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The effect of implant number and position on the stress behavior of mandibular implant retained overdentures: A three-dimensional finite element analysis

Tolga Topkaya [a,*], Murat Yavuz Solmaz [b]

[a] Batman University, Engineering and Architecture Faculty, Mechanical Engineering Department, Turkey
[b] Fırat University Engineering Faculty, Mechanical Engineering Department, Turkey

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ABSTRACT

The present study evaluated the effects of ball anchor abutment attached to implants with a 4.30 mm diameter and 11 mm insert length on stress distribution in a patient without any remaining teeth in the lower jaw. In the study, the stress analysis was performed for five different configurations (2 with 4 implant-supported and 3 with 2 implant-supported) and three different loading types using ANSYS Workbench software. The stresses measured in the 4 implant-supported models were lower compared to the stresses measured in the 2 implant-supported models. The stresses on the implants intensified on the cervical region of the implants. When the effects of the loading sites on the stress were examined, the loading on the first molar tooth produced the highest stresses on the implants.

1. Introduction

The struggle and desire to esthetically restore the lost body parts is as old as the history of humanity. Restoring the function and esthetics of the lost tissues has been the main focus of scientists for centuries. It has been reported that stone, wood, and even animal teeth have been used as the supportive structure in the maxilla (upper jaw) and mandible (lower jaw) (ME, 1995). The improvements have been made to this approach in dentistry, and implants have been developed and introduced into the practice of dentistry to restore lost functions. The materials used in dental implants vary greatly, along with the multiplicity of models. Experimental and mathematical stress analyses are required to select the appropriate geometry and material of dental implants. Generally, the finite element method is used in mathematical analysis. Barbier et al. evaluated axial and non-axial forces around intraosseous implant systems using the finite element method, and showed the need for reducing horizontal loading (Barbier et al., 1998). Lin et al. used functionally graded material (FGM) and titanium as the implant material and evaluated the distribution of stress on the cortical and trabecular bone in a two dimensional mathematical model, in which FGM was found to have provided more homogeneous stress distribution. Their study showed that functionally graded material provided better fusion of the implant in the jaw bone and the bone tissue, and faster recovery of the bone tissue (Lin. et al., 2010). Bonnet et al. evaluated biomechanical behaviors of the 4 implant-supported prosthesis according to isotropic and non-isotropic bone characteristics using the finite element method. They constructed the mandible without any remaining teeth and the geometry of the prosthesis using computerized tomography (CT) images. Isotropic and non-isotropic models were compared after the insertion of two vertical and two inclined implants into the mandible, and they found significant differences in terms of stress, strain, and the intensity of strain-energy. They showed that the inclined insertion of the implants created high strain forces (Bonnet et al., 2009). Kleis et al. applied two implant-supported prosthesis by individual alignment or using ball anchor implants, and the connectors were compared after one year. They concluded that individual alignment required higher maintenance when compared to ball anchor implants (Kleis et al., 2010). Sadowsky et al. inserted bar-supported overdentures to the lower jaw, and using a photoelastic method, they experimentally evaluated the difference in stress distribution caused by the use of two or three implant supports (Sadowsky and Caputo, 2004). Barao et al. evaluated the effects of different designs in implant-supported overdentures and implant fixed prosthesis on the stress distribution using finite element method (Barao et al., 2013). Liu et al. investigated the effects of the number of implants used in implant-supported overdentures in three different loading conditions using the finite element method (Liu et al., 2013). Daas et al. investigated the effects of fixed or removable

* Correspondence to: Batman University, Engineering and Architecture Faculty, Mechanical Engineering Department 72100 Batman, TURKEY.
E-mail address: tolga.topkaya@batman.edu.tr (T. Topkaya).

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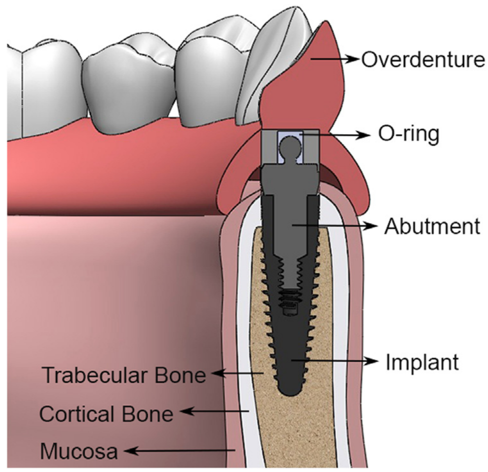

Fig. 1. Model of implant system.

Table 1
Material properties.

