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Original

A Three-dimensional Finite Element Analysis for the Biomechanical Characteristics of Orthodontic Anchorage Micro-implant

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Abstract: Objective: To establish a three-dimension finite element model for orthodontic anchorage micro-implant and analyze the influence of different titled angle on the biomechanical characteristics of orthodontic anchorage implant-bone interface. Methods: Use ANSYS (Analysis System) finite element analysis software to perform the finite element modeling of the micro-implant with 7 different tilted angle, including 30°, 40°, 50°, 60°, 70°, 80°and 90°. A simulated orthodontic force, which was 200 grams, was loaded mesiodistally to the mathematical models, the stress and displacement distribution on the implant-bone interface was analyzed. Results: As the titled angle increased , the Von-Mises stress at the cervix of the implants were 1.0792Mpa, 1.0104Mpa, 0.8848Mpa, 0.8181Mpa, 0.7583Mpa, 0.6339Mpa and 0.5608Mpa while the displacement were 5.5513µm, 4.9900µm, 3.7419µm, 3.1264µm, 2.5874µm, 1.3624µm and 0.8027µm. Conclusion: The micro-implant can be safely loaded with 200 grams mesiodistal orthodontic force. The increase of the titled angle can efficaciously enhance the implant's ability of bearing mesiodistal orthodontic force. Thus we should choose the vertical angle when the micro-implant is embedded.

Kye words: Micro-implant, Finite element method, Stress analysis, Biomechanics

Introduction

Anchorage is one of the most important factors in a successful orthodontic treatment. Compared with other methods used as anchorage, micro-implants have the advantages of easy insertion and removal minimal anatomic limitation instant loading good patients compliance and low expenses. To understand micro-implant better, it is imperative to do biomechanics analysis, and Three-Dimensional Finite Element Method (3D FEM) is by far the most reliable method. In this study, 3D FEM was used to analyze the influence of different titled angles on the biomechanical characteristics of implant-bone interface[1-3].

Materials and Methods

There are four primary considerations in the development of the three-dimensional finite element model: micro-implant design, geometry of the micro-implant and bone structures, establishment of three-dimensional finite element model of the micro-implant and material properties.

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Micro-implant design

The geometry morphology of our micro-implant used in this study had been experimentally determined. We designed the micro-implant as a knife-shaped sharp threaded columnar pure titanium screw (external diameter=2mm, interior diameter=1.6mm, length=9mm, threaded deepness flight depth=0.2mm, threaded angle =60°, threaded distance thread interval=0.3mm). There would be 3mm left when the micro-implant was embedded in the bone. The cortical bone around the micro-implant was postulated as 1mm in thickness and considered as continuous sequential, well-distributed, homogeneous isotropic and linear and elastic body.

Model Geometry

ANSYS (Analysis System) 6.1 finite element software was used to establish the finite element model of the micro-implant. The geometry of our three-dimensional finite element model of a micro-implant, was developed manually according to what had designed before. Establishment of three-dimensional finite element model of the micro-implant.

The 9387 nodes and 5038 elements got from this model were manually input into the finite element software that was used for this study. After the model was completed, boundary conditions were defined at all peripheral nodes of the bone with 0 of movement in all directions. Each element was then assigned a specific material property.

Material properties

The material referred in this study was postulated as sequential, isotropic and linear elastic. The Young's modulus and the Poisson's ratio of the material derived from related research.

Biomechanics analysis

ANSYS finite element analysis software was used to perform the finite element modeling of the micro-implant with 7 different angle, including 30°, 40°, 50°, 60°, 70°, 80°and 90°respectively. A simulated orthodontic force 200 grams was loaded horizontal to the mathematic model, the stress and displacement distribution on the implant-bone interface were analyzed.

Results

The distributions of stress and displacement were obtained from the micro-implant 3D FEM model. The stress distributions on the implant-bone interface with different tilted angles were displayed in figure 1-7, while the corresponding displacement distributions were displayed in figure8-14.

The Von-Mises stress on the implant-bone interface mainly focused on the cervix and decreased rapidly in the cortical bone, while that in the spongy bone was very small. The Von-Mises stress on the cervix of the implant were 1.0792Mpa, 1.0104MPa, 0.8848MPa, 0.8181MPa, 0.7583Mpa, 0.6339Mpa and 0.5608MPa respectively according to different tilted angles. The maximum Von-Mises stress decreased significantly with the increasing of titled angle.

The displacements of the implant-bone interface were very small under whatever conditions when the micro-implant was loaded with 200 gram horizontal orthodontic force. The maximum displacement was only 6.5253µm at the loading point. The displacements of micro-implant were also regularly distributed with relative larger displacement on cervix and apex. The displacement on the implant cervix is larger than that on the apix and in opposite directions. The maximum displacements on the implant-bone interface were 5.5513µm, 4.9900µm, 3,7419µm, 3.1264µm, 2.5874µm, 1.3624µm and 0.8027µm respectively with the increasing of tilted angle. The maximum displacement on the

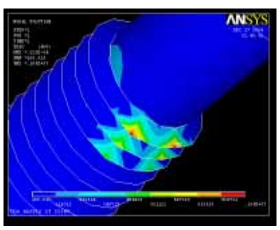

Fig.1. The stress distribution on the implant-bone interface when the titled angle is 30°.

