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Biomechanical analysis of different implant-abutments interfaces in different bone types: An in silico analysis

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ABSTRACT

The purpose of this study was to analyze the stress distribution of bone tissue around implants with different implant-abutment interfaces: platform switching (PSW); external hexagon (EH) and Morse taper (MT) with different diameters (regular: Ø 4 mm and wide: Ø 5 mm), bone types (I–IV) and subjected to axial and oblique load conditions using three-dimensional finite element analysis (3D-FEA). Sixteen 3D models of various configurations were simulated using InVesalius, Rhinoceros 3D 4.0, and SolidWorks 2011 software, and processed using Femap 11.2 and NeiNastran 11.0 programs. Axial and oblique forces of 200 N and 100 N, respectively, applied at the occlusal surface of prostheses. Maximum principal stress values were obtained from the peri-implant cortical bone of each model. Statistical analyses were performed using ANOVA and Tukey's test for maximum principal stress values. Oblique loading showed higher tensile stress than axial loading ($P < 0.001$). Wide-diameter implants showed lower stress concentration rather than regular-diameter implants, regardless of both connection and bone type ($P < 0.001$). Under axial loading, wide-diameter EH implants with regular platforms showed more favorable stress distribution than PSW implants for axial loading ($P < 0.001$); however, under oblique loading, PSW implants exhibited lower stress concentrations ($P < 0.001$). Regular-diameter MT implants showed lower stress than EH implants ($P < 0.001$). Bone type IV showed higher stress in the cortical region than bone types I and II ($P < 0.001$), but no significant difference when compared with bone type III ($P > 0.05$). The conclusion drawn from this in silico is that MT implants should be considered for use in situations that preclude the placement of wide-diameter implants, particularly where bone types III and IV are concerned.

1. Introduction

Preserving the bone level around implants is considered an important challenge in implant dentistry [1]. Reports indicate that implant survival may be compromised by external factors - such as apical migration of peri-implant tissues and local bacterial colonization - that have been associated with an increased risk for bone resorption and subsequent rehabilitation failure [2].

In view of this, platform switching (PSW) concept has been considered as an alternative means of reducing marginal bone loss around the implants [3]. The PSW concept refers to selection of a reduced prosthetic platform in relation to implant diameter, thereby increasing the horizontal distance between the abutment-implant interface and bone tissue [4]. While some studies have attributed this influence due to the stress distribution in the long axis of the PSW implants [3], implant diameter is considered the more influential variable [5].

Bone tissue quality and quantity are also believed to directly influence stress distribution [6]. Some studies report low-density bone tissue to have limited stress tolerance and an increased risk for bone resorption [7]. Clinically, low-density bone is associated with reduced implant survival rates compared to those bone of normal-density [8]. With other biomechanical studies having found no correlation between bone density and stress distribution, however, consensus remains unresolved [3,9].

Morse taper (MT) implants incorporating PSW concept show better stress distribution than implants with external connections [1,3]. However, there is no consensus regarding whether regular-diameter MT implants are comparable to wide-diameter external hexagon (EH)

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Table 1
Models description.

Models	Bone type	Description
M1	I	EH – Ø 5 × 10 mm with UCLA 4 mm (PSW)
M2		EH – Ø 5 × 10 mm with UCLA 5 mm
M3		EH – Ø 4 × 10 mm with UCLA 4 mm
M4		MT – Ø 4 × 10 mm with Pilar Speed
M5	II	EH – Ø 5 × 10 mm with UCLA 4 mm (PSW)
M6		EH – Ø 5 × 10 mm with UCLA 5 mm
M7		EH – Ø 4 × 10 mm with UCLA 4 mm
M8		MT – Ø 4 × 10 mm with Pilar Speed
M9	III	EH – Ø 5 × 10 mm with UCLA 4 mm (PSW)
M10		EH – Ø 5 × 10 mm with UCLA 5 mm
M11		EH – Ø 4 × 10 mm with UCLA 4 mm
M12		MT – Ø 4 × 10 mm with Pilar Speed
M13	IV	EH – Ø 5 × 10 mm with UCLA 4 mm (PSW)
M14		EH – Ø 5 × 10 mm with UCLA 5 mm
M15		EH – Ø 4 × 10 mm with UCLA 4 mm
M16		MT – Ø 4 × 10 mm with Pilar Speed

implants in terms of stress distribution. Thus, the aim of this study was to evaluate the biomechanical behavior of different implant-abutment interfaces in relation to implant diameter (regular and wide) and bone tissue type (I–IV). The null hypotheses were as follows: (1) the implant diameter did not influence stress distribution in the cortical bone tissue, (2) the implant-abutment connection did not influence stress distribution in the cortical bone tissue, and (3) the quality of bone tissue did not influence stress concentration in the cortical bone tissue.

2. Material and methods

2.1. In silico experimental design

This research was designed to consider three variable factors: 1) diameter (Ø 4 and Ø 5 mm); 2) implant-abutment interface (EH, MT, and PSW), and 3) bone tissue type (I–IV). Sixteen models were created to test these factors under axial and oblique loading (Table 1).

