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Biological-data-based finite-element stress analysis of mandibular bone with implant-supported overdenture

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ABSTRACT

Background: This study aimed to evaluate the stress distribution in a mandibular bone with an implant-supported overdenture by a biological-data-based finite element analysis (FEA) utilizing personal CT images and *in vivo* loading data, and to evaluate the influence of the number and alignment of implants and bone conditions on the stress in peri-implant bone.
Methods: FEA models of a mandible were constructed for two types of overdentures: 4 implants supported overdenture (4-OD) and 2 implants supported overdenture (2-OD). The geometry of these models was constructed from CT images of a subject, who wore an implant-supported overdenture. The magnitude and direction of the loads on the implants for two types of overdentures during the maximal voluntary clenching were measured with 3D force transducers. FEA using these loads was carried out to observe stress distributions in peri-implant bone.
Results: Higher stress was observed in cortical bone around the implant neck. Stress in peri-implant bone for 4-OD was reduced in comparison with those for the 2-OD. For the 4-OD, notwithstanding such reduction of the stress, the stress concentrated at the cortical bone around the implant aligned with large deviation from load direction.
Conclusions: In this study, biological data from a certain subject was successfully duplicated to the FEA models. The results demonstrate the mechanical prominence of using more implants. Even in 4 implants model, high stress was found around an implant with a large inclination and with thin cortical bone. This suffices to demonstrate the capability and usefulness of the biological-data-based FEA.

1. Introduction

An implant-supported overdenture (OD) is applied increasingly in recent years, supported by excellent clinical outcomes [1–3]. It offers significant improvements for subjects who are lacking stability and retention of their denture. In long-term results of implant-supported overdentures, despite achieving satisfactory survival rate, the prosthetic complications such as screw loosening and fracturing of the prosthetic component were often observed and significantly affected by biomechanical conditions [4]. Additionally, possible association between biomechanical conditions and peri-implant bone loss was reported [5]. Mechanical stress in peri-implant bone, induced by occlusal loads transmitted to these implants, is known to affect bone homeostasis [6].

In human study, the duration of load was found to significantly affect bone loss and implant failure [7]. In animal study, excessive and dynamic loads induced marginal bone loss [8,9]. Thus, it is important to investigate this mechanical stress, which plays a prominent role in long-term prognosis of implant treatment and mechanobiological reaction of the tissue. In particular, the effect of mechanical stress might be more detrimental in unfavorable patient's conditions, such as low bone quality, limited bone quantity, adverse functional habits, and compromised medical health [10]. Finite element analysis (FEA) has come to be utilized to investigate stress on the implant components and peri-implant bone. As confirmed by several FEA study, mechanical stress in peri-implant bone is strongly affected by implant number, diameter, length, thread profile, material properties of implant components, quality and quantity of surrounding bone [11–15]. It is also well known that the performance of FEA is dependent on various factors of the model, such as geometry, load conditions, material properties, and boundary conditions [16]. Recent development of digital imaging techniques made it possible to obtain

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subject-specific biological data of bone geometry and property for FEA modeling [17–19].

In previous studies, we developed a methodology to measure 3-D forces exerted on implants *in vivo* [20–22]. We also conducted a pilot study to construct a biological-data-based FEA model of a mandible with implants, utilizing CT images and *in vivo* load data of a subject with an implant-supported overdenture, in whom 3-D force on each implants had been measured. The measured load on the implant was unpredictable and the bone morphology and quality are peculiar to individual patients. Therefore, patient's specific "biological-data-based FEA" could be worthy to improve understanding of biomechanical conditions relating to the implant treatment. The purpose of this study was to investigate the mechanical stress distribution in a mandibular bone of the subject with an implant-supported overdenture by a biological-data-based FEA and to evaluate the influence of the number of implants on the stress in peri-implant bone.

2. Materials and methods

The present FEA was based on biological data collected from a 62-year-old female subject, who wore an overdenture (OD) supported by four dental implants 3.75 mm in diameter, 13 mm in length (MkIII RP, Nobel Biocare, Kloten, Switzerland). The implants were installed between the mental foramens of mandible (Fig. 1a and b), which were labeled with 1 to 4, with Imp1 being the right distal implant and Imp4 the left distal one. The subject had no systemic disease and no abnormalities and disorders in her stomatognathic system. CT images of the subject, taken before the implants installation, were used to constructing FEA models geometry. Bone quality and bone quantity were classified in B-3 type described by Lekholm and Zarb [23]. It was characteristic of the subject that the left distal implant was supported by thin cortical bone. All of four implants were installed nearly vertical to her occlusal plane, according to the common guideline of implant insertion.