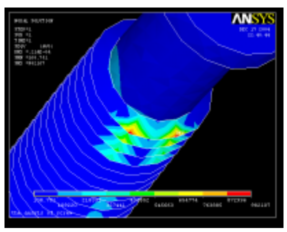

Fig. 2. The stress distribution on the implant-bone interface when the titled angle is 40°.

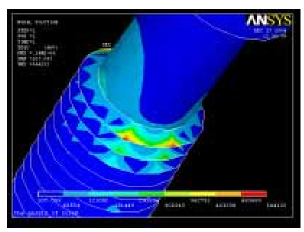

Fig. 7. The stress distribution on the implant-bone interface when the titled angle is 90°

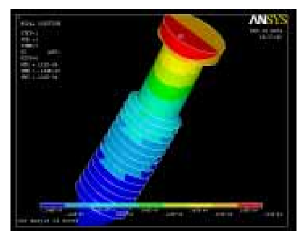

Fig.8.The displacement distribution on the implant-bone interface when the titled angle is 30°

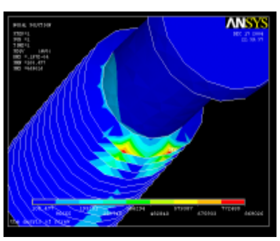

Fig. 3. The stress distribution on the implant-bone interface when the titled angle is 50°.

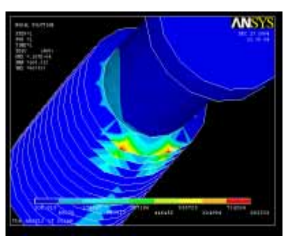

Fig. 4. The stress distribution on the implant-bone interface when the titled angle is 60°.

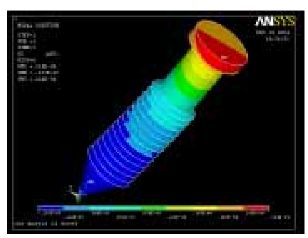

Fig.9.The displacement distribution on the implant-bone interface when the titled angle is 40°

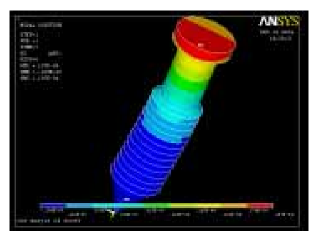

Fig.10. The displacement distribution on the implant-bone interface when the titled angle is 50°

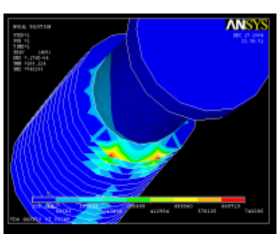

Fig.5. The stress distribution on the implant-bone interface when the titled angle is 70°.

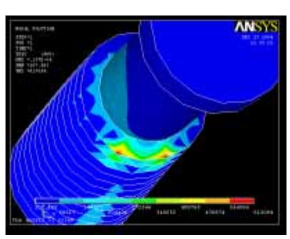

Fig. 6. The stress distribution on the implant-bone interface when the titled angle is 80°

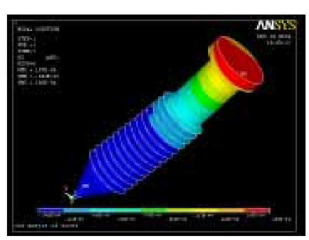

Fig.11. The displacement distribution on the implant-bone interface when the titled angle is 60°

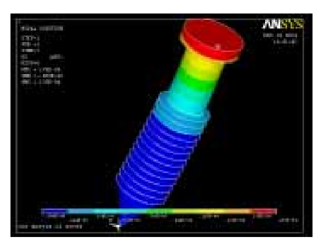

Fig. 12. The displacement distribution on the implant-bone interface when the titled angle is 70°

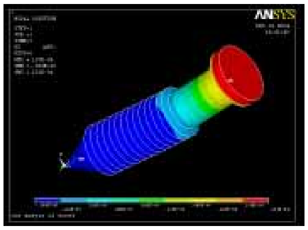

Fig.13. The displacement distribution on the implant-bone interface when the titled angle is 80°

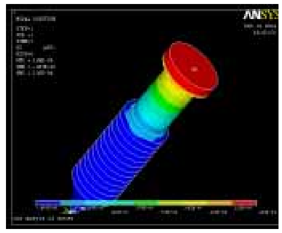

Fig.14.The displacemen distribution on the implant-bon interface when the titled angle is 9

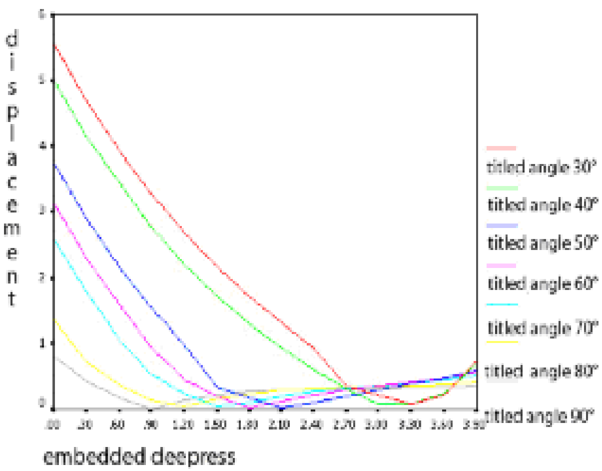

Fig. 16. Line graph between embedded deepness and displacement .

