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Original Article

The effect of implant neck microthread design on stress distribution of peri-implant bone with different level: A finite element analysis

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Abstract *Background/purpose:* Significant research has proposed that the implant with microthread in the neck can significantly reduce marginal bone loss, but whether it is consistent in the condition of marginal bone loss is still unknown. The objective of this study is to investigate the effect of microthread on stress distribution in peri-implant bone with different bone level using finite element analysis.

Materials and methods: A series of computational models of mandible segments with different bone resorption and implant models with or without microthread in the neck was installed by computer-aided design software. The simulated occlusal force of 150N was applied buccolingually on the top center point of implant. The FEA was performed, and the von Mises stress, principal stress and shear stress in peri-implant bone were recorded and analyzed.

Results: In all models, the T-neck group exhibits higher von Mises stress and principal stress, as well as lower shear stress than S-neck group. Three types of stresses increase with the depth of bone resorption developed, but the differences of shear stress between two groups of implants were gradually decreased.

Conclusion: The micro-thread design in implant neck can reduce marginal bone loss by decreasing shear stress in peri-implant bone, but this effect is gradually weakened with the decline of the marginal bone level.

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Introduction

Compared to the traditional removable and fixed denture, dental implant restoration can resume masticatory function and aesthetic requirement of missing tooth to a greater extent, which has become an optimized choice in dentistry.[1–3] The dental implant survival rates after 5-year follow-ups is reported to be up to 98.9%.[4] The superior biocompatibility and favorable biomechanics environment of implant–bone interface are also importance for the long-term survival of dental implants.

Considering the stress is mainly concentrated on cortical bone around implant neck under the functional load, much focus has been paid on maintenance of marginal bone level. Many methods have been proposed to optimize the stress distribution around implant to reduce marginal bone resorption, such as changing the diameter and thread profile of implant and/or applying the platform switching technique in implant-abutment joint,[5–7] which has shown to improve marginal bone preservation and maintain the level of soft tissue. Nevertheless, marginal bone loss around implant is still inevitable. Adell et al. reported that the marginal bone resorption of 1.2 mm within one year after implantation under normal occlusal force.[8] At present, many scholars followed a success criterion, established by Albrektsson et al., that the marginal bone loss should not be more than 1.5 mm in the first year and 0.2 mm annually from the second year.[9]

Literatures on microthread design at implant neck have drawn a lot of attention. Clinical and animal studies have found the implant with microthread in the neck can significantly reduce marginal bone loss. Lee et al. concluded the implant with microthread might have a positive effect on against marginal bone loss.[10] Furthermore, an experimental study in dogs demonstrated microthread configuration increased the degree of bone–implant contact when compared with the non-microthreaded implants and provided a potential contribution on osseointegration, as well as on the maintenance of marginal bone.[11]

Three-dimensional finite element analysis (FEA) has been widely used for the complex mechanical investigating which are difficult to perform in vivo or in vitro.[12–14] Presently, many scholars explored and revealed the biomechanical effect of microthread on implant–bone interface by FEA. Unfortunately, most of studies involved FEA model without bone resorption and ignored the changes of marginal bone level. Thus, this study was conducted to investigate the effect of the presence or absence of microthread on stress distribution in peri-implant bone with different bone level.

Materials and methods

The creation of a bone block model

The mandibular bone of a healthy adult male was selected and scanned by cone beam computed tomography (CBCT) at 300 μm resolution in School and Hospital of Stomatology, Wuhan University. The acquired CT images were saved as DICOM format and then imported into image processing software (Mimics v17, Materialise, Leuven, Belgium). The segmentation and reconstruction of three dimensional solid model was performed based on gray scale values of different tissues. The right premolar area of the mandible was selected for analysis (Fig. 1A). The final bone model consists of cancellous bone surrounded by a cortical bone layer, with the cavities corresponding to different implants. Dimensions were indicated in Fig. 1B. The bone model was divided into four groups: non-resorption, 0.25 mm resorption, 0.5 mm resorption, and 0.75 mm resorption respectively, according to bone level of the planting area.

