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Original article

Bone morphological effects on post-implantation remodeling of maxillary anterior buccal bone: A clinical and biomechanical study

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ABSTRACT

Purpose: This study combines clinical investigation with finite element (FE) analysis to explore the effects of buccal bone thickness (BBT) on the morphological changes of buccal bone induced by the loaded implant.
Methods: One specific patient who had undergone an implant treatment in the anterior maxilla and experienced the buccal bone resorption on the implant was studied. Morphological changes of the bone were measured through a series of cone-beam computed tomography (CT) scans. A three-dimensional heterogeneous nonlinear FE model was constructed based on the CT images of this patient, and the *in-vivo* BBT changes are correlated to the FE *in-silico* mechanobiological stimuli; namely, von Mises equivalent stress, equivalent strain, and strain energy density. The anterior incisory bone region of this model was then varied systematically to simulate five different BBTs (0.5, 1.0, 1.5, 2.0, and 2.5 mm), and the optimal BBT was inversely determined to minimize the risk of resorption.
Results: Significant changes in BBTs were observed clinically after 6 month loading on the implant. The pattern of bone resorption fell into a strong correlation with the distribution of mechanobiological stimuli onsite. The initial BBT appeared to play a critical role in distributing mechanobiological stimuli, thereby determining subsequent variation in BBT. A minimum initial thickness of 1.5 mm might be suggested to reduce bone resorption.
Conclusions: This study revealed that the initial BBT can significantly affect mechanobiological responses, which consequentially determines the bone remodeling process. A sufficient initial BBT is considered essential to assure a long-term stability of implant treatment.

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1. Introduction

Long-term stability is one of the most critical indicators to the success of dental implant treatment [1,2]. Other clinical indicators include the enhanced bone volume, health of peri-implant tissue and esthetic alignment with the natural teeth, etc. [3–5]. Especially in the anterior maxilla region, the buccal bone morphology around the implants is widely considered a primary feature in determining peri-implant tissue and soft-tissue esthetics [6–9]. Thickness of the buccal bone around the implant placed in the anterior maxilla is thus thought to be a critical factor for achieving a favorable outcome.

To date, several clinical findings concerning the bone volume reduction, especially the short-term morphological changes in the buccal bone around implant immediately placed into extraction sockets, have been reported in both animal [10–12] and human studies [13–15]. During the healing stage of immediately placed implant, marginal gaps between the implant and bone tissue are recognized to be closed with new bone formation, but this may be accompanied by bone resorption from the external ridge [13,14]. Clinically, it has been suggested that a minimum buccal bone thickness (BBT) of 2 mm is required for maintaining a proper soft-tissue support on implant [6,7]. This threshold may be interpolated correctly from short-term observation during the bone healing periods after implant placement [16].

A major clinical challenge is that the BBT can continuously reduce over a long period of time even with an implant inserted in the healed maxillary anterior ridge [17]. The buccal bone on the implant may likely to resorb due to adverse remodeling activities induced by implant placement and functional loading, evidenced by the recent longitudinal computed tomography (CT) studies (7 years) [18,19]. Another case-series study revealed that none of the examined implants had complete buccal bone coverage after an average of 8.9 years in the non-bone grafted implant treatments [20]. Consequently, such bone resorption can lead to not only the instability of the implant, but also a high risk of soft tissue recession [6,21]. Unfortunately, there has been limited information available regarding the mechanism behind BBT reduction to recommend the required minimal BBT on the implant in the anterior maxillary for ongoing longitudinal stability, thereby preventing bone resorption under loading.

This study aimed to investigate bone morphological changes in the anterior maxilla after loading, where a patient-specific clinical case was investigated for ongoing time-dependent buccal bone reduction. A series of CT scans were acquired at different time points to measure morphological changes in bone, which was correlated to the mechanobiological stimuli obtained from three-dimensional (3D) patient-specific finite element (FE) analysis. Intrinsically, this study established an *in-silico* approach to exploring the effects of initial BBT on mechanobiological responses, thus estimating the potential bone remodeling outcomes in various bone morphologies. This new framework with both *in-vivo* clinical measurements and *in-silico* numerical modeling provides an effective tool for predicting the bone remodeling activities with different surgical options; thereby gaining new clinical and biomechanical insights into the minimal BBT required for preventing bone resorption.

2. Materials and methods

2.1. Patient condition and treatment

A 52-year-old healthy female patient, who experienced the buccal bone resorption on the implant after loading, was recruited. The patient was diagnosed with tooth root fracture of her maxillary right incisor at the Dental Implant Center, Tohoku University Hospital in Japan. As a result of the treatment consultation, the patient chose to replace the fractured tooth with the dental implant restoration. The initial cone-beam (CB) CT scan (3D Accuitomo, MORITA Corp., Kyoto, Japan) was performed at a standardized exposure of 90 kV and 35 mA and with slice width of 0.25 mm before tooth extraction (Scan-1), and then flap-less tooth extraction was undertaken. The SimPlant software (Materialise Dental, Leuven, Belgium) was used for 3D surgical planning with the position and orientation of implant placement. The planning results were transferred to the surgery and implemented by means of a stereolithographic surgical guide system (SurgiGuide, Materialise Dental). An implant (Osseospeed TX 3.5S, DENTSPLY Implants, Mölndal, Sweden), with 3.5 mm diameter and 13.0 mm length, was inserted after a healing period of 8 week post extraction stabilization [4]. The implant showed good primary stability after placement with an insertion torque $\geq$20 N cm. The second CBCT scan (Scan-2) was performed at the same setting in 6 months after implant placement, along with installation of a temporary crown for loading. The third CBCT scan (Scan-3) was performed 12 months after the implant placement (*i.e.* 6 months with loading) during the follow-up examination. After the final restoration, the patient was recalled every 3 months for prosthetic and oral hygiene examinations.

The research protocol for this study was approved by the research ethics committee of Tohoku University Graduate School of Dentistry (Reference Number 26-34). The patient has given written consents for utilizing the image data and publishing these case details after full explanation of the procedure, risks and benefits.

2.2. Image processing and analysis

The CBCT data were processed with medical image viewer software (EV Insite S, PSP, Tokyo, Japan), which allows the detection and alignment of anatomic landmarks between the different cross-sectional examinations. The buccal-palatal cross-sectional images were selected for dimensional comparison across the implant by the multiple planar reconstruction (MPR) technique [22]. BBT was measured in terms of the thickness between the outer surface of cortical bone and implant-bone interface. The lines parallel to the implant platform were placed at 1, 2, 4, 6, 8, and 12 mm apical to the implant platform (Fig. 1), to measure the distances from the implant surface (thread peaks) to the outline of the buccal bone. In this study, the bone morphological changes,