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Impairment of an atrophic mandible by preparation of the implant cavity: a biomechanical study

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Abstract

An important complication during insertion of implants in atrophic mandibles is the fracture that can be induced by preparation of the cavity. We designed this study to identify which configuration of cavities in the interforaminal region was the least likely to fracture. An electromechanical testing machine was used to measure breaking loads of specifically-designed synthetic models of atrophic mandibles. The implant cavities correlated with the common clinical patterns. Intact atrophied synthetic mandibles broke at a mean (SD) load of 729.48 (59.94) N (control group). Models with four different configurations of cavities fractured as follows: two short, wide cavities (8 x 4.2 mm) at a mean (SD) load of 569.17 (67.7) N; two long, thin cavities (15 x2.8 mm) at a load of 563.40 (62.0) N; four short, wide cavities (8 x 4.2 mm) at a load of 667.01 (71.89) N; and four long, thin cavities (15 x 2.8 mm) at a load of 409.50 (43.61) N. Biomechanical findings showed that there was a greater risk of fracture of atrophic mandibular models in long, thin implant cavities with more preparation sites. Each cavity prepared for an implant increased the risk of fracture in an atrophic mandible. The risk of fracture is greatest with long, thin cavities.

Keywords: Dental implants; Mandibular atrophy; Mandibular fracture; Biomechanics

Introduction

Life expectancy is increasing in all parts of the world, most people born after the year 2000 will celebrate their 100th birthday,[1] and tooth loss will remain a problem for elderly people.[2]

Conventional prostheses have many disadvantages and are losing popularity with edentulous patients. Implant-borne prostheses have numerous advantages,[3,4] and several studies have reported good results with implants placed in the interforaminal region to retain removable dentures, particularly in atrophic mandibles.[5,6]

Implants may prevent bony loss as they apply a nearly physiological load on to the mandibular bone, but they are also at risk of fracturing bones, particularly mandibles that have been completely edentulous for a long time and are highly atrophic. The process of preparation of the cavity in these patients – that is, the drilling of the cavities for implants

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with conventional steel burs - may cause the mandible to fracture.

We know of few data about the fracture rate after implantation in atrophic mandibles, and there is a lack of large prospective studies. Most publications are retrospective single case-studies. Treatment using short implants or those of small diameter are insufficiently documented,[7] and there are few empirical data on the primary stability of so-called "mini implants".

One way to obtain information on the fracture behaviour of an atrophic mandible, and the primary stability of the implants, is by biomechanical experiments. However, before this study we could find no suitable artificial models of the mandible available on the market. Commercial manufacturers of artificial bone models for biomechanical experiments restricted themselves to models of dentate mandibles, so we developed custom-made, artificial, bone models of atrophic jaws for this biomechanical investigation. With these specimens, cavities for different configurations of implants were prepared and biomechanically loaded into a specially-adjusted experimental machine.

Our hypothesis was that the configuration of the different sizes and numbers of implants has a decisive impact on the mechanical strength of atrophic mandibles to withstand incisive loading.

Material and Methods

Models of artificial mandibles

An integral part of realistic experiments is the standard anatomical structure of the specimens. The distinctive variability of mandibular atrophy makes a biomechanical investigation of the behaviour of fractures and fixing implants in human cadavers difficult. The statistical variance in the morphology of the mandible must be considered for biomechanical experiments that should mimic the mean population, so we generated a data-based anatomical specimen of an atrophic mandible. A computer algorithm was created that was capable of calculating the shape of a mean mandible, and certain distinctive anatomical landmarks were defined (Fig. 1A).

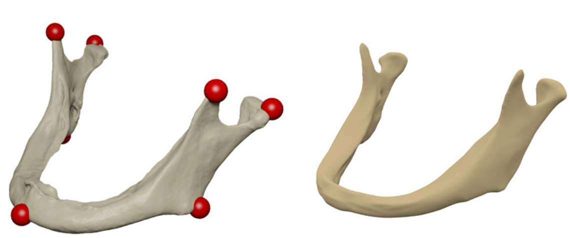

Fig. 1. (A): Segmented computed tomographic scan of an atrophic mandible and relevant anatomical landmarks seen as red spheres. (B) Atrophic mandible models calculated from arithmetically averaged computed tomographic data (Synbone®).

A database of 27 edentulous mandibles from cadavers with varying degrees of atrophy was assessed and grouped according to Cawood and Howell's classification.[8] Surrounding soft tissue was removed from the mandibles and computed tomographic scans taken (Philips Brilliance iCTR®, Philips Medical Systems DMC GmbH, Hamburg, Germany). Voxel resolution was set to $512 \times 512 \times 538$ and the slice thickness was set to $0.352 \times 0.352 \times 0.334$ mm. The data were stored in a DICOM file and the bone geometry was segmented with semiautomated threshold-based algorithms in appropriate software (Mimics 14.0, Materialise, Leuven, Belgium).

The predefined anatomical landmarks for all the mandibles were detected in a fully automated procedure that has been implemented in Python programming language (Python 3.2, Python Software Foundation, Delaware, USA). Based on the anatomical landmarks assessed, the mean morphological shape of the collected mandibles could be calculated with shape-morphing algorithms. The resulting shape was used to generate casts from which mandibular models could be manufactured by a company that specialised in manufacturing biomimetic bone models (Synbone, Malans, Switzerland). The specimens were produced in individual casts (PUR foam). The cortical and trabecular bones, respectively, were modelled by using materials with two different densities (Fig. 1B).

The specimens were drilled in a box column drill with a tapping machine under standard conditions. Cylinder-shaped drill bits (Straumann®) were used for the preparation of the cavities. Two different diameters were used: Straumann® drill set for 2.8 mm (long, thin cavity corresponding to Straumann® Bone Level Implant, Ø 3,3 mm NC, SLActive 14 mm, TiZr) and drill set for 4.2 mm (short, wide cavity corresponding to Straumann® Bone Level Implant, Ø 4,8 mm RC, SLActive 8 mm, TiZr).

Experimental instrumentation

The models of atrophic mandibles were mechanically loaded on an electromechanical testing machine (Zwick i-line 5 kN, Zwick Messtechnik, Ulm, Germany) with a specially-developed platform (Fig. 2) which is suited to experimental tests on artificial bone as well as on cadaveric mandibles. Its applicability has been confirmed in previous studies by our research group.[9–12]

The functional principle of the testing device is the application of incisal bite forces. The temporomandibular joints are modelled through bearings made of concave, lathed spherical boxes to indicate the anatomical shape of the temporomandibular fossae. Biting forces are applied with stiff ropes, which are pulled by the electromechanical cylinder of the Zwick machine under displacement control to apply the required forces on the mandibular models. Muscular forces are also modelled by ropes that are fixed on to the framework of the experimental device. In our simulation all muscular forces are integrated in one noose of the rope at each side of the mandible located at the mandibular angle, which allows