Creation of implant models

The cylindrical implant model with 11.5 mm in length, 4.0 mm in diameter and a 2.5 mm pitch V-shape thread was constructed by finite element software. A 4 mm high abutment and implant were simplified to a single unit as the abutment was not considered in this paper. Two types of implant models were generated according to the different neck configurations. S-neck group: the implant neck with a smooth portion. T-neck group: the implant neck with a microthread (Fig. 1B). Except for the difference of implant neck structure, all implant configurations were identical between two groups.

Finite element analysis

Eight models with four bone and two implant configurations were assembled into finite element processing software (Abaqus2016, Dassault Systemes, Paris, France). The implants were embedded into the center of bone model in horizontal plane, with the neck of implant located at the highest level of alveolar crest.

All materials used in FEA were assumed as homogenous, linearly elastic, and isotropic (Table 1).[15,16] The bone and implant was considered as complete osseointegration, and the interface of bone-implant was defined as the bonded contact.[17] In all models, the tetrahedral solid element was adopted for the mesh. In order to improve the accuracy of results during the simulation, a finer mesh was used along the interface at the region of implant neck. An oblique

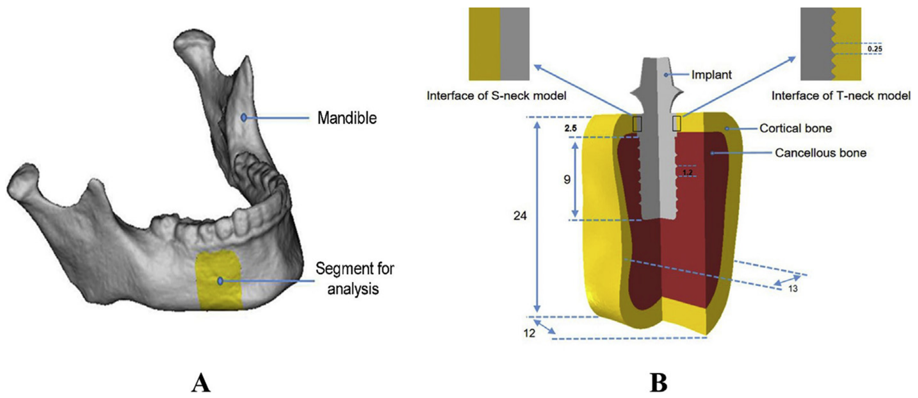

Figure 1 (A) Location of analysis section in a mandible (B) Dimensions of bone and implant model.

Table 1 Material properties of implant and bone.

Component	Young's modulus (MPa)	Poisson ratio
Implant (Titanium)	110000	0.3
Cortical bone	13700	0.3
Cancellous bone	950	0.3

static force of 150 N was applied on the top center point of abutment from buccal to lingual at 45-degree angle to the long axis of implant. The boundary condition was determined that the all nodes of mesial and distal border of bone model were fixed in all directions. The von Mises stress (equivalent stress), principal stress and shear stress were recorded.

Results

For all models, the values in cortical bone were far higher than those in cancellous bone. The marginal bone was the region of interest for analysis, and the stress distribution on cancellous bone was ignored.

The stress distribution of the two groups of implants in full-bone model

T-neck group displayed higher maximum of von Mises stress and principal stress than S-neck group. The details of stress values were presented in Table 2.

Figure 2A shows the principal stress distribution in cortical bone from the mesial view. The compressive stress (minimum principal stress) was observed in the most of the lingual region (compressive side), and the tensile stress (maximum principal stress) was generated at buccal region (tensile side), as well as the lower portion of lingual region. The compressive and tensile stresses were separated by an oblique line, which represented the boundary of them. The highest compressive stress concentrations in S-neck model appeared a homogeneous band-like distribution at the top of lingual bone around the implant neck (black solid arrow), whereas those in T-neck model were scattered at three points on the disto-lingual peri-implant bone (red solid arrow). Fig. 2C shows the cross-section of principal stress distribution on the bone around implant neck. Y-axis was introduced to describe the cross-section position in coronal-apical direction. Y-axis coordinate values corresponding to the top and bottom of implant neck were marked as 0 and 2.5. The interval of every section was 0.1 (Fig. 2B). The penetration depth of highest compressive stress concentrations in S-neck and T-neck model along the Y-axis direction (vertical or coronal-apical direction) were 0.8 mm and 0.6 mm, respectively.

