Journal of Biomechanics 46 (2013) 1312–1320

Contents lists available at SciVerse ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Comparison of different designs of implant-retained overdentures and fixed full-arch implant-supported prosthesis on stress distribution in edentulous mandible – A computed tomography-based three-dimensional finite element analysis

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ARTICLE INFO

Article history:
Accepted 9 February 2013

Keywords:
Dental Implants
Overdenture
Fixed full-arch prosthesis
Biomechanics
Finite element analysis

ABSTRACT

A finite element analysis was used to compare the effect of different designs of implant-retained overdentures and fixed full-arch implant-supported prosthesis on stress distribution in edentulous mandible. Four models of an human mandible were constructed. In the OR (O'ring) group, the mandible was restored with an overdenture retained by four unsplinted implants with O'ring attachment; in the BC (bar-clip) -C and BC groups, the mandibles were restored with overdentures retained by four splinted implants with bar-clip anchor associated or not with two distally placed cantilevers, respectively; in the FD (fixed denture) group, the mandible was restored with a fixed full-arch four-implant-supported prosthesis. Models were supported by the masticatory muscles and temporomandibular joints. A 100-N oblique load was applied on the left first molar. Von Mises (σ_{vM}), maximum (σ_{max}) and minimum (σ_{min}) principal stresses (in MPa) analyses were obtained. BC-C group exhibited the highest stress values (σ_{vM}=398.8, σ_{max}=580.5 and σ_{min}=−455.2) while FD group showed the lowest one (σ_{vM}=128.9, σ_{max}=185.9 and σ_{min}=−172.1). Within overdenture groups, the use of unsplinted implants reduced the stress level in the implant/prosthetic components (59.4% for σ_{vM}, 66.2% for σ_{max} and 57.7% for σ_{min} versus BC-C group) and supporting tissues (maximum stress reduction of 72% and 79.5% for σ_{max}, and 15.7% and 85.7% for σ_{min} on the cortical and trabecular bones, respectively). Cortical bone exhibited greater stress concentration than the trabecular bone for all groups. The use of fixed implant dentures and removable dentures retained by unsplinted implants to rehabilitate edentulous mandible reduced the stresses in the periimplant bone tissue, mucosa and implant/prosthetic components.

1. Introduction

The oral rehabilitation of edentulous patients has been improved by the use of dental implants (Branemark et al., 1977; Gallucci et al., 2009a) using fixed and removable prosthesis (Akca et al., 2007; Ekelund et al., 2003). The use of two or four implants to retain mandibular overdentures has been indicated with similar clinical and radiographic outcomes (Batenburg et al., 1998; Visser et al., 2005). In situations with short or narrow implants that require increased retention, more than two implants are inserted (Mericske-Stern et al., 2000). In order to support mandibular fixed full-arch implant prosthesis, four to six implants are placed in the foramina area (Chee and Jivraj, 2006).

Several factors play a role on the decision between fixed and removable implant dentures as inter-foraminal space, inter-jaw relationship, oral hygiene, cost and patient's preference (Stellingsma et al., 2004). Overdentures are indicated when patients are not satisfied with stability and retention of the conventional removable denture but no complain about pain and discomfort of mucosa should exist (Zitzmann et al., 2005). Fixed full-arch implant-supported prosthesis is indicated in the presence of enough bone and inter-arch space (Chee and Jivraj, 2006). However, when there is loss of soft and hard tissues to support the facial tissue by the buccal denture flange, fixed prosthesis is contraindicated (Zitzmann and Marinello, 2002).

Overdentures are considered a simple, cost-effective, viable, less invasive and successful treatment option for edentulous

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http://dx.doi.org/10.1016/j.jbiomech.2013.02.008

patients (Assuncao et al., 2008; Barao et al., 2009). However, controversies toward the design of attachment systems exist (Bilhan et al., 2011). In vivo (Duyck et al., 1999; Menicucci et al., 1998) and biomechanical studies using finite element (FE) (Barao et al., 2009; Menicucci et al., 1998), strain gauge (Porter et al., 2002; Tokuhisa et al., 2003) and photoelastic (Celik and Uludag, 2007; Kenney and Richards, 1998) analyses displayed better stress distribution for overdentures retained by unsplinted implants while others showed superiority with the use of splinted implants (Assuncao et al., 2008; Cekic et al., 2007; Fanuscu and Caputo, 2004; Jofre et al., 2010).

Loading transmission during mastication influence the success of implant restorations (Tabata et al., 2011) and the loading distribution pattern in implant-retained overdentures would differ from those in implant-supported fixed restorations (Tokuhisa et al., 2003). However, no study has investigated the stress pattern of implant-retained overdentures versus fixed full-arch supported prosthesis.

This study aimed to compare the effect of different designs of implant-retained overdentures and fixed full-arch implant-supported prosthesis on stress distribution in edentulous mandible by using a 3D finite element analysis (FEA). The research hypotheses were: (i) fixed prosthesis would result in less stress level in the implant/prosthetic components and periimplant bone when compared to overdentures, (ii) the different designs of overdenture attachment systems would induce distinguished stress distribution and level in the implant/prosthetic components and periimplant bone.

2. Method

Four FE models of a complete edentulous human mandible were constructed and restored with different designs of implant-retained overdentures and fixed full-arch implant-supported prosthesis. In the OR group, mandible was restored with overdenture retained by four unsplinted implants with O'ring attachment system; in the BC-C and BC groups, mandibles were restored with overdentures retained by four splinted implants with bar-clip attachment system associated or not with two distally placed cantilevers, respectively. Finally, in the FD group, mandible was restored with fixed full-arch four-implant-supported prosthesis.

