Three-dimension Finite Element Analysis on Micro-Implant Anchorage Malor Distalization Mandibular Teeth

XINHUI LI, RONGFENG XIONG, XUE LEI, NUO XU and ZHENLIN GE

ABSTRACT

Objective: To obtain orthodontic force which is the most suitable for mandibular 3-7 group-teeth malor distalization by finite element method analysis; observe and compare the distalization condition of mandibular second molar during pushing single-tooth malor distalization and group-teeth malor distalization for guiding clinics; Method: spiral CT was adopted for maxillofacial region CT scanning on one individual normal jaw patient, mimics, Geomagic Studio and Abaqus software were combined to establish two groups of finite element models, namely model I of micro-implant anchorage between mandibular first and second molars, and model II of micro-implant anchorage in mandibular external oblique line, and all models underwent stress application and calculation. Results: 1. When 150g horizontal force was used to push mandibular second molar for malor distalization, the movement mode of the tooth is inclination movement accompanied with lingual reverse, and the tooth also suffered from tongue inclination and elongation during malor distalization; 2. When implants were embedded into external oblique line zone for group-teeth malor distalization, and the movement mode of mandibular second molar was similar to integral movement; 3. Too large force value was not beneficial for tooth movement, and the most suitable orthodontic force for 3-7 group-teeth malor distalization is 250g. Conclusion: group-teeth malor distalization is more beneficial for tooth integral movement, 250g is the the most suitable orthodontic force for group-teeth malor distalization.

KEYWORDS
Malor Distalization, Three-dimension Finite Element Analysis, External Oblique Line.

INTRODUCTION

In orthodontic clinic, molar should undergo malor distalization frequently in order to correct molar relationship and relieve congestion [1] Orthodontic doctors commonly adopt the following methods for malor distalization of mandibular molars: Dependent orthodontic appliance: removable orthodontic appliance setting organum spirale, lip bumper and slide bar are matched with class III traction, J hook is matched with low level extraoral traction, facebow is utilized for low level extraoral traction; non-dependent orthodontic appliance: double-rail molar malor distalization device,
Micro-implant anchorage, addition of tip-back bend on mandibular arch wire, utilization of group-teeth anchorage, hyoid arch combination with spiral spring for pushing mandibular molar malor distalization [2]. However, the above molar distalization mode has defects of poor comfort, high requirements on patient cooperation, tedious clinical operation, etc. Implant anchorage solves a series of problems. Miniature implant does not depend on synostosis for fixation, and the mechanical interlocking strength between implant and bone tissue plays certain role. It has many advantages of reliable curative effect, small trauma, stable anchorage, low dependence on patients, etc. The technique is recognized by more and more doctors and patients [9]. In orthodontic treatment, implant anchorage can be utilized for molar distalization to adjust molar relationship, solve anterior region crowding and similar problems. Since implant anchorage molar distalization of molar has no influence on opposite tooth, implant anchorage is more and more popular among orthodontic doctors due to progress of minimally invasive surgery department in recent years. In the clinic, micro-implant anchorage among tooth roots can be utilized for molar distalization of molar with slide bar or micro-implant can be used for enhancing anterior teeth anchorage, and spring, etc. can be used for molar distalization of molar; micro-implant also can be embedded into mandibular external oblique line zone, tension spring, etc. are used for pulling mandibular group-teeth molar distalization. In the experiment, horizontal force application is simulated to push single-tooth molar distalization and 3-7 group-teeth molar distalization through finite element method, the effects thereof are analyzed and compared for guiding clinic.

THREE-DIMENSION FINITE ELEMENT MODEL ESTABLISHMENT OF MICRO-IMPLANT ANCHORAGE MALOR DISTALIZATION OF MANDIBULAR TEETH

CT scanning:

One 27-year-old female patient of individual normal jaw was selected, cone beam X-ray computer fault scanning system, namely cone beam CT, was used for oral cavity fault CT scanning on dentognathic system. Mandibular postural position was adopted to avoid contact of upper and lower teeth and unclear data after scanning. The scanning scope lasted from upper edge of condyle process to lower edge of mandibular bone for continuous scanning. The scanning parameters include the follows: spacing is 0.25 mm, exposure time is 14.7s, a total of 550 faultage images were obtained. Data obtained from scanning is exported in DICOM (medicine digital imaging and communication) format.

Establishment of mandibular bone, mandibular teeth and parodontium model

The previously scanned data is imported into Mimics17.0 software, images of 14 mandibular teeth and mandibular bones are manually extracted through threshold processing. The tooth root surface is expanded outwards for 2.0mm to obtain parodontium, the teeth and mandibular bones are stored after surface smoothing and other treatment.
Establishment of bracket, arch wire and micro-implant model

Croe3.0 software was used for establishing bracket and buccal tube models according to clinical commonly-used MBT bracket and buccal tube dimension (groove is 0.022 inch); micro-implant model with length of 8mm and diameter of 2.0mm as well as 0.019 inch×0.025-inch stainless steel rectangular wire models were established according to the dimension of clinical commonly-used pure titanium mandibular micro-implant. Finally, the established mandibular teeth, mandibular bone, parodontium, bracket, arch wire and micro-implant are assