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Prediction at long-term condyle screw fixation of temporomandibular joint implant: A numerical study

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ABSTRACT

The fixation of commercial temporomandibular joint (TMJ) implant is accomplished by using screws, which, in some cases, can lead to loosening of the implant. The aim of this study was to predict the evolution of fixation success of a TMJ.

Numerical models using a Christensen TMJ implant were developed to analyze strain distributions in the adjacent mandibular bone. The geometry of a human mandible was developed based on computed tomography (CT) scans from a cadaveric mandible on which a TMJ implant was subsequently placed. In this study, the five most important muscle forces acting were applied and the anatomical conditions replicated. The evolution of fixation was defined according to bone response methodology focused in strain distribution around the screws.

Strain and micromotions were analyzed to evaluate implant stability, and the evolution process conduct at three different stages: start with all nine screws in place (initial stage); middle stage, with three screws removed (middle stage), and end stage, with only three screws in place (final stage). With regard to loosening, the implant success fixation changed the strains in the bone between 21% and 30%, when considering the last stage. The most important screw positions were #1, #7, and #9.

It was observed that, despite the commercial Christensen TMJ implant providing nine screw positions for fixation, only three screws were necessary to ensure implant stability and fixation success.

1. Introduction

The temporomandibular joint (TMJ) plays an extremely important role in daily activities; and since it is involved in many different everyday tasks such as communicating, feeding, or even sleeping, with up to 2000 motion cycles per day, it is consequently the most exercised joint in the human body (Guarda-Nardini et al., 2008; Tanaka and Koolstra, 2008). According to previous studies, 20%–40% of the population presents with TMJ disorders. However, contrary to what would be expected, TMJ implants have been studied mostly in terms of clinical cases and without the use of numerical predictions (Solberg et al., 1979; Okeson, 1997; Hsu et al., 2006).

Temporomandibular joint diseases affect almost half of the population during their lifetime, and although some of these problems can be treated with drugs and physiotherapy, some individuals still need a TMJ implant. For this reason and because the TMJ implant success rate has been much lower than for total hip replacement or total knee replacement (van Loon et al., 1995; Hsu et al., 2011), this study attempted to investigate the best TMJ implant fixation position (Chase et al., 1995; Mishima et al., 2003; Mercuri and Giobbie-Hurder, 2004).

Surgical treatment for a TMJ implant includes a total or partial condylectomy and the replacement of the disk by autografts or alloplastic materials (Chase et al., 1995) Nowadays, there are tree TMJ implants as options available on the market using screws to fixate the mandible part of the implant to the bone (Kanatas et al., 2012; Schuurhuis et al., 2012). Because the structures involved in this joint are very complex, the best implant fixation technique and the optimal number of screws remain uncertain. However, implant stability (Sidebottom and Gruber, 2013; Shen et al., 2014) is one of the most important and decisive factors in implant success (van Loon et al., 1995). The surgeon fixes, with screws, the mandible implants as lateral plates in the TMJ implants to the bone (Bujtár et al., 2014; Shen et al., 2014), normally using all or almost all of

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the available screw positions. However, this does not mean that the best implant stability is guaranteed (Hsu et al., 2006; Chowdhury et al., 2011; Hsu et al., 2011), and low levels of micromotion generated at the interface can hamper bone integration.

The aim of this study was to analyze implant stability, simulating a long period of support as a function of the screw positions and strain distributions in the bone adjacent to the TMJ implant.

2. Material and methods

One clean cadaveric mandible, without teeth, of a 45-year-old woman was analyzed. The mandible geometry was obtained through CT images with a resolution of 0.780 × 78 × 0.25 mm. The model reconstruction was obtained using Simpleware software Scan IP and then converted to a solid model, using CAD software Dassault Systèmes CATIA V5. In this process, both bone structures were considered, the cancellous bone defined between 600 and 1300 HU and the cortical bone between 1300 and 1600 HU (Bujtar et al., 2010; Bujtár et al., 2014).

A commercial condylar implant (Christensen Prosthesis TMJ Implants, Inc., CO) with 9 screw holes was placed on the left ramus of the mandible (Ramos and Mesnard, 2014a,b). The implant was fixed with Ø 2.0-mm and 8-mm-long bicortical screws as in previous studies (Mesnard et al., 2011; Ramos et al., 2011, 2014). All of the screws had the same length and diameter (Fig. 1).

The materials were considered isotropic and linear elastic (Table 1) in accordance with previous studies (Hsu et al., 2011; Mesnard et al., 2014). Finite element analyses were performed using the Dassault Systèmes software CATIA V5 simulation module with four-node tetrahedrons.