Figure 3A shows the similar shear stress patterns in both implant model, which were concentrated on the mesial and distal side of peri-implant bone. The positive and negative values represented different directions. The maximum shear stresses in T-neck group was 8.6 MPa, which was lower than that of S-neck group (9.9 MPa). In addition, the portional bone around implant neck was selected, and the bone volume fraction associated with different stress ranges were obtained. It could be seen that the bone volume related to low stress ranges (less than 4 Mpa) in T-neck group was more than that in S-neck group (Fig. 3B).

The stress distribution of the two groups of implants in bone resorption model

The maximum von Mises stress, principal stress, and shear stress enhanced while the bone resorption increased for all model (Table 2).The shear stress distributions in all bone model from the lingual view were shown in Fig. 4. In general, the shear stress in T-neck group was lower than in S-neck group for all of the bone resorption models, but the differences were gradually decreased with the depth of bone resorption developed (Fig. 5).

Discussion

After the implantation, occlusal forces are transmitted to the surrounding bone through implant. Cortical bone bears most of stress for its higher elastic modulus than cancellous bone, which was called stress shielding effect.[18–20] It will increase the risk of marginal bone resorption. Some scholars has confirmed that a rough surface in implant neck installed by microthread plays a crucial role in minimizing peri-implant marginal bone loss and was considered as retentive elements.[21] Moreover, it is determined that

Table 2 The maximum value of three types of stress peri-implant bone with different level for S-neck and T-neck model under oblique loading.

	S-neck implant				T-neck implant			
Stress value (Mpa)	Full bone	0.25-mm resorption	0.5-mm resorption	0.75-mm resorption	Full bone	0.25-mm resorption	0.5-mm resorption	0.75-mm resorption
von Mises stress	20.22	21.52	23.89	25.83	27.39	30.25	35.46	39.98
Compressive Stress	23.64	25.79	28.52	30.58	25.47	33.4	34.33	43.14
Tensile Stress	11.93	12.78	14.8	14.9	15.94	16.07	16.86	20.06
Shear stress	9.87	10.27	10.64	11.73	8.6	9.16	10.02	11.38

microthreaded in implant neck can reduce the marginal bone resorption and could be selected to maintain bone level in a related meta-analysis.[22]

The shear stress was distributed at mesiodistal side of peri-implant bone for both groups under oblique load, similar to prior studies.[23] Additionaly, the lower peak shear stress was noticed in T-neck model compared with S-neck model, which is supported with the previous reports that the stress pattern of implant—bone interface was changed as the existence of microthreads.[10,24] The oblique force applied on the implant—bone interface was divided into three components: the compressive and tensile stress that are perpendicular to the interface and the shear stress that is parallel with the interface. Bone exhibits different degree of resistance to three types of stress components. Cortical bone is strongest to compressive loads, 30% weaker to tensile forces, and 65% weaker to shear forces compared to compressive forces.[25] It indicated that the shear stress

