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Effect of attachment types and number of implants supporting mandibular overdentures on stress distribution: A computed tomography-based 3D finite element analysis

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ABSTRACT

The objective of this study was to calculate stresses in bone tissue surrounding uncoupled and splinted implants that are induced by a bite force applied to the mandible and to determine whether the number of mandibular overdenture supporting implants in mandibular bone influence the stress distribution. A human adult edentulous mandible retrieved from a formalin fixed cadaver was used to define the geometry of finite element (FE) model and the FE model was verified with experimental measurements. Following the FE model validation, three different biting situations were simulated for the 2-, 3- and 4-implant retentive anchor as well as bar attachment overdentures under vertical loading of 100 N. As a result of the analyses, it was concluded that an increment in implant number and the splinted attachment type tended to cause lower stresses and the use of two single attachments seems to be a safe and sufficient solution for the treatment of mandibular edentulism with overdentures.

1. Introduction

With the rise of the number of aged people, it is estimated that the ratio of individuals over 65 years of age will reach up to 50% of the whole population in the coming decades and the number of edentulous patients even in countries with a high standard of dental health care will be significant in near future. Especially in edentulous cases, implant overdentures (IODs) help obtain better retention, thus a more comfortable function (Jemt and Staldblad, 1986).

The finite element (FE) methods are widely used in implant dentistry to predict the effects of clinical factors on implant success (DeTolla et al., 2000; Geng et al., 2001; Cruz et al., 2009). Validation of biomechanical stress and strain measurements by using strain gauges is important to have reliable results (Baiamonte et al., 1996). Nonetheless, strain gauge measurements are limited to the area where the gauge is bonded, whereas the FE methods can be used to calculate stress and strain in any location of the model (Baiamonte et al., 1996).

In literature, comparison of stress distribution between complete dentures and IODs, effects of mucosa thicknesses and resiliency on stress distribution of IODs (Barão et al., 2008; Assunção et al., 2009), influence of the retention mechanism on biomechanical behavior of IOD with two implants (Daas et al., 2008), comparison of stress distribution of IOD with ball, O-ring and magnetic attachments (John et al., 2012), stress analyses of IODs with four different bar heights (Rismanchian et al., 2012), effect of different implant positions on pre-implant bone stress of IODs with two-implants (Hong et al., 2012) and effect of different designs of IODs and fixed full-arch implant-supported prosthesis on stress distribution in edentulous mandible (Barão et al., 2013) were investigated by using the FE methods. The influence of different attachment types (namely, bar and ball attachments) on stress distribution was also investigated in several studies (Assunção et al., 2008; Barão et al., 2009; Vafaei et al., 2011) and no significant difference between these attachments was reported (Thayer and Caputo, 1980; Skalak, 1983; Menicucci et al., 1998a,1998b; Duyck et al., 1999; Vafaei et al., 2011). While there are studies having evaluated satisfaction and reporting higher scores for bar attachments (Cune et al., 2005; Timmerman et al., 2004), other studies contend equal (Gotfredsen and Holm, 2000; MacEntee et al., 2005) or less satisfaction of patients (Naert et al., 2004) with bar attachments. To date, there is no consensus on the influence of

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implant number on stress distribution (Meijer et al., 1996; Klemetti, 2008; Liu et al., 2013). Usually, two implants are considered sufficient to support an IOD (Klemetti, 2008) and there is no concrete evidence that such IODs have a better success and satisfaction rate.

A few validated comprehensive comparative FE studies exist in literature that consider the influence of different attachment types, implant numbers and loading conditions on biomechanical behavior of IODs. The aim of this study is to calculate stresses occurring during occlusal loadings of mandibular IODs with two different attachment types and varying numbers of supporting implants and to give clinicians, from force distribution point of view, a comparative insight on the influence of implant number as well as IOD attachment type.

2. Materials and methods

A human adult edentulous mandible retrieved from a formalin fixed cadaver, that is judged by visual inspection, is used to define the geometry of the FE model. Following, a 3D advanced computer-aided design (CAD) model is created by using a commercially available CAD software (CATIA, Dassault Systemes, Vélizy-Villacoublay Cedex, France) from dental volumetric cone beam tomography scan data (Newtom, Elmsford, NY, USA) of the mandible. Overdentures and the supporting soft tissue are included in the model as well. The mucosa thickness is taken as constant and used in the experimental in-vitro studies (Tokuhisa et al., 2003; Gonda et al., 2004); hence, possible changes in denture movement around the fulcrum due to posterior mucosa resilience are neglected. The mucosa thickness of 1.5 mm covering the cortical bone thickness of 2 mm is defined around the cancellous core. The denture is scanned in 3D by using a scanner (i.e., Atos II, Gom GmbH, Braunschweig, Germany) and later it is modeled as a wax rim with a denture base without the teeth to simplify the FE model and mounted on the mucosa. The 3D solid models of implants and abutments are developed by using a comparative technique involving high-resolution pictures and actual implants. The CAD models of a 4.1/12 mm Standard Plus Straumann dental implant (i.e., Straumann, Basel, Switzerland) with either a 7 mm transmucosal extension representing the connected bar abutment or the connected ball abutment are created by the CATIA program. To simulate the bar reconstruction, the most coronal 3 mm of the implant models were connected to each other, and the implants, abutments and screws are assumed to be one-piece and rigidly connected to the representative model of the bar superstructure, because the mechanical behavior of the Morse taper implant-abutment connection resembles a one-piece structure (Cehreli et al., 2004). The ball abutments and implants are taken as a one-piece structure and rigidly connected to the denture as well. Three different bar constructions are modeled for 2, 3 and 4-implant retained situations. The constructed models are imported to the FE analysis software of ANSYS 12/ Workbench (ANSYS 12 Workbench, ANSYS, Canonsburg, PA, USA) for the analyses of stress levels in the mandible caused by bite force loading (Fig. 1).

