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Original Article

Three-dimensional finite element stress analysis of micro-implant anchorage-assisted intrusion of orthodontic teeth molar

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Abstract: Objective: To analyze the changes of biomechanical characteristics of micro-implant-bone interface by establishing a three-dimensional (3-D) finite element model of stress variation of micro-implant anchorage-assisted intrusion of orthodontic teeth molar (OTM). Methods: ANSYS software was used for modeling. And the pure titanium micro-implants were implanted into the alveolar bone, leaving 3 mm outside the alveolar bone. Cortical bone around the micro-implant was continuous and homogeneous with 1 mm-thickness, and continuous cancellous bone was under the micro-implant. Von-Mises stress and displacement (mean displacement and peak displacement) under the five tilt angles of 30°, 45°, 60°, 75°, and 90° were calculated by applying 200 g of horizontal force. Results: Under the 200 g of horizontal force, the Von-Mises stresses and the mean displacements decreased with the increase of the special tilt angles. Under the tilt angles of 30°, 45°, 60°, 75° and 90°, the Von-Mises stresses were 1.3184 Mpa, 1.1834 Mpa, 0.9384 Mpa, 0.7341 Mpa and 0.5184 Mpa respectively; and the mean displacements were 6.1934 μm, 5.0413 μm, 3.9475 μm, 3.2851 μm, 2.4852 μm respectively. Under the 200 g of horizontal force, all peak displacements of different tilt angles were relatively small (all peak displacements ≤6.9453 μm). Conclusion: The molar micro-implant has certain stability under the 200 g of horizontal force, so it is beneficial for OTM.

Keywords: Micro-implant, orthodontic teeth molar, biomechanics, three-dimensional finite element model

Introduction

As a new treatment for deformity correction, micro-implant anchorage is to place a micro-implant inside the bone as the anchorage base to support the moving teeth without patient's active coordination in the course of treatment [1]. The stress of bone tissue is affected by many factors, including the orthodontic force, tilt angle, etc. [2], which has a very important clinical significance on the research of mechanical effects of the micro-implant and bone tissue [3]. And the evaluation of the later functional adaptation of the micro-implant relies on this research [4]. Three-dimensional (3-D) finite element model of micro-implant and bone tissue [5], can be used to study the mechanics of micro-implant and bone tissue at a certain tilt angle and to further analyze the displacement of the bone interface, thereby providing basis for the implantation of micro-implant in clinic [6]. This study discusses the biomechanics of micro-implant anchorage for orthodontic teeth molar (OTM) through 3-D finite element analysis.

Materials and methods

Instrument and software

The computer system adopted in this study was Windows XP, and the software was ANSYS6.1 finite element software developed by the United States ANSYS Group. This study was in line with the requirements of our hospital's Ethics Committee and approved by the committee.

Material

Threaded pure titanium micro-implants were used in this study.

Methods

Design of micro-implant modeling: The micro-implant was made from pure titanium, and its shape was a knife-edged threaded cylinder (cyl-

Table 1. Von-Mises stress analysis at five different tilt angles (Mpa)

Angle	30°	45°	60°	75°	90°
Peak stress	1.3184	1.1834	0.9384	0.7341	0.5184

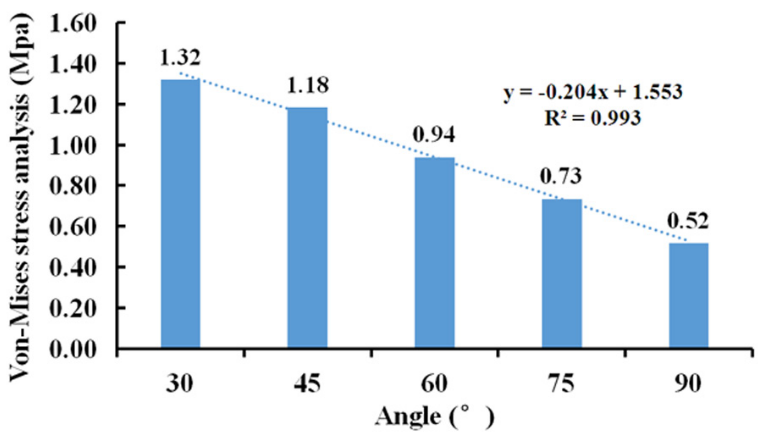

Figure 1. Von-Mises stress analysis at five different tilt angles. Under 200 g of horizontal force, the implant's stress decreased with the increasing of angle.

Table 2. Mean displacement analysis at five different tilt angles (μm)

Angle	30°	45°	60°	75°	90°
Mean displacement	6.1934	5.0413	3.9475	3.2851	2.4852

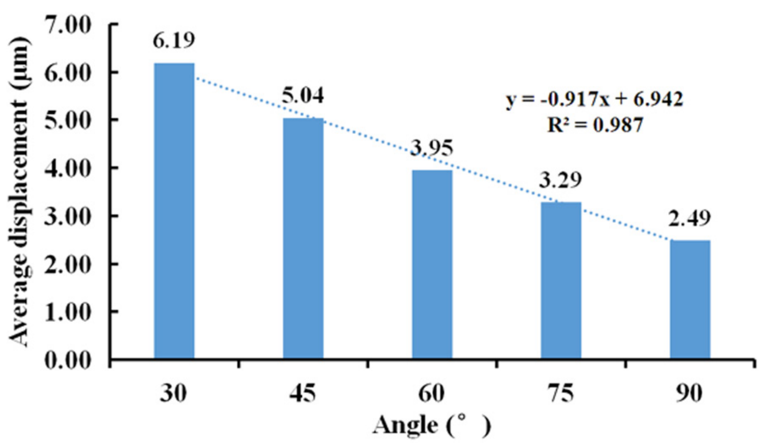

Figure 2. Mean displacement analysis at five different tilt angles. Under 200 g of horizontal force, the mean displacement of the implants decreased with the increasing of angle.

