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ORIGINAL ARTICLE

# Difference of natural teeth and implant-supported restoration: A comparison of bone remodeling simulations

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**KEYWORDS**
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**Abstract** *Background/purpose:* Although there are existing numerical simulation studies on biomechanical responses induced by dental implants, particular attention has not been paid to the discrepancies of alveolar bone around natural teeth and dental implants. The purpose of this study was to compare and assess the different consequences of alveolar bone remodeling before and after dental implantation.

*Materials and methods:* Two three-dimensional finite element (FE) models of a maxillary bone segment were developed, comprising either implant-supported dental bridgework or natural teeth. A set of three-dimensional orthotropic bone remodeling algorithms was implemented in the FE models to analyze the stress, strain, and density distribution in the supporting bone.

*Results:* There were significant differences in the stress, strain, and density distribution between the intact model and implanted model. The variation of stress value was remarkably different in both models, and evident differences were found in the high stress region. Strain value was elevated in cortical bone around the implant neck, but in the intact bone strain value was distributed more evenly. In addition, bone density distribution around natural teeth was more uniform and homogeneous.

*Conclusion:* Simulations of adaptive bone remodeling, validated by clinical data, can be proved as a useful way to bring more insight into the mechanisms behind bone adaptation. In consideration of the crucial role of the periodontal ligament (PDL) in determining the mechanical environment in alveolar bone, it is suggested that the effect of the PDL on the bone remodeling response should be considered in future dental implant design.



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## Introduction

Teeth are typically lost due to disease, accidents, the aging process, or dental decay. To replace missing teeth, a dental bridgework is usually used to restore natural function and appearance. An implant-supported restoration can provide an advanced alternative to traditional denture replacement. Benefitting from recent advances in dental implants related technology and materials, surgical placement of standard implants boasts a success rate of approximately 97% in the short term.[1,2] However, dental implant failures are generally higher in some specific groups of patients, such as patients with severe bone loss in the jawbone, periodontal disease, and bruxism problems.[3,4]

According to the classic Wolff law,[5] bone has the ability to change its internal material properties and external geometry to adapt to loads placed upon it, via a biological process called bone remodeling. During this process, bone resorption and formation are executed and regulated by bone cells (osteoclasts and osteoblasts).[6] Based on the Frost mechanostat theory,[7] bone will resorb when the mechanical loading drops below a lower threshold. When the load reaches an upper threshold values, bone apposition will occur. If the mechanical stimulus is between the upper and lower threshold values, remodeling will not take place. Moreover, where mechanical loading increases excessively, overload resorption may occur with bone loss. Changes in the mechanical loading environment due to the insertion of an implant into the jawbone have been well addressed in previous dental studies.[8–10] Therefore, in order to further improve the effectiveness of dental implants, especially over the long term, it is necessary to investigate the remodeling responses of peri-implant bone in order to obtain more detailed information about the biomechanical behavior of bone-anchored prosthetic devices.

Based on the aforementioned bone adaptation theory, some numerical studies have detailed the biomechanical responses induced by dental implants. In the field of dental biomechanics, the computational simulation of supporting bone remodeling has been carried out by previous researchers.[11,12] A bone remodeling algorithm has been developed for internal bone remodeling in the cortical and trabecular bone within jawbone. In the study by Li et al,[12] improvements in simulation methods by integrating overload bone resorption have allowed for more accurate prediction of dental implants. A study by Chou et al[13] predicted a nonhomogeneous distribution of density/elastic modulus of the mandible around various dental implant systems. Furthermore, by using a set of segmented algorithms, Lin et al[14] investigated bone remodeling around implant systems under different loading conditions, and recommended attaining proper occlusal adjustment to reduce the lateral force. Some investigators developed a series of numerical dental models correlating to clinical computed tomography (CT) data.[10,14–16] In addition, other groups focused on simulating trabecular architecture around dental implants.[17,18]

Although there are existing numerical simulation studies on biomechanical responses induced by dental implants, particular attention has not been paid to the discrepancies of alveolar bone around natural teeth and dental implants. Accordingly, more specific studies are required to qualify and quantify such differences. The objective of this work is to compare and assess the consequences of remodeling in alveolar bone before and after implantation. To achieve this, two three-dimensional (3D) finite element (FE) models of a maxillary bone segment were developed for this biomechanical analysis, comprising either the natural teeth or the three-unit implant-supported cantilever bridgework, and a set of 3D orthotropic bone remodeling algorithms were implemented herein. Furthermore, the density contours were qualitatively compared with clinical radiographic images.

## Materials and methods

### Finite element modeling

The 3D geometry of the maxilla was modeled from CT images of a middle-aged male patient. The CT images consisted of 312 transverse sections with a slice thickness of 0.5 mm and a pixel width of 0.398 mm. Using the software Mimics (Materialise, Leuven, Belgium) and Geomagic (Geomagic Company, NC, USA), 3D models of a segment of the maxilla (including cortical and trabecular bony structure) without teeth were built. Two FE models with natural teeth and implant-supported cantilever bridgework were constructed for evaluating the progression of bone remodeling, as shown in Fig. 1. For the intact model, two central incisors and one lateral incisor were incorporated. The periodontal ligament (PDL) was generated around the root with an average thickness of 0.2 mm. For the implanted model, a three-unit implant-supported restoration with cantilever was built. The two dental implants were 10 mm long with a diameter of 3.75 mm, based on Straumann Standard Plus Implant system (Straumann, Basel, Switzerland). The dental implants and crowns were made of titanium alloy (Ti6Al4V) and ceramics, respectively. The models were checked by a dentist to ensure the geometrical similarity, similar to previous publications.[19,20]

The models were meshed using 10-node quadratic tetrahedral elements with a global element size of 1 mm in ANSYS Workbench (Swanson Analysis System Co., Houston, TX, USA). The convergence tests for the intact and implanted models resulted in 62805 elements (nodes: 109246) and 63573 elements (nodes: 100900), respectively. Detailed elements assignments are listed in Table 1.

Occlusal mastication forces in this simulation varied for each region of the teeth. The two central incisors and lateral incisor were occlusally loaded with forces of 100 N, 100 N, and 90 N, respectively, in the buccal-lingual plane at 11° (Fig. 1). According to the actual situation, the occlusal loading forces were applied on the palatal surface about one third of crown length from incisal edge. Fully bonded interfaces were assumed between the bone and implant, simulating complete osseointegration. Moreover, the interfaces between the bones and PDL, PDL and teeth, trabecular bone and cortical bone, and abutment/implant and restoration are assumed to be perfectly bonded. As boundary conditions, the top, mesial, and distal borders of the maxilla were considered fixed to restrain all forms of movements, as shown in Fig. 1.