All models mainly consist of 3-D 10-node tetrahedral structural solid elements. These elements have a quadratic displacement behavior and well suited to model irregular meshes. To obtain the best balanced accuracy and efficiency of numerical simulations, a standard convergence test is applied. As a result, the smallest model has 300,017 nodes and 167,375 elements, while the largest model has 441,144 nodes and 250,327 elements.

Six different models (namely, 2-implant ball and bar attachments, 3-implant ball and bar attachments, and 4-implant ball and bar attachments) with three different loading conditions (i.e., anterior loading ($F_1=F_2=0$ N, $F_3=100$ N), loading on the right ($F_1=100$ N, $F_2=F_3=0$ N), and loading bilaterally on left and right ($F_1+F_2=100$ N, $F_3=0$ N) are simulated with a static occlusal force of 100 N (Mericske-Stern et al., 1993; Barão et al., 2008,2009,2013) (Fig. 2). Since a bending moment is expected during the posterior loading, due to the tendency of saddle movement towards the alveolar crest, the occlusal load is applied to different locations to mimic the mastication.

The mandibular boundary conditions are applied by mimicking the experimental set up of the strain gauge study (Arat Bilhan et al., 2013 in which a computed tomography-based 3D FE model was constructed by using a real human adult edentulous mandible (Fig. 2). Two different contact types such as the bonded and no separation contacts are used in ANSYS/Workbench to describe the contact

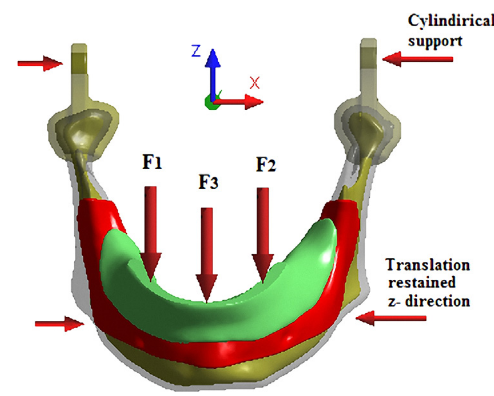

Fig. 2. Three different biting situations and boundary conditions in FE models: anterior loading ($F_1=F_2=0$ N, $F_3=100$ N), loading on the right ($F_1=100$ N, $F_2=F_3=0$ N), loading bilaterally on left and right ($F_1+F_2=100$ N, $F_3=0$ N).

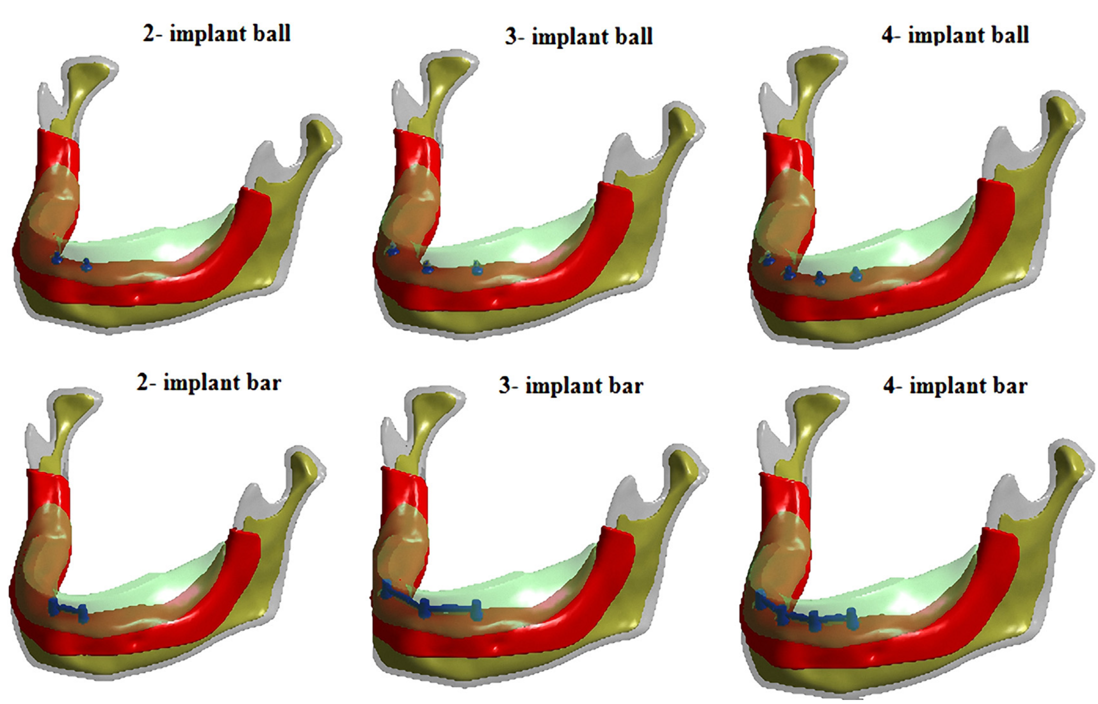

Fig. 1. Six different FE models which consist of cortical bone, cancellous bone, mucosa, overdenture, implants and prosthetic components.