Table 3. Peak displacement analysis at five different tilt angles (μm)

Angle	30°	45°	60°	75°	90°
Peak Displacement	6.8375	6.4853	6.9453	6.4794	6.7584

inder outer diameter was 2 mm, inner diameter 1.6 mm and the total length 9 mm; the thread depth was 0.2 mm, the pitch 0.3 mm, and the vertex angle 60°) [7]. After such a micro-implant was placed into the alveolar bone, a 3 mm-non-thread place was left outside the alveolar bone. Cortical bone around the micro-implant was continuous and homogeneous with 1 mm-thickness, and its material was a kind of isotropic elastomer; and continuous cancellous bone was under the micro-implant [8].

Establishment of 3-D solid model of micro-implant-bone: Three-dimensional model of micro-implant and bone tissue was established and then assembled with ANSYS software to form a 3-D model of micro-implant-bone, which was introduced into ANSYS-6.1 finite element software for correlation analysis [9].

Setting of parameters: The elastic modulus of the micro-implant was set to 103,400 Mpa, and its Poisson's ratio to 0.34; the elastic modulus of the cortical bone was set to 13,700 Mpa, and its Poisson's ratio to 0.30; and the elastic modulus of the cancellous bone was set to 1,500 Mpa, and its Poisson's ratio to 0.30 [10].

Meshing: Six was selected as the default precision [11], and then the three vertebral body and node modeling was used to deal with the unit, so as to get a 3-D finite element model, whose total nodes and units were 9,387 and 5,038 respectively [12].

Conditional assumptions: The materials and tissues in the model were homogeneous and continuous, and they were currently isotropic materials. In the model, there was a smaller deformation of the materials after stress, and the osseo-integration of bone tissue and micro-implant were 100%. The implanted directions were set, and the reference variables were the angles between the micro-implant and the alveolar bone plate as 30°, 45°, 60°, 75°, 90°, respectively [13].

Appropriate orthodontic load: A horizontal force of 200 g was added on the micro-implant at a distance of 0.5 mm from the top of the micro-implant.

Data acquisition: According to the long axis of the micro-implant, the finite element model was longitudinal profiled by centering the micro-implant. On the pressure side of the bone interface, the values of displacement (mean displacement and peak displacement) and Von-Mises stresses were collected at intervals of 0.3 mm from the micro-implant neck in the direction of the long axis of the micro-implant.

Results

Von-mises stress analysis at five different tilt angles

Under a horizontal force of 200 g, the strain on the micro-implants at five different tilt angles were 1.3184 Mpa, 1.1834 Mpa, 0.9384 Mpa, 0.7341 Mpa and 0.5184 Mpa, respectively, showing a decreasing trend. See **Table 1** and **Figure 1**.

Mean displacement analysis at five different tilt angles

Under a horizontal force of 200 g, the mean displacements of five different tilt angles were 6.1934 μm, 5.0413 μm, 3.9475 μm, 3.2851 μm and 2.4852 μm, respectively, showing a decreasing trend. See **Table 2** and **Figure 2**.

Peak displacement analysis at 5 different tilt angles

Under a horizontal force of 200 g, all peak displacements at five different tilt angles were small, and even the largest one was no more than 6.9453 μm. See **Table 3**.

Discussion

The effect of micro-implant was related to many factors, including micro-implant length, tilt angle, implanted anatomical position, etc. [14]. A micro-implant with good stability can provide a strong anchorage [15]. Also, it is important to select an appropriate material for the micro-implant. The effect of orthodontic treatment and the selection of the micro-implant as an anchorage can be guaranteed if the micro-implant can keep stability [16]. It has been controversial that some scholars believed that micro-implants had certain defects in stability [17]. Thus, studying the implantation of micro-implants will contribute to the research of micro-implant stability.

The finite element analysis software used in this study was able to split the elastomer into finite elements, and to analyze each unit, thereby further understand the overall effect. This analysis can get a better way of implantation to achieve a better stability [18]. In this study, we studied on the tilt angles (ranged from 30° to 90°). The results characterized that under a horizontal force, the received forces of the micro-implants were different at different tilt angles. Besides, the greater the tilt angle was, the smaller the received force and displacement were. And the maximum displacement did not exceed 6.9453 μm. It indicated that the micro-implants were able to withstand the horizontal force of 200 g at any ranged angles, and they could ensure good stability under the force [19, 20]. Cha et al. proposed a similar study, however, the peak displacements of their study were similar to those of our study under a horizontal force of 300 g. But the displacements under a horizontal force of 200 g in this study were relatively large which might result from the lower elastic modulus of cancellous bone [16]. The results of Mccabe et al. were consistent with those of our study, while their study was even richer [19].

By comparison, with single study content and no analysis of the effect on the displacement owing to different force or implantation length, this study exists some limitations, and it should be further explored with multiple factors in the future.

In conclusion, the micro-implants can maintain certain stability under a horizontal force of 200 g.

Disclosure of conflict of interest

None.

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