We considered that both condyles were fixed in the X and Y directions and the incisor tooth fixed in the Y and Z directions, allowing only rotation of the model as shown in Fig. 2. The forces applied were based on previous studies (Ramos et al., 2010, 2011) with respect to the five most relevant muscle forces acting on the mandible and insertion points, as defined by magnetic resonance imaging (MRI). The actions and boundary conditions are presented in Fig. 2 and muscle action magnitude is shown in Table 2.

The cortical and cancellous bone structures were considered to be glued, whereas the screw–implant and screw–bone interfaces were considered to be in contact with a friction coefficient of 0.1 and 0.3, respectively. At their interface, the implant and the bone were modeled as surface-to-surface contact elements.

In this study, seven different stages of evolution in screw fixation were considered. The algorithm used as a decisive factor was based on a CAD mandible model that was used to construct the finite element model. Next, the stresses (σ), strains (ε), and displacements (ΔL) were obtained.

The $\Delta\varepsilon$ and ΔL were analyzed around the screw fixation to the bone. If the $\Delta\varepsilon$ were more than 15% higher than in the previous analysis, the analysis was stopped; otherwise the mean and maximal strain values were analyzed. If these results were higher than 4000 $\mu\varepsilon$, we left the screw in place; if not, we removed the screw and the hole with the lowest strains and started once again the procedure shown in Fig. 3.

Table 1
Material properties.

Component	Material	E (GPa)	ν
Cortical bone	Cortical bone	13.0	0.3
Cancellous bone	Cancellous bone	1.6	0.3
Christensen implant	Titanium	110.0	0.3
Screws	Titanium	110.0	0.3

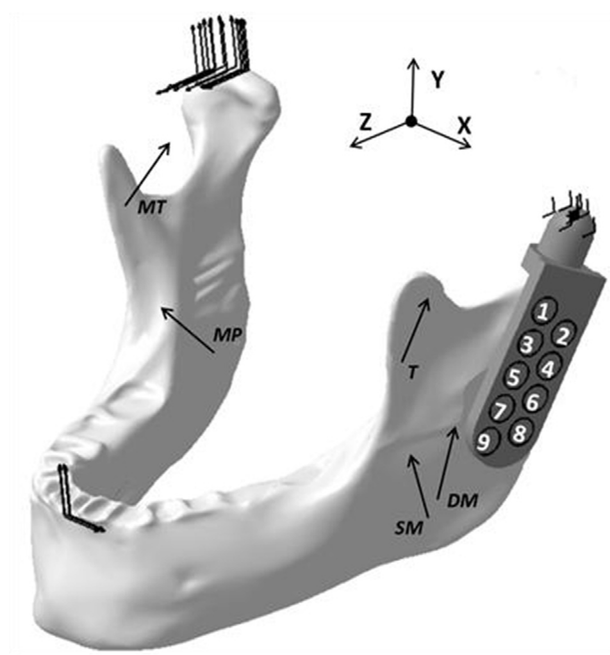

Fig. 2. Loads and restrictions applied to the mandible.

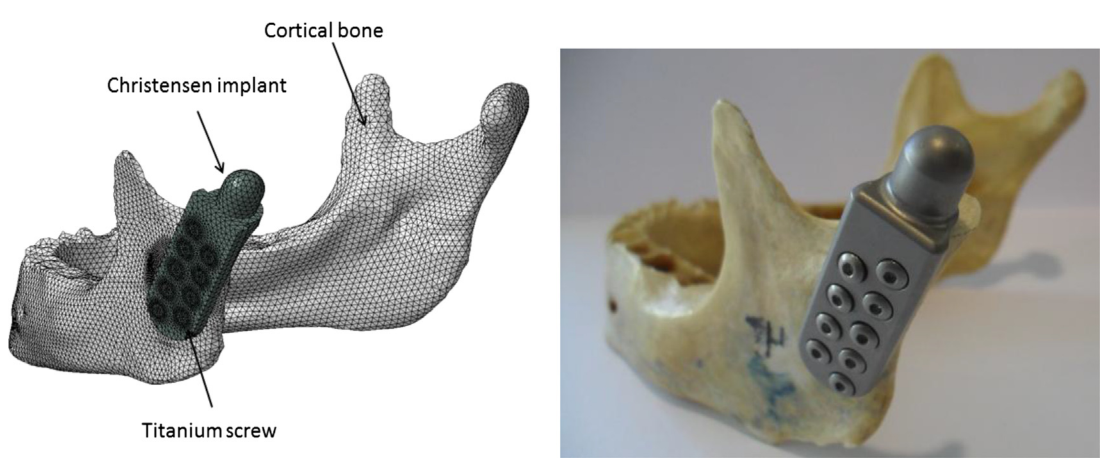

Fig. 1. FEM of the implanted mandible.