2.1. Model design

The 3D geometry of the mandible and denture was reconstructed from cone beam computerized tomography (CBCT) (I-Cat Cone Beam Volumetric Tomography System, Imaging Sciences International, Hatfield, PA, USA) of a complete edentulous mandible of a 60-year-old man prepared with a radio-opaque (acrylic resin mixed with barium sulfate – 3:1 ratio) duplicate of his denture (Fig. 1). It was done an effort to provide the accurate relationship between denture and mandible. The mandibular section profiles were collected at 2 mm-increments. Patient signed an informed consent form according to our local Human Research Ethics Committee (#2008-00939).

The CBCT files were imported into the Simpleware 4.1 software (Simpleware Ltd, Rennes Drive, Exeter, UK) for construction of the 3D solid geometries of mandible and denture. Based on the actual position of mandible and denture, the precise geometry of mucosa in contact with the inner surface of the denture was deduced (Daas et al., 2008). In mandible, cortical and trabecular bones were delimitated based on the CBCT data. The thickness of mucosa and cortical bone were approximately 3.0 mm and 1.5 mm in the interforamina area, respectively. The temporomandibular joint was modeled simulating the condyle resting in the glenoid fossa of the temporal bone (Devocht et al., 2001) with no articular disc.

Four cylindrical titanium implants with 11.5-mm length and 3.75-mm diameter were modeled (SolidWorks 2010, Dassault Systèmes SolidWorks Corp., Concord, MA, USA) and virtually inserted into each model. In all models, implants were placed in the center of the mandibular crest at 10 and 20 mm away from the midline on both sides of the mandible (Zarone et al., 2003) (Fig. 2).

The different attachment systems of the overdentures and the superstructure of the fixed full-arch implant-supported prosthesis were created into the same CAD software. The distal cantilever of the BC-C group had 3.5-mm height, 1.8-mm width and 7-mm length (Sadowsky and Caputo, 2000). In the FD group, the superstructure presented 4-mm height and 6-mm width (Sertgoz and Guvener, 1996) and a cantilever with 10-mm length (Zarone et al., 2003) (Fig. 2).

The implants and prosthetic components were imported into the Simpleware software and merged with the mandible and denture. For the FD group, denture bottom was reduced and planned. In the overdenture groups, the space for each attachment system in the inner surface of the denture was provided by a boolean operation (Fig. 2). Finally, models were meshed with parabolic tetrahedral interpolation solid elements. Mesh refinement was based on the analysis convergence (6%) (Pessoa et al., 2010). The models had 319,644 elements and 89,912 nodes in OR group,

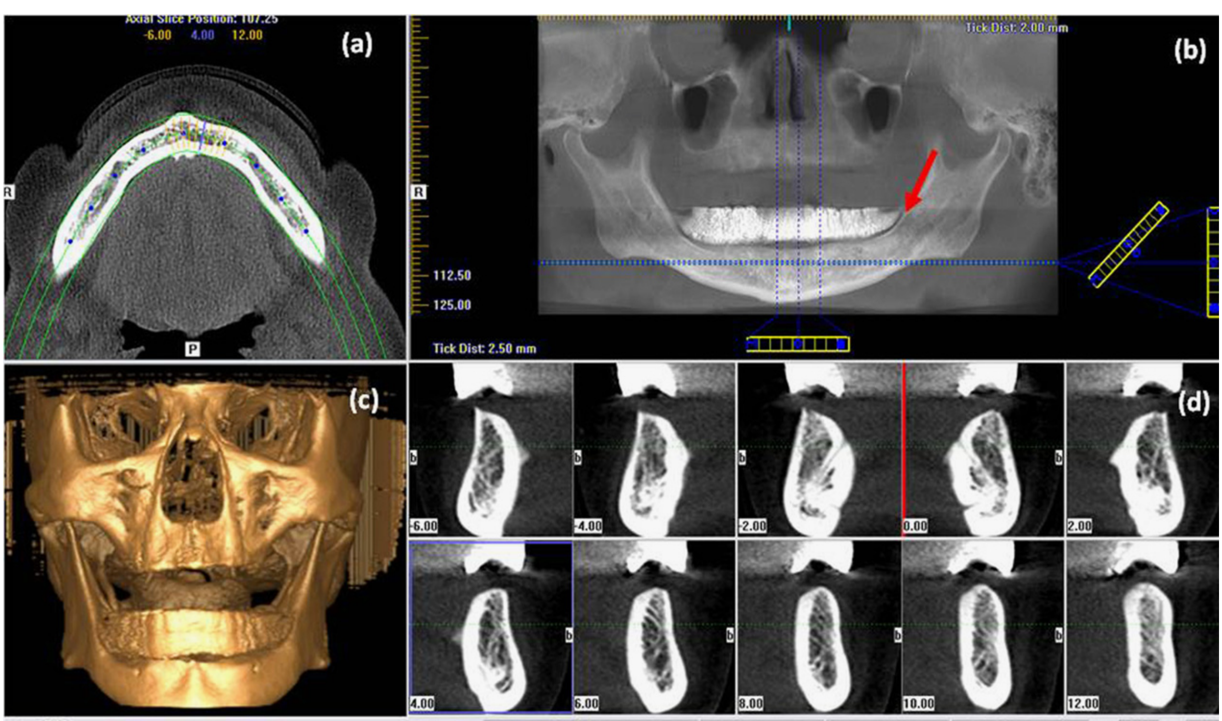

Fig. 1. Mandible CT scan of an edentulous patient with the radiopaque duplicated lower denture in position (a) Inferior view of the mandibular arch. (b) Panoramic view of the mandible with the lower denture in position (red arrow). (c) Instant 3D reconstruction of the CT scan. (d) Transverse section (2-mm thickness) of the mandible. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)