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Effect of bar cross-section geometry on stress distribution in overdenture-retaining system simulating horizontal misfit and bone loss

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ABSTRACT

This study evaluated the influence of cross-section geometry of the bar framework on the distribution of static stresses in an overdenture-retaining bar system simulating horizontal misfit and bone loss. Three-dimensional FE models were created including two titanium implants and three cross-section geometries (circular, ovoid or Hader) of bar framework placed in the anterior part of a severely resorbed jaw. One model with 1.4-mm vertical loss of the peri-implant tissue was also created. The models set were exported to mechanical simulation software, where horizontal displacement (10, 50 or 100 μm) was applied simulating the settling of the framework, which suffered shrinkage during the laboratory procedures. The bar material used for the bar framework was a cobalt—chromium alloy. For evaluation of bone loss effect, only the 50-μm horizontal misfit was simulated. Data were qualitatively and quantitatively evaluated using von Mises stress for the mechanical part and maximum principal stress and μ-strain for peri-implant bone tissue given by the software. Stresses were concentrated along the bar and in the join between the bar and cylinder. In the peri-implant bone tissue, the μ-strain was higher in the cervical third. Higher stress levels and μ-strain were found for the models using the Hader bar. The bone loss simulated presented considerable increase on maximum principal stresses and μ-strain in the peri-implant bone tissue. In addition, for the amplification of the horizontal misfit, the higher complexity of the bar cross-section geometry and bone loss increases the levels of static stresses in the peri-implant bone tissue.

1. Introduction

Edentulous patients with severely resorbed mandible often experience problems with conventional dentures, such as insufficient stability and retention, together with a decrease in chewing ability (Bergman and Carlsson, 1985; van Waas, 1990). These problems can be solved with the use of implant-retained or implant-supported overdentures (Andreiotelli et al., 2010; Attard and Zarb, 2004). Overdenture in mandible presents the following benefits comparing to complete denture treatment: better chewing ability, better fit and retention, improved function, and improved quality of life (Fueki et al., 2007).

Mandibular implant overdenture retained to independent balls attachments (O-rings) allow the prosthesis to rotate in all directions (Kimoto et al., 2009), although they provide patient satisfaction for the treatment (Burns et al., 2011). Sometimes, however, the inclination of the implants may preclude the use of these attachments. Resilient attachments are another possibility to affix the denture to a rigid bar assembly that interconnects with the osseointegrated implants (Romero et al., 2000). When this system is chosen, a passive fit between the bar framework and the implants is required for successful restoration (al-Turki et al., 2002; Zarb and Symington, 1983). The major difference to teeth is that osseointegrated implants do not have the resiliency of the periodontal membrane found in natural dentition (Richter, 1989). Therefore, the implants are unable to fit to the misfits (Spazzin et al., 2011b).

Potential distortion can be created at any step of the implant prosthesis fabrication process. The error is due primarily to the volumetric and linear dimensional changes of the fabrication materials used (Assif et al., 1996; Carr and Stewart, 1993;

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Rubenstein and Ma, 1999). Several techniques have been developed to correct inaccuracies of fit resulting from the fabrication process (Karl et al., 2012; Sartori et al., 2004; Silva et al., 2008); however, implant prosthesis misfits are a clinical reality, as even these procedures are unable to completely eliminate these challenges (Sahin and Cehreli, 2001).

A previous study using finite element analysis (FEA) showed that the amplification of vertical misfits increased the concentration of static stress in the mechanical part of an overdenture-retaining bar system, although this increase was not considerable in the peri-implant bone tissue (Spazzin et al., 2011a). Another study evaluating the influence of horizontal misfit in static stress distribution in overdenture-retaining bar system showed considerable increase of the stress levels in mechanical and biological parts of the system (Spazzin et al., 2011b). The researchers suggested that horizontal misfits could do more damage for the peri-implant bone tissue in multi-unit implant prostheses.

Several cross-section geometry of the bar are available, including circular, ovoid and Hader. The latter is an eponym of technician Helmut Hader for a rigid bar connecting two or more abutments; when viewed in cross-section, it resembles a keyhole, consisting of a rectangular bar with a rounded superior (occlusal) ridge that creates a retentive undercut for the female clip within the removable prosthesis (Anon, 2005). The bar material has presented to effect the stress concentration, where stiffer material increases the stress in the system when misfit are found (Spazzin et al., 2011b). Therefore, the different cross-section geometry of the bar could also influence stress distribution.

Another factor with limited information concerns occurrence of stress distribution in overdenture bars after bone loss. Studies have shown a bone loss of 1.4 mm after 5- and 10-year evaluation (Meijer et al., 2004; 2009). In this context, it is important to know the cross-section geometry of the bar to present better mechanical behavior when bone loss and misfit are found. Therefore, the aim of this study was to evaluate, using 3D FEA, the influence of: (1) cross-section geometry of the bar (circular, ovoid, or Hader) simulating three different horizontal misfits (10, 50 or 100 μm); and (2) cross section of the bar (circular, ovoid, or Hader) and marginal bone loss (0 or 1.4 mm) simulating 50-μm horizontal misfit on the distribution of static stresses in an overdenture-retaining bar system. The hypothesis tested was that the circular cross-section would present lower levels of static stresses in mechanical and biological parts when misfits and bone loss are found.