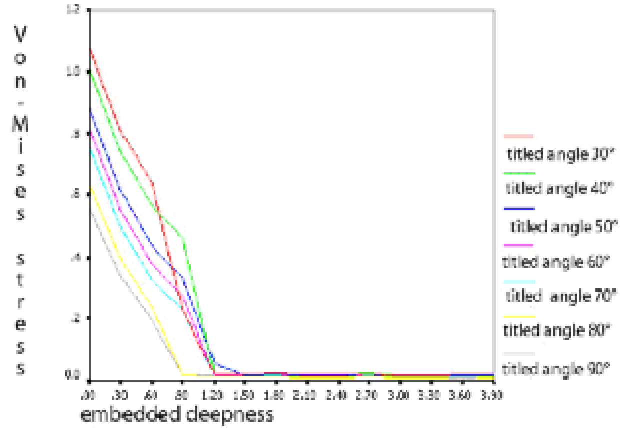

Fig.15. Line graph between embedded deepness and Von-Mises stress

implant-bone interface decreased significantly with the increasing of titled angle.

The graph reflecting the relationship between inserting depths and the Von-Mises stresses on the implant-bone interface when loaded with 200 gram horizontal orthodontic force and embedded with different angles were displayed in figure 15, that reflecting the relationship between inserting depths and the displacement was displayed in figure 16.

Discussion

Micro-implant selection

Micro-implants have been widely used all over the world. The stability of micro-implant loaded with orthodontic forces was the key to the success of orthodontic therapy. Many possible factors could affect the stability of micro-implant. For instance, the shape of the micro-implant, the titled angle, the loading of the orthodontic force and the hard tissue around the micro-implant are the most important[3-5].

Tilted angle selection

Seven different angles from 30°to 90°were used in our study, two angles which were 10°and 20°were excluded. There would be many possible factors which could affect the titled angle, such as the possibility in clinical operation, the length of the micro-implant, the comfort of the patients, the condition of the bone, etc. Once the micro-implant was embedded with a tilted angle lower than 30° the length of the micro-implant would be doubled correspondingly to penetrate the cortical bone. And it is inconsistent with its definition. In addition, along with the tilted angle decreased, the insertion operation will be more difficult, and it is almost impossible that inserting a micro-implant with the titled angle lower than 30°in clinical opperation.

The biomechanical effect of tilted angle on micro-implant anchorage

Based on stress screen theory within the implant-cortical bone-spongy bone system the cortical bone would received larger stress while forces were conducted from micro-implant to the implant-bone interface owing to the higher elastic modulus of cortical bone compared with that of spongy bone. Therefore while the tilted angle decreased the contact area of micro-implant and cortical bone increased to enhance the stability of micro-implants accordingly. The result agreed with those of Liu et al. However, horizontal moment of force on micro-implant would increase with the decrease of tilted angle to increase the stress on implant-bone interface. The combination effect of the two modes mentioned above play an important role in influencing the stability of micro-implant.

It was shown that the stress distribution pattern on the implant-bone interface almost coincided with each other but existed slight differences among various tilted angles. The stress concentrated significantly on the cervixes of micro-implant and decreased remarkably at cortical bone and adjacent spongy bone which coincided with supra stress screen theory. However, the decreasing tendency of Von-Mises peak value with increasing of tilted angle showed that the change of orthodontics force moment, which comes from the change of micro-implant tilted angle played an important role in the stress distribution on implant-bone interface. It was implicated that micro-implant should be inserted into alveolar bone vertical to the buccal side of the cortical bone.

The displacement of micro-implant was far less than that of teeth. If the micro-implant displacement exceed the specified physiologic limit it is likely to cause micro fracture of the bone trabecula and result in absorption and necrosis of the osseous tissue in implant-bone interface ultimately lead to the failure of the micro-implant.

In this study, the displacement of the implant on the implant-bone interface, under the loading of 200g horizontal force, remained small with maximum displacement of 6.5253 μm with any tilted angle. It was implicated that under the loading of 200g horizontal force, the implant scarcely move and remain stability. Meanwhile, the distributions of the implant displacement showed an obviously pattern: the larger displacements appeared in the neck and apical zone in opposite directions, and the displacement on the neck is larger than that of the apical zone. Along with the increasing of tilted angle, the peak value of the displacement on the neck and apical zone diminished, and the rotation center moves towards the neck part, in accordance with the changes of stress on the implant-bone interface.

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