and the loading × geometry interaction ($p < 0.05$). Preloading contributed for 77.89% of the stress ($p < 0.05$). There were no statistically significant differences to the other factors ($p > 0.05$).
Conclusion: The screw was the piece most intensely affected, mainly through the preload force, independent of the abutment's material.

1. Introduction

Osseointegration of dental implants achieves high predictability and survival rates, allowing successful use of minimally invasive surgical techniques that preserve the bone site [1,2]. Consequently, a major challenge for modern implantology is to obtain an ideal clinical outcome when rehabilitating single spaces in the anterior area of the maxilla, because of the great aesthetic need and inherent limitations of commercially available prosthetic components [3].

Ceramic components made of zirconia (Zr) are commonly used to construct single abutments in the anterior area, since these abutments have aesthetic advantages over conventional titanium (Ti) components in terms of their optical properties and light transmission characteristics. Zirconia components are similar to the dental structure and can prevent graying along the gum line [4–6] due to their better compatibility with the soft tissues [7].

Prosthetic zirconia abutments can be also personalized without compromising their mechanical resistance, thus allowing better aesthetics compared to their aluminum predecessors [8–10]. However, the large difference between zirconia's elastic modulus and the titanium screw of the implant might lead to microstrain at the implant-abutment interface which compromises the reliability [11]. This is analogous to the more extreme case of microstrain formation at the implant-tissue interface which has a markedly higher contrast in elastic moduli.

Although zirconia resists loading over time well, in vitro simulations have shown that its material properties can be influenced by its preparation technique and the design of the prosthetic components [3,12–14]. Moreover, these factors can directly influence the type of failure that occurs during mastication. Although the fracture resistance and the location of flaws in ceramic prosthetic abutments subjected to

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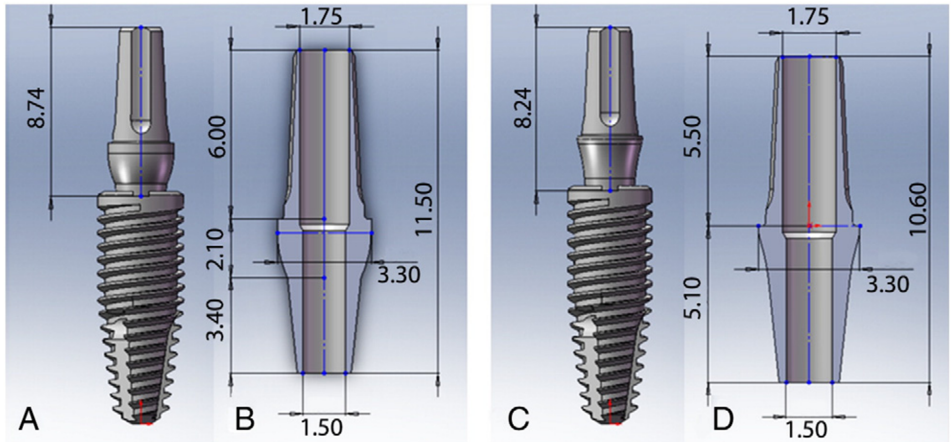

Fig. 1. Prosthetic abutments dimensions and geometry according to the manufacture. A–B: Titanium Universal Abutment; C–D: Zirconia Universal Abutment.

oblique force has shown to be similar to those for titanium abutments, the failure mechanism is distinct [9]. Failures related to ceramic abutments were observed in the interior of the prosthetic component, where the main cracked area was primarily in the cervical part of the buccal area. According to Aramouni et al. [9], this region receives greater torque and, consequently, the highest concentration of stress through levering effects.

Despite the high flexural strength, zirconia prosthetic abutments are able of distributing the induced stresses. However, there has been little discussion about the effects of the material and design of the prosthetic abutments on the stress distribution in the prosthesis-implant unit. The reported survival rates of zirconia abutments are close to 100%, with observation periods between 6 months to 4 years [15,16]. However, few clinical studies available and only one longitudinal study of 5 years has demonstrated a fracture or failure rate of approximately 10% when these abutments are in function [17].

The long-term clinical success of an implant is impacted by several factors, such as the type of loading, the implant-abutment connection, the type of material, and the bone-implant interface [18,19]. Previous studies evaluated the stress distribution in the bone tissue or compared different implant geometries [3,5,20,21]. However, realistic clinical simulations of the modalities of prosthetic restorations have not been considered so far. Quantitative and qualitative studies about the stress distribution behavior of prosthetic components made in zirconia rather than titanium might clarify the mechanism that predisposes the prosthetic unit to fail, especially in the anterior area of the maxilla whereas is submitted to oblique loading. This study evaluates the biomechanical behavior of zirconia and titanium prosthetic abutments installed in the anterior maxilla region through a finite element method analysis (FEA). This setup allowed to test the hypothesis that the zirconia abutments concentrate higher stress values and are more predictable to fail or damage the prosthetic abutment or crown, independent of the loading mode.

2. Materials and methods

2.1. Experimental design

The investigated factors of the in silico study were the abutment material (titanium vs. zirconia), the collar geometry of the abutments, and the type of loading (preloading vs. preloading + chewing force). Four models were studied: TM1 (titanium) and ZM1 (zirconia), both control groups are commercially available in different dimensions; TM2—titanium abutment with mechanical characteristics of zirconia; and ZM2—zirconia abutment with the mechanical characteristics of titanium.

After generating the mesh and inserting the friction coefficients, the preload traction for the prosthetic screw was calculated using the Faulckner modulus. The loading test was performed applying the preload to the screw and maintaining it until the end of the trial followed to the application of the chewing load in the center of the palatal surface of the prosthetic crown. The values were quantitatively determined through the maximum von Mises stress and qualitatively by describing the stress distribution. Data were analyzed by a two-way ANOVA ($\alpha = 5\%$).

2.2. Model construction

To generate the three-dimensional (3D) models, universal computer-aided design format of solid models of implant, abutment,

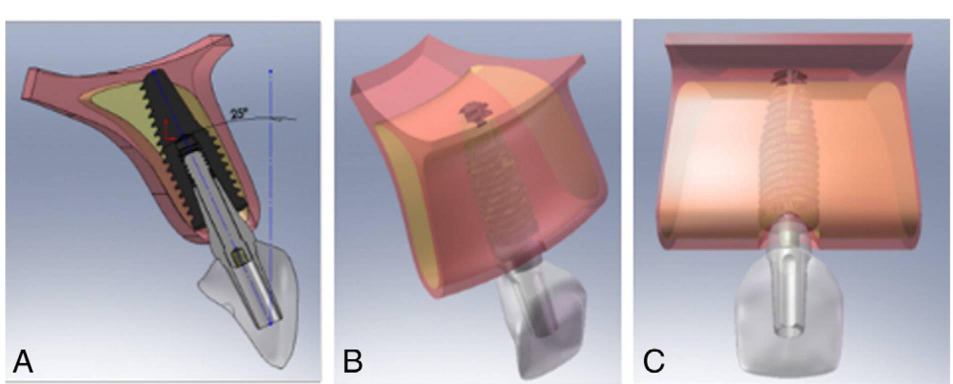

Fig. 2. Internal, lateral and frontal view of implant-abutment sets positioned on the bone model considering 2 mm below the bone crest, two ends in bicortical contact and inclination of 25°; A–B–C. Titanium Universal Abutment.