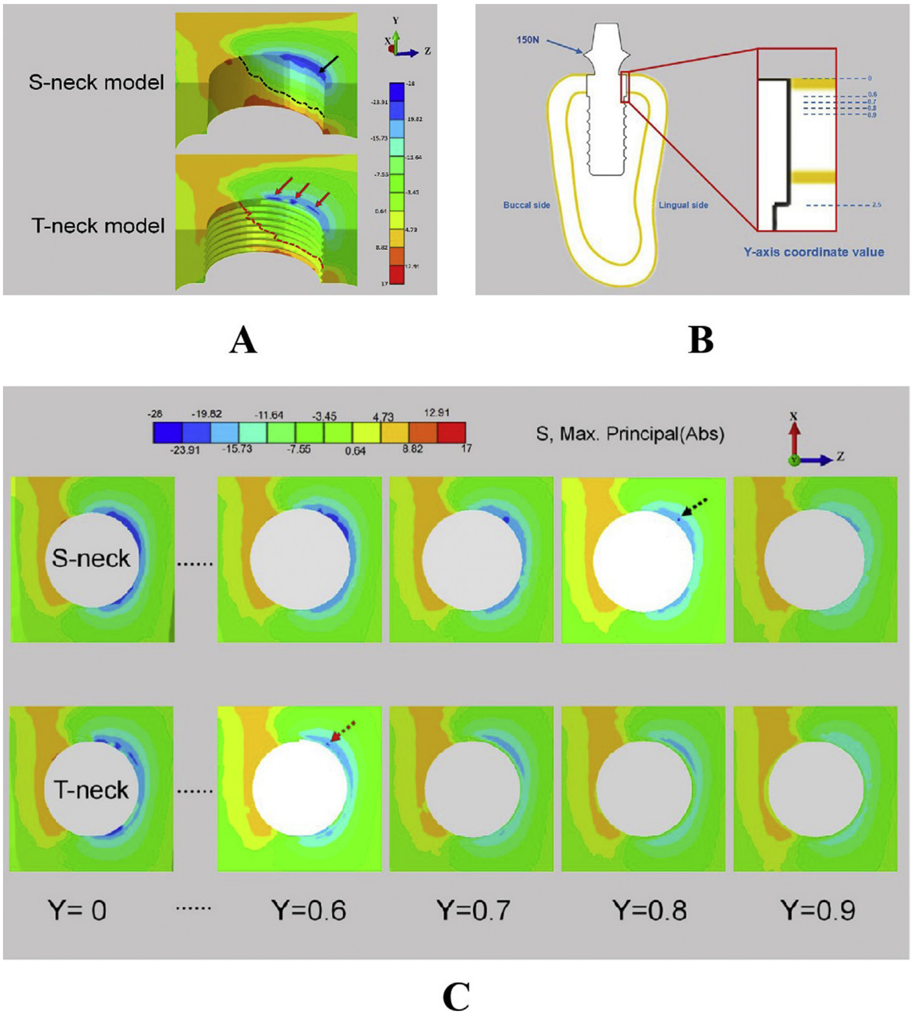

Figure 2 Principal stress distribution for two groups of implants (A) In the bucco-lingual section view. Dotted line shows the boundary between the compressive and tensile stress. Black and red arrow shows the concentration of compressive stress, respectively (B) Diagrammatic sketch of describing the cross-section position in coronal-apical direction by Y-axis (C) In the cross section view. Black dotted arrow and red dotted arrow indicates that the penetration depth of highest compressive stress concentrations in S-neck and T-neck model along the Y-axis direction were 0.8 mm and 0.6 mm, respectively.

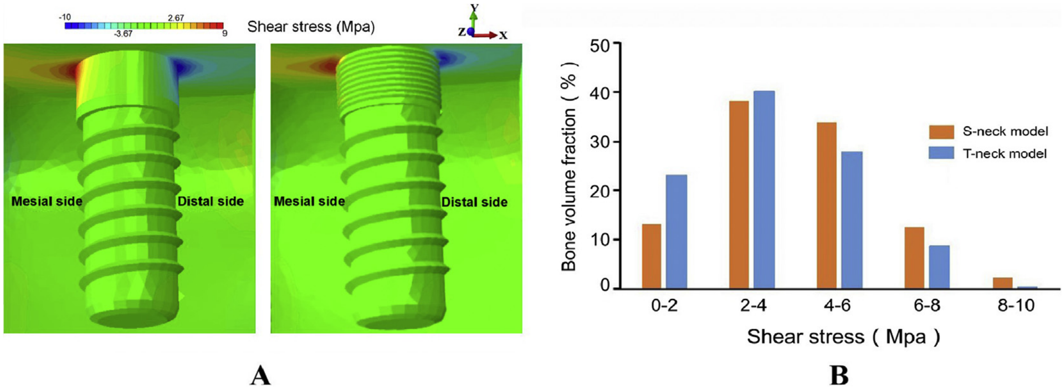

Figure 3 (A) Shear stress distributions for two groups of implants from the lingual view (B) Volume fraction of peri-implant cortical bone related to different stress ranges for two groups of implants.

was more destructive to bone and more crucial in aspect to marginal bone loss. Without the cushion effect of periodontal ligament in natural teeth, the occlusal force applies directly on the implant—bone interface after osseointegration and will be susceptible to cause interfacial failures.[26] In T-neck model, the shear force at the interface was transformed into the compressive force to which bone is the most resistant by microthread, especially the first thread. Hence, the lower shear values were found in T-neck model, which revealed the predicted effect of microthread design.