Material	Elastic modulus (MPa)	Poissons ratio
Ti6Al4V (Bonnet et al. 2009, Sevimay et al. 2005, Zhu et al. 2007)	110,000	0.35
Prosthesis (Bonnet et al. 2009)	2940	0.3
Cortical bone (Sevimay et al. 2005, Kitagawa et al. 2005)	13,700	0.3
Trabecular bone (Sevimay et al. 2005, Kitagawa et al. 2005)	1370	0.3
O-ring (Bonnet et al. 2009)	15	0.4
Mucosa (Bonnet et al. 2009, Fatalla et al. 2012, Sevimay et al. 2005]	1	0.3

Table 2
Maximum von Mises stress (MPa) in different components of Nobel Active Implant System.

Loading angle	(Chang et al., 2013)		Present analysis	
	0º	30º	0º	30º
Crown	7.5512	84.5432	7.8326	86.235
Abutment	13.8777	274.2010	16.242	271.065
Screw	12.1696	123.0210	11.6205	123.9852
Implant	23.6874	254.6440	23.237	249.02
Cortical bone	2.3523	20.9631	2.022	18.6324
Cancellous bone	2.5809	7.9157	0.15524	1.8632

connections between the abutment and prosthesis in two implant-supported removable prostheses on the stress distribution using the three-dimensional finite element method (Daas et al., 2008).

Many studies have been conducted on the number of implants to be used in implant-supported prostheses. In treatment planning, the number of implants to support the prosthesis is the most important question to be answered. Burns reported that two or four implants were preferred in implant-supported removable prostheses, and the minimum number was two for the implants, and increasing the number of implants shifted the support from mucosal surfaces to the implants (Burns, 2004). It is possible that the prosthesis is supported by the implants or there are models in which remaining teeth and implants are used to support the prosthesis (Dalkiz et al., 2002). The present study evaluated the effects of the number and configuration of the implants in lower jaw overdentures supported by ball anchor connectors on the distribution of stress on the bone-implant system assembly using finite element method. A design model of an overdenture-implant system and lower jaw from computerized tomographic (CT) images were constructed using Solidworks 2012 software, and a stress analysis was performed using the ANSYS 14.0 Workbench program.

2. Materials and methods

The present study evaluated the effects of the number and configuration of the implants inserted to the lower jaw without any remaining teeth to support lower overdenture on the stress distribution on the lower jaw and implant system assembly using the finite element method. Clinical applications show that osseointegration between the implant and jaw bone takes a period of 3–6 months (Bozkaya and Müftü, 2003). The present study assumed that osseointegration between the implant and the bone has been completed. This assumption facilitates the design of the model and shortens the time to the solution; however, it may cause differences to occur between the analyses and clinical applications. The present study differs from the previous studies since it evaluates not only the effects of the number of configuration of the implants, but also the contribution of loading parts on the stress distribution in each model.

The solid structures of the implant and human lower jaw bone constructed by the SolidWorks 2012 program were transferred to the ANSYS Workbench program for analysis with the finite element method. Computerized tomographic images were used for the construction of the mandible and overdenture.

Nobel Replace model implants (Nobel Biocare) were used. Implants with different sizes and diameters can be used depending on the characteristics of the jaw (Topkaya et al., 2013). The present study used implants with a 4.30 mm diameter and 11 mm insert length. The implant system and overdenture were placed on the jaw bone model that was created using CT images. Fig. 1 shows a section from the implant insertion site in the incisor teeth in the two implant-supported model.

Different configurations can be used for the insertion of implants in implant-supported prostheses. The two or four implant-supported models are the most commonly preferred configurations. The configurations used in the present study are presented below.

The materials and fabric used in the study show different mechanical and physical characteristics. These materials were considered isotropic and homogeneous, and the elasticity modulus and Poisson's ratios were acquired from the literature. Elasticity modules and Poisson's ratios of the materials are presented in Table 1.

2.1. Method validation

For validating the method Chang et al. model was solved for same material properties and boundary conditions (Chang et al., 2013). Results show that used model has good agreement with reference investigation. Maximum von Mises stress values of reference model and current analysis given in Table 2. Stress distributions of Nobel Active implant for two different loading conditions is given in Fig. 2.

2.2. Boundary conditions and loading

During mastication, the jaw muscles exert different pressures on different regions (Daas et al., 2008). While defining the boundary conditions, varying loading pressures were applied to three different loading sites. The loading sites and loading pressures were obtained from the study of Daas et al. The jawbone was considered motionless and the cortical bone was immobilized. The loading sites and load levels are given below. (Figs. 3 and 4)

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