2.2. Three-dimensional and finite-element analysis

This methodology follows protocols from previous studies [1,3]. In silico three dimensional finite-element models were created to represent a mandibular bone section from the second molar region. Modeling was based on sagittal computerized tomography and accomplished using InVesalius software (CTI Renato Archer, Campinas, SP, Brazil). Surface simplification was performed using Rhinoceros 4.0 software (NURBS Modeling for Windows, Seattle, WA, USA). Different bone tissues were simulated according to the Lekholm and Zarb classification for the bone tissue [10]: type I, consisting of cortical bone only; type II, consisting of a 2-mm cortical layer and trabecular bone of normal density; type III consisting of a 1-mm cortical layer and trabecular bone of normal density; and type IV, consisting of a 1-mm cortical layer and trabecular bone of low density.

Implant and abutment was obtained from a version of the original connection (Conexão Sistemas de Prótese Ltda, Aruja, SP, Brazil), and simplified using SolidWorks 2010 (SolidWorks Corp, Concord, MA, USA) and Rhinoceros 4.0 software. Each bone model was fitted with either an EH implant and UCLA abutment or MT implant with solid abutment. Implants were 10 mm in length and either Ø 4.0 or Ø 5.0 mm in diameter (Fig. 1). The implant-supported crown was simulated with a screw-retained system for EH implant models, while MT models employed a cement-retained system with a cement layer thickness of 0.08-mm. Crowns were modeled on an artificial second molar tooth were simulated using a 3D scanner (MDX-20w, Roland DG, SP, Brazil) for digitalization (Odontofix Industria e Comercio de Material Odontologico Ltda., Ribeirao Preto, SP, Brazil). Feldspathic porcelain was used as the veneering material on external crown surfaces, and a nickel–chromium alloy was used of the framework.

After the modeling phase, all geometries were exported to finite-element analysis software FEMAP 11.2 (Siemens PLM Software Inc., Santa Ana, CA, USA) for pre- and post-processing. FEMAP was used to create finite element models from meshes of tetrahedral parabolic solid elements. The mechanical properties of each simulated material were determined according to previously published studies (Table 2) [11,12]. All materials were considered isotropic, homogeneous, and linearly elastic.

The crown-abutment and abutment-implant interfaces were assumed to have symmetrical contacts, and all other contacts were also assumed to be symmetrically welded. Constraint conditions were fixed in all axes (x, y, and z) at the anterior and posterior surfaces of each bone sections. All of the other model parts were unrestricted. A force of 200 N was distributed axially at four points on the internal slope of each cusps, and 100 N was distributed obliquely at two points on the internal slope of the lingual cusps (Fig. 1). Functional load was applied perpendicularly to the chewing surfaces of the cusps [1,3].

After the pre-processing in FEMAP 11.2 software, the models were exported for mathematical calculation in the NeiNastran 11.0 software package (Noran Engineering, Westminster, CA, USA). With analytical problems solving complete, the models were then imported to FEMAP 11.2 for post-processing and visualization of stress maps. Maximum principal stress analysis was used to identify traction and compression stresses in peri-implant cortical bone due to the friable nature of the tissue. Measurement was in mega-Pascal (MPa) units, and tensile and compressive stresses were distinguishable by positive and negative values, respectively.

2.3. Statistical analysis

The highest 50 values for elements of maximum principal stress in peri-implant cortical bone [13] were compiled in Excel (Microsoft Office Excel, Redmond, WA, USA) and the spreadsheets exported to Sigma Plot 12.0 software package (Systat Software Inc., San Jose, CA, USA). Data were analyzed for normality (test Shapiro-Wilk test) and equal variance, before being subject to analysis of variance (ANOVA). Two-way ANOVA was conducted on diameter versus bone type, and abutment-implant interface versus bone type, under axial and oblique loading. Regions (mesial, buccal, lingual, and distal) and loading (axial and oblique) were analyzed using three-way ANOVA (connection, loading, and region). The Tukey post hoc test was used to identify differences between groups with significance set at $P < 0.05$.

3. Results

3.1. Diameter analysis

Under axial loading, regular-diameter implants (Ø 4 mm) showed higher compressive stress (mean: 1.324 MPa) than those wide-diameter (Ø 5 mm) implants (mean: 0.636 MPa) ($P < 0.001$). In bone type I, lower stress concentrations without significant influence of diameter ($P = 0.553$) were observed; however, in the other bone types the wide-diameter contributed to stress distribution more than the regular-diameter ($P < 0.001$) (Fig. 2). Under oblique loading, wide-diameter implants showed lower tensile and compressive stresses (mean: 3.078 MPa) than the regular-diameter implants (mean: 9.773 MPa), regardless of both connection and bone type ($P < 0.001$) (Fig. 3).

3.2. Implant-abutment interfaces analysis

Maximum principal stress analysis revealed that regular-diameter MT implants show lower tensile stress than EH implants under both loadings ($P < 0.001$); Wide-diameter EH implants exhibited lower stress concentration than PSW implants under axial loading ($P < 0.001$) (Figs. 2 and 4). Under oblique loading, however, the PSW