The maximum shear stress of T-neck group was lower than S-neck group in both full-bone and bone-resorption models. But the difference was decreasing while the bone resorption. It was speculated that the first microthread contacted with cortical bone was below the top of implant neck when bone resorption occurs. The function of changing pattern of load transfer and maintaining the marginal bone level by the first microthread become weaker and weaker in successive bone-resorption models. In a related study, Song et al. revealed that more peri-implant bone loss was observed in implant with microthread placed below the top of neck compared to those with microthreads placed at the top.[27] So it minimize the difference of peak shear stress between two groups of implants in bone-resorption model.

It is remarkable that the peak shear stress value increased with the bone resorption. In the similar study, Wolff assessed different implant geometries on the strain distributions under different bone conditions, including full bone, horizontal bone loss and circular bone loss. And he mentioned the strain magnitude in bone defect model was higher than in full-bone model.[28] It seems to be a vicious circle that the decline of marginal bone level causes the

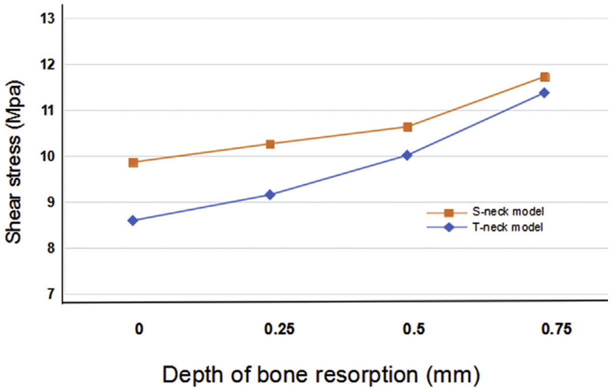

Figure 5 Peak shear stress value of peri-implant bone for two groups of implants in a series of bone levels.

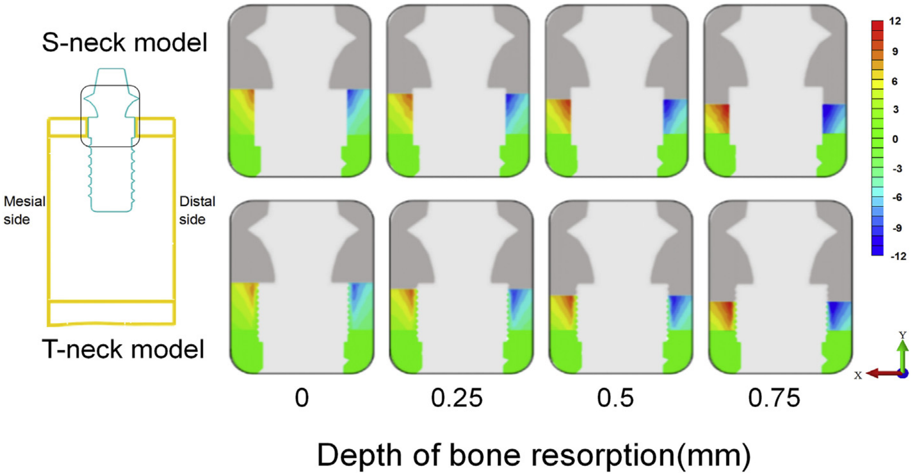

Figure 4 Shear stress distributions in full-bone and bone-resorption models for two groups of implants.

higher stress and in turn, the increase of stress become the risk factor of bone loss. Nevertheless, a growing and aggravate absorption was not appeared in clinical. Many researchers have stated that the bone loss occur mostly in the first year after implantation and it gradually decreases subsequently. One possible explanation of this result was that the mechanical and thermal damage during surgery played a significant role on early bone loss.[29] Also, the occlusal force reached a steady state after a few years and the bone loss slows down by establishing an equilibrium between the occlusal load and marginal bone loss.[8] In present FEA model, the constant static occlusal load was applied in all bone model, which is inconsistent with the situation in reality. Thus, a dynamic and adaptable loading suitable for various bone level need to be considered for better simulating the actual clinical situation in further research.

Declaration of Competing Interest

The authors declare no conflict of interest.

Acknowledgements

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