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Biomechanical effects of titanium implants with full arch bridge rehabilitation on a synthetic model of the human jaw

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Abstract

A composite model of the mandible, constituted by an inner polymeric core and a glass fibre reinforced outer shell, has been developed and equipped with six ITI titanium implants and a full gold alloy arch bridge prosthesis. The effects of this oral rehabilitation on the biomechanics of the mandible are investigated through a simulation of the lateral component of the pterygoid muscles. These muscles are involved as the mouth is opened and closed, hence their activity is very frequent. An increase of the mandible stiffness due to the prosthesis is observed; moreover, the coupling of the relatively stiff rehabilitation devices with the natural tissue analogue leads to stress-shielding and stress-concentration in the incisal and molar regions, respectively. Although the amplitude of the force generated by pterygoid muscles is quite small, high strains over the incisal region are measured. A stress-shielding effect, of about 20%, is observed at the symphysis as the full arch bridge prosthesis is fixed on the implants. Therefore, the presence of the prosthesis leads to significant modification of the stress field experienced by the mandible, and this may be relevant in relation to the biomechanics of mandibular bone remodelling.

Keywords: Dental implants; Arch bridge prosthesis; Composite model; Mechanical properties; Stress-shielding

1. Introduction

Dental implants, used as osseointegrated supports for arch bridges, are being applied increasingly in order to restore the mechanical function, aesthetics, comfort and speech of edentulous patients. Dental implants are generally made of metals, and titanium is preferred for mechanical and biological reasons: compared to other materials, titanium and its alloys show an intrinsic stiffness which is closer to hard tissues, and their osseointegration capabilities are also well documented [1,2].

However, the biomechanics of an edentulous mandible that has been rehabilitated through implantology are different from those of a healthy mandible in at least three aspects: the prosthetic materials are stiffer than bone, the artificial teeth are connected by the full arch bridge superstructure and the restored mandible lacks a shock absorbing system at the implant–bone interface, like the periodontal ligament [3,4]. As a result, the mandibular bone undergoes stress-concentration and stress-shielding effects, which can explain some negative effects on the bone–implant stability [5,6]. Therefore the stress transfer between implants and bone are topics of great interest, but, unfortunately, quantitative data concerning these issues are still missing. Nevertheless, a proper knowledge of a rehabilitated mandible is essential to improve prosthetic devices and their design.

It has been suggested [7,8] that the effects of implant rehabilitation on the mandible biomechanics are already

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evident for the simple clinical condition of mouth opening and closing [9]. In fact, through this mandible activity, a lateral component of the force exerted by the pterygoid muscles, estimated to be between 10 N and 20 N, determines an arch width decrease [10–12]. Although these mandible deformations are the consequence of small loads, they are of great concern in implantology because they are very frequent, as they occur, for instance, during speech [13,14].

Whole bone models are developed in order to assess the mechanical behaviour of natural and synthetic structures. Polymeric mandibular analogues are often used to investigate the biomechanics of rehabilitated mandibles [15–17]. However, these synthetic models behave like homogeneous and isotropic materials; thus the composite nature of bone, comprising cortical and spongy bone, is not reproduced. As a consequence, the conclusions which may be drawn based on such experimental models of the jaw may be misleading.

While several mandible theoretical models (e.g. finite element models) are available in the literature [8,18,19], experimental anisotropic synthetic models of the human jaw are still not available. Nevertheless, experimental results are essential to calibrate models in order to obtain reliable predictions. Therefore, almost all of the theoretical mandible models are calibrated using the limited set of data derived from experimental testing *in vivo* and from cadaveric human mandibles.

In previous works [20,21] a composite mandible, made of a poly(methylmethacrylate) (PMMA) inner core and a glass fibre reinforced outer shell has been introduced. Glass fibre reinforced polymers can be used as compact bone analogues, since they can conveniently reproduce the anisotropy of the cortical shell of natural mandibles. The synthetic mandible model, replicating the properties of edentulous human jaw, was used to validate a finite element model of the edentulous mandible [21].

The aim of this report was to investigate the biomechanical effects of a full arch bridge rehabilitation on an edentulous mandible due to the lateral loads generated by pterygoid muscles. The action of these muscles is important since they are extremely active in several tasks such as mouth opening and closing or during chewing by biasing the force generated by other muscles [7–14].

The synthetic model is thus equipped with titanium implants and a full arch bridge prosthesis, and experimental simulations are performed. The results will be compared to the analogous ones obtained from synthetic models representing a completely edentulous mandible.

2. Materials and methods

Composite mandibles are manufactured as described in a previous work [20]; readers interested in the details are referred to that paper. Here it will suffice to say that the resulting models are composed as follows: the inner part is made of a PMMA-based self-curing bone cement (Symplex P®, Howmedica), while the outer shell is made of a glass fibre epoxy prepreg (Narmco Materials, California) type 120 (with a laminated thickness of 127 μm). The glass fibres are mainly oriented parallel to the axis of the mandible arch in the mandible arch itself, and obliquely in the mandible ramous, these being the main osteons directions in the mandibular arch and ramous.

The stiffness of this synthetic mandible arch, when loaded through the gonion regions, is 35 N/mm, thus reproducing the mechanical behaviour of an edentulous mandible [8,17,21].

Ten composite specimens (Group A), representing edentulous mandibles (Fig. 1a and b), were manufactured. Five mandibles were randomly selected and prosthesized (Fig. 1c and d) through a full arch bridge rehabilitation (Group B). Regarding Group B, six parallel holes were drilled in each mandible model using a Cendres&Metaux (Briel, Switzerland) parallelometer. In such holes ITI® (Institut Straumann AG, Basel, Switzerland) dental implants (with diameter and length of 4.1 mm and 12 mm, respectively) were cemented. ITI Octa abutments (Institut Straumann AG, Basel, Switzerland) were tightened on each implant with a torque of 0.35 Nm using an Imada HTG-5N torque device (Toyohashi, Japan).

A regular viscosity polyether (Permadyne, 3M ESPE, Minnesota), mixed through an appropriate dispenser (Pentamix 2, ESPE Dental, Germany), was the impression material used for all transfer procedures. Each impression held the three-dimensional geometrical properties of the mandible equipped with implants. Cast gold alloy X33 full arch bridge prostheses (Institut Straumann AG, Basel, Switzerland) were manufactured and screwed on each model (Fig. 1c and d). A pressure spot indicator (Coltene PSI, Cuyahoga Falls, OH, USA) was used to verify the correct fit of the prosthetic structures. Diamond rotary burs were used to remove possible friction areas.

The static behaviour of Group A and Group B jaws was analysed by laterally loading the devices in the gonion regions of the sagittal mandible ramous or through the condyles (Fig. 2a), this loading condition approximating the lateral component of the action of the pterygoid muscles [12]. An Instron 4204 screw driven dynamometer (Bucks, UK) with a load cell of 100N was used to perform the mechanical testing on these jaws at a cross head speed of 1 mm/min. Thus, from a mechanical point of view, this system (Fig. 2b) represents distally supported or cantilevered bridges. As the load is applied through the condyles, the test (Fig. 2a) simulates the action of pterygoid muscles in the lateral-medial direction with respect to the frontal plane of the mandible [11,21]. Loading the mandible through the gonion regions (Fig. 2a and b) is a powerful protocol to assess the performance of the mandible arch, the part of the jaw where most of the biomechanical effects of arch prostheses are expected [11].

In order to evaluate the arch width change and the condyles convergence as the load was applied, the optical