2. Materials and methods

2.1. Geometric model

Three-dimensional solid models reproducing anterior part of a resorbed mandible (without and 1.4-mm bone loss) and different overdenture-retaining bar systems (circular, ovoid, or Hader) above two osseointegrated implants (4-mm diameter × 10-mm length) (Fig. 1) were built using 3-D modelling software (SolidWorks 2010; SolidWorks Corp., Concord, MA, USA). The bone dimensions were the following: 11-mm buccolingual width, 29-mm mesiodistal length, 14.5-mm of height, and cortical bone with 0.5-mm thickness. The dimensions of the bar framework were the following: circular bar presented 15-mm diameter; ovoid bar presented 20-mm height and 15-mm diameter in your superior part; and Hader bar presented 25-mm height, 15-mm diameter in circular superior part, and 10-mm width in rectangular inferior part.

2.2. Finite element model

FE models were obtained by importing the solid model into mechanical simulation software (ANSYS Workbench 11; Ansys Inc., Canonsburg, PA, USA.). All materials used in the models were considered to be isotropic, homogeneous and linearly elastic. The elastic properties used (Table 1) were taken from literature (Abu-Hammad et al., 2000; Craig, 1989; Korioth and Johann, 1999; Sakaguchi and Borgersen, 1993).

Two FEAs were performed separately. In the first analysis, nine models were created with three bar cross-section geometries — circular (C), ovoid (O), or Hader (H) — and three levels of horizontal misfit (10, 50, or 100 μm): C10, O10, H10, C50, O50, H50, C100, O100 and H100. For the second analysis, three models were created with three bar cross-section geometries — circular (C), ovoid (O), or Hader (H) — and 1.4-mm bone loss (bl) with 50-μm horizontal misfit: C50-bl, O50-bl and H50-bl. The models C50, O50 and H50 were used as control (without bone loss).

Horizontal displacements in the mesiodistal direction were applied on the bar end to simulate the closing of the horizontal misfit through tightening of the retaining screws. In other words, the bar end was pulled horizontally in the direction described previously. The horizontal misfits simulate a condition of length linear change. This can be created by contraction during the casting process, reducing the bar length (Fig. 1B). The elements used were tetrahedral with 10 nodes. The total of elements generated in the FE models range from 368,366 to 434,597; and total de nodes ranged from 596,904 to 698,045.

Model stability was performed to obtain reliable models, which were regarded as relevant to engineering and clinical aspects. Particular attention was paid to the refinement of the mesh at the bone-implant interface. The implant thread was removed because convergence tests found it was not relevant to the analysis and provided a relevant reduction in elements.

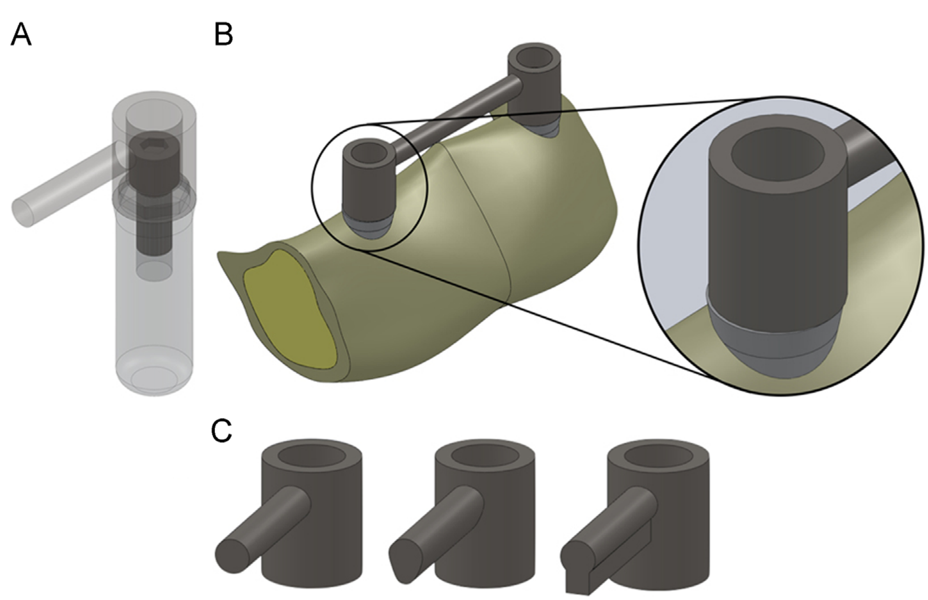

Fig. 1. (A) Design of the bar end, screw and implant. (B) Design of the geometric model and misfit simulated. (C) Design of the different cross-section geometry of the bar.