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A study of force distribution of loading stresses on implant—bone interface on short implant length using 3-dimensional finite element analysis

Ning Kang, DDS, MMed, Yan-yun Wu, MMed, PhD student, Ping Gong, DDS, PhD, Li Yue, DT, and Guo-min Ou, DDS, PhD
The State Key Laboratory of Oral Diseases, West China School of Stomatology, Sichuan University, Chengdu, China

Objective. The purpose of this study is to evaluate the biomechanics of short dental implants.
Study Design. Three-dimensional finite element analysis was used to simulate stress distribution of 8-mm implants with 6 different diameters in I to IV types of bone densities; meanwhile, axial and oblique loads were applied in this study.
Results. It was found that the maximum Von-Mises stress varied significantly when the diameter was within 3.3 mm and 5 mm, whereas the change of peak stress was not obvious when the diameter was within 5.5 mm to 7.1 mm. The peak stress on the implant—bone interface increased with the reduction of bone density. The stress in types I and II had similar distribution and the same was true for types III and IV.
Conclusions. These results revealed that implants with larger diameter (<5.5 mm) and bone quality enhancement may be preferable to get better clinical effects. Prospective clinical studies are required to confirm this. (Oral Surg Oral Med Oral Pathol Oral Radiol 2014;118:519-523)

Atrophic alveolar ridge is common in edentulous mandible, in which the available bone height usually turns out to be insufficient for traditional implantation. Various bone augmentation methods, such as on-lay graft, guided bone regeneration, and bone distraction, are alternatives to address this condition. However, it would prolong the whole prosthetic process to use bone augmentation techniques because a few months always elapse during osteogenesis.

Dental implants with a length of less than 10 mm are called short implants and are usually applied in the alveolar bone with decreased height. By adopting such implants, it becomes possible to shorten the treatment period because the surgeons don't have to augment the ridge vertically. The popular dental implant systems all provide short implants with lengths of 8 mm or less. Some data have indicated that the failure rate of the short implants is higher than that with a length of more than 10 mm,[1] and early loosening is more often observed in cases with the short ones.[2] However, other reports indicated that the overall success rate of the short implants in varied zones was 98.1% to 99.7%, similar to that of long ones.[3] Draenert et al.[4] also reported that short implants have similar survival rates in 1 to 3 years compared with that of the long ones. Diameter and bone density are the 2 vital factors that influence the success rate of the short implants,[3] although previous researchers had not elucidated how these 2 factors affect stress distribution on implant—bone interface.[5] Most of the recent studies that have focused on three-dimensional finite element analysis (3-D FEA) have mainly obtained their results under hypothetical 100% bone-to-implant contact (BIC)[6-8]; in fact, it is almost impossible to achieve full bone contact.[9] Generally, the BIC was thought to range between 30% and 70%,[10] and the contact status is related with bone density.[11,12] Block[13] found the implantation could acquire success while the contact rate was around 50%. Although short implants are mostly applied in cases with deficient bone volume, which is often caused by periodontitis-related bone resorption or longtime disuse, poor bone quality usually coexists in these situations. In the present study, 40% BIC was chosen as a relatively extreme parameter to simulate bone contact condition of short implants.

The aim of the present study is to discuss how implant diameter and bone density influence the stress distribution on implant—bone interface by 3-D-FEA, with the condition of 8-mm implant and 40% BIC. This may provide some guidance for prospective clinical trials for the short implants.

MATERIALS AND METHODS

Material properties

The material properties of mandible and titanium implants were taken from published data that were

Statement of Clinical Relevance

The authors propose to provide guidance for clinical application of short dental implants by the 3-dimensional finite element analysis method of exploring stress distribution on implant—bone interface, with varied diameters of 8-mm implants in different bone densities.

Department of Implantology, West China School of Stomatology, Sichuan University, Chengdu 610041, China.

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Table I. Mechanical properties ascribed to materials in the model[7,8,12]

Material	*Young's modulus (MPa)*	*Poisson's ratio*
Cortical bone	13700	0.30
Cancellous bone I	9500	0.30
Cancellous bone II	5500	0.30
Cancellous bone III	1600	0.30
Cancellous bone IV	690	0.30
Titanium	110000	0.35

obtained by ultrasonic wave methods and other material testing techniques. The implant body was assumed to be isotropic, homogenous, and linearly elastic, although the cortical and cancellous bone of the mandible could be considered to be transversely isotropic, with a higher elastic modulus in the vertical direction and a lower elastic modulus in transverse directions. Four types of bone quality have been simulated according to individual Young's modulus and Poisson's ratio, which are listed in Table I.

