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Research Paper
Dental Implants

Effects of inter-implant distance and implant length on the response to frontal traumatic force of two anterior implants in an atrophic mandible: three-dimensional finite element analysis

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Abstract. The aim of this three-dimensional finite element analysis study was to examine the biomechanical behaviour of dental implants and the surrounding bone under traumatic frontal force. Models were created of an edentulous atrophic mandible using cone beam computed tomography data from a patient; two titanium alloy implants (Ti–6Al–4V) were virtually inserted into the anterior of the mandible. Six different variations were modelled to represent differences in implant location (lateral incisor vs. canine placement) and implant length (monocortical, bicortical, and long-bicortical). A static force of 10 MPa was applied frontally to the symphysis region of each model, and the maximum equivalent von Mises strain of bone, maximum von Mises stress of implants, and chromatic force distributions in bone and implants were recorded. In general, when compared to lateral incisor placement, canine placement of implants resulted in greater von Mises stress on implants and greater equivalent von Mises strain on bone. The findings of the present study showed the distribution of traumatic force to be affected more by inter-implant distance than by implant length. The insertion of implants in the lateral incisor area was found to be a better solution than canine area placement in terms of frontal plane trauma and fracture risk.

Key words: mandible; fracture; dental implant; von Mises.

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The use of a prosthesis over dental implants is currently the primary treatment modality for the rehabilitation of missing teeth.[1] Particularly in atrophic edentulous jaws, the large volume of the denture and the small retentive area makes it impossible to construct a stable denture without the support of implants.[2]

Overdentures supported by implants have a long history of use, and the literature includes numerous reports of successful treatment and patient satisfaction.[3] A removable prosthesis for an edentulous mandible may be manufactured with varying numbers and placements of dental implants.[2,4] In the case of an atrophic mandible with insufficient height in the posterior region, rehabilitation using an overdenture with a ball attachment or locator (ZEST Anchors LLC, Escondido, CA, USA) over two implants inserted in the anterior mandible is the easiest treatment modality to increase prosthetic stabilization.[1,2]

Possible complications following dental implant surgery are numerous and include bleeding, infection, and jaw fracture, a rare complication occurring mainly in atrophic mandibles and as a result of trauma or other unknown causes.[5–14] Trauma to the maxillofacial region may occur for a number of reasons, including traffic accidents and assaults. A study by the World Health Organization concluded that the number of trauma victims can be expected to increase in the future.[15,16] Considering that the use of dental implants also continues to increase due to significant advancements in treatment and thus patient satisfaction, it will become increasingly likely in the future that maxillofacial surgeons will encounter maxillofacial trauma victims with dental implants.

This study aimed to compare how inter-implant distance and implant length affect the biomechanical response to traumatic force of an atrophic mandible with two titanium dental implants, using three-dimensional (3D) finite element analysis (FEA).

Materials and methods

Modelling

This study was conducted using a scanned cone beam computed tomography (CBCT) image of a completely edentulous mandible (ProMax, Planmeca, Helsinki, Finland). The raw image data were exported to a computer in DICOM format with a pixel resolution of 651 × 651, 96 kV, and increment slices of 0.2 mm in thickness. DICOM files were imported into Mimics 12.1 software (Materialise, Leuven, Belgium) in order to obtain accurate cortical and cancellous bone hemimandible geometry. Image enhancing of cortical and cancellous bone was performed using the 'thresholding' and 'region-growing' tools, and geometry, especially of the cancellous bone, was adjusted using manual editing tools ('draw' and 'erase' functions). The rough model was imported in STL format to the reverse-engineering software Geomagic 3D (3D Systems, Rock Hill, SC, USA) in order to generate a smooth computer-aided design (CAD) model of the hemimandible, which was then mirrored along the mandibular median plane to construct a model of a complete mandible.

After modelling the mandible, SOLIDWORKS software (Dassault Systèmes SolidWorks Corp., Waltham, MA, USA) was used to generate CAD models of 3.75-mm diameter conical dental implants of different lengths. Implant models were simplified by excluding the screw threads. Using the same software, two implants were virtually inserted into each mandible, with the cylindrical axis of the implant aligned vertically to simulate *in vivo* conditions. Six different variations were modelled: the first grouping was by implant location, either lateral incisor placement (La) or canine placement (Ca), and these two groups were divided into sub-groups according to the implant length – monocortical (MC), bicortical (BC), or long-bicortical (LBC). MC implants were stabilized in crestal cortical and trabecular bone, BC implants were stabilized in crestal cortical, trabecular, and apical cortical bone, and LBC implants were stabilized in crestal cortical, trabecular, and apical cortical bone, and the cortical bone of the mandibular base. Implant placements and lengths are shown in Figs 1 and 2, respectively. A mandible without implants was also modelled and used as a control.

Material properties

Ti–6Al–4V titanium alloy was selected as the implant material. The implants, cortical bone, and cancellous bone were rendered as linearly elastic, homogeneous, and isotropic. The elastic moduli and Poisson ratios were obtained from the literature and are given in Table 1.[17]

Force loading and contact conditions

CAD models were imported into FEA software (ANSYS Workbench 15.0; ANSYS Inc., Providence, RI, USA). Implant and bone models were meshed with 3D quadratic tetrahedral elements of 0.5 mm and 1 mm, respectively. Complete contact between bone tissue and implants was assumed.

A static force of 10 MPa was applied frontally to the symphysis region of the mandible, perpendicular to the frontal plane, in accordance with Gallas Torreira and Fernandez[17] (as shown in Fig. 3).

Boundary conditions

Mandible models were constrained in all degrees of freedom at the proximal portion of the condyles (Fig. 3). In order to reduce the file size and speed data processing, the

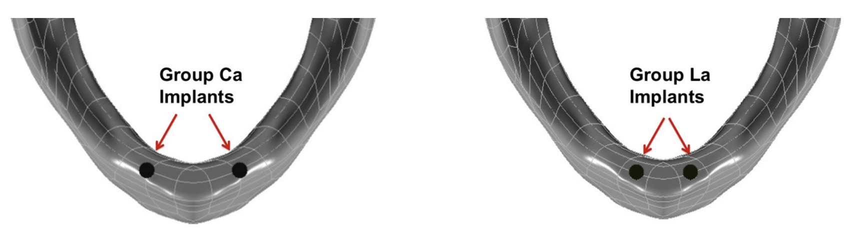

Fig. 1. Occlusal view of the mandible with the two implants: groups Ca (canine placement) and La (lateral incisor placement).

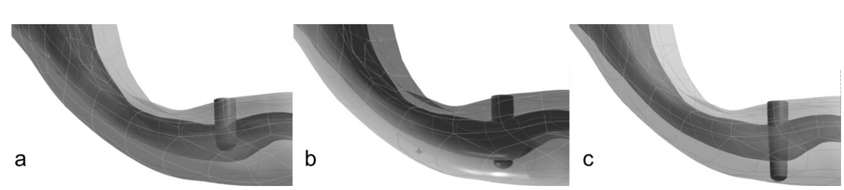

Fig. 2. (a) Monocortical (MC) insertion, (b) bicortical (BC) insertion, (c) long-bicortical (LBC) insertion.