The magnitude and direction of forces exerted on implants during maximal voluntary clenching (MVC) were recorded with 3-D load-measuring devices, consisting of piezoelectric force transducers (Type Z18400, Kistler Instrument, Winterthur, Switzerland) (Fig. 1c). The lower part of this device was connected to the abutment with a titanium screw, and its upper part was connected with a bar attachment (Fig. 1d). These transducers can record triaxial forces simultaneously and independently with high linearity, low hysteresis and good temperature stability for each measuring axis as described in detail in the literature [24]. Measured loads were analyzed according to the three dimensional coordinates defined as vertical (z), antero-posterior (y) and mediolateral (x) axes based on the

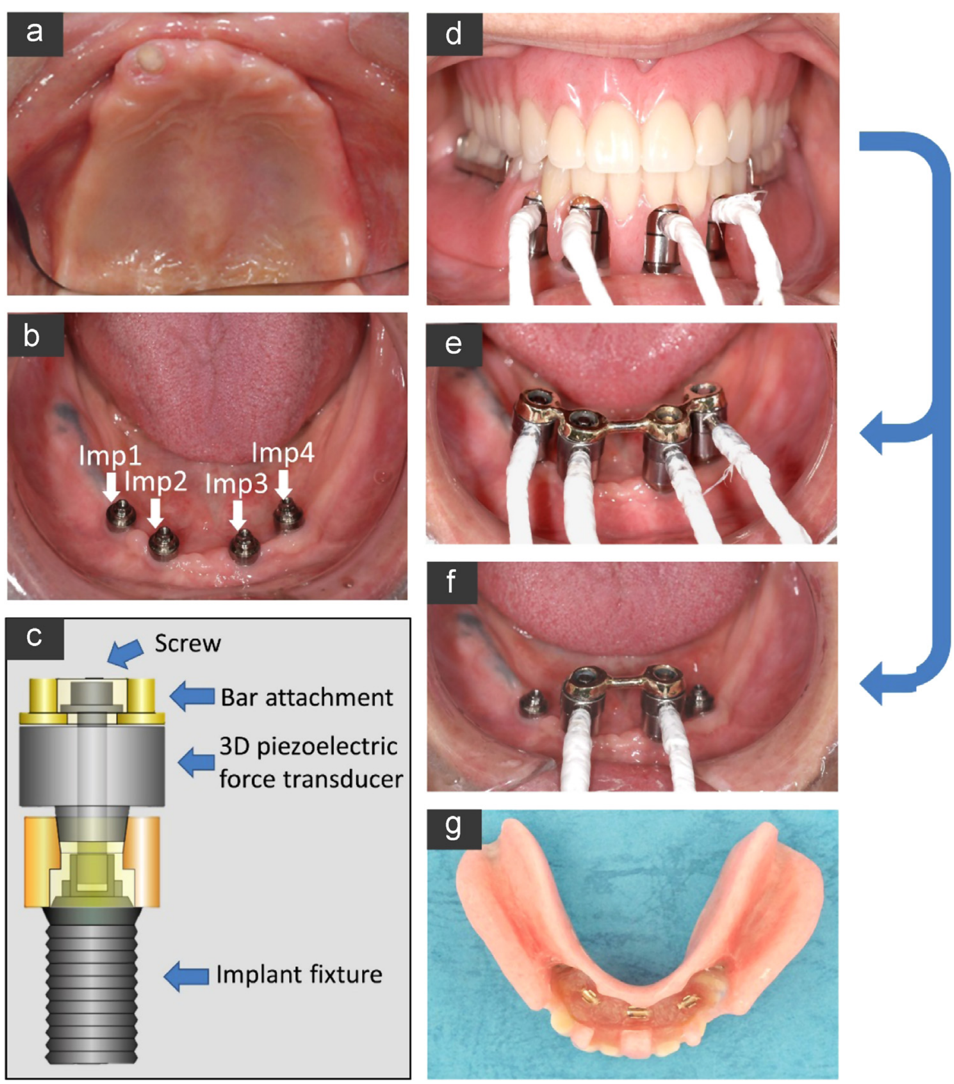

Fig. 1. *In vivo* three-dimensional force measurement. ((a) and (b)) Intra oral view of the subject, (c) the implant overdenture had 3 clip attachments, (d) load-measuring device in the mouth, (e) schematic view of the measuring unit, (f) 4 implants supported overdenture (4-OD), (g) 2 implants supported overdenture (2-OD).