Construction of implant with 6 different diameters model. Using ANSYS 5.7 software (ANSYS, Inc., Canonsburg, PA, USA), 6 diameters of cylindrical implant models 8 mm long were constructed and meshing followed. Tetrahedral elements for the implant models were used because they were more harmonious with the design structure and hence produced more accurate results.

Construction of mandible model. Multi-slice spiral computed tomography (CT) (Siemens sensation, Type 16) was adopted in this experiment, with parameters of 120 kV, 100 mA, 1 mm/s, and 0.5 mm thick. Mandible was scanned with reference to the Frankfort horizontal plane and a total of 196 images were acquired. The images obtained were transferred into the software MIMICS 8.1 (MATERIALISE Co., Leuven, Belgium), and finally, the data in Standard Template Library (STL) delivered by MIMICS were imported into ANSYS and the graphical representation of the mandible was formed. Once the graphical representation of the finite element model was obtained, meshing was done. The mandibular models with 4 types of bone quality were meshed with tetrahedrons and hexahedrons.

Construction of osseointegration model. Because BIC is an index to indicate the osseointegration level, the imitation of BIC was chosen in this study to reflect the actual osseointegration condition. Assignment of random variable *connect* to implant model elements followed a 0-1 distribution. When *connect* = *1*, it meant that bone contact existed for 1 element; when *connect* = *0*, it meant no bone contact in the relevant element. By setting the *connect=1* probability for more than 1636 elements to be 40%, the actual BIC achieved in our osseointegration model was 36% to 44%. Eventually, with 4 type of bones and 6 diameters of implant modeled, 24 (4 × 6) finite element models of implant–bone integration were obtained, as shown in Figure 1.

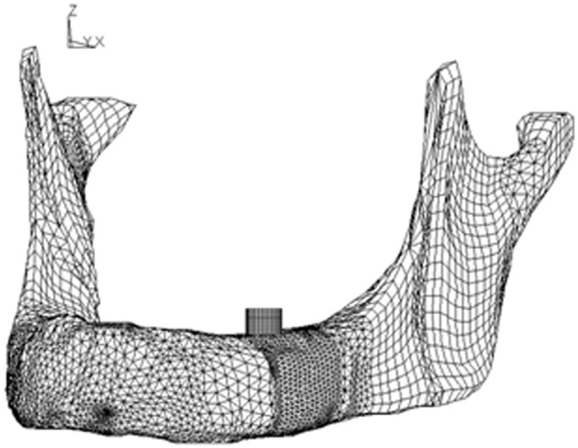

Fig. 1. The 3-dimensional finite element model of osseointegration.

Sample validation. In our modeling of osseointegration design, the idea probability of BIC was set to 0.4, and the design goal was a difference (error) no more than 0.04 (δ), given a significance level of 0.05 (α) and power of 0.8 ($1-\beta$), and this was achieved by constructing enough elements (samples) in our FEA modeling.

As introduced earlier, the elements have a property *connect,* which is a 0-1 distribution random variable with the probability of *connect* = *1* equal to 0.4 (p). Thus the minimum elements (n) required to achieve difference of 0.04 (δ), given significance level of 0.05 (α) and power of 0.8 ($1-\beta$), was calculated by the following equation:

$$n = \left[\frac{(z_{\alpha/2} + z_\beta)}{\delta}\right]^2 \times p \times \left(1 - p\right)$$

$z_{\alpha/2}$: The point of Gaussian distribution corresponding to the upper tail probability $\alpha/2$.

z_β: The point of Gaussian distribution corresponding to the upper tail probability β.

The minimum requested elements number n is 1185. In our osseointegration modeling, with more than 1636 elements constructed, which was far more than requested, the design goal was achieved.

Constraints and loads. The entire assembly was constrained at the attachment regions of masticatory muscles (masseter, temporalis, medial pterygoid, and lateral pterygoid) to prevent rotation of the model around the condyles, as shown in Figure 2. The constraints were allocated because the contraction of these muscles limits the mandibular movement in actual cases. The pattern of loading consisted of vertical loads with 200 N and 45 degrees buccolingually oblique loads with 100 N on the top of the implant abutment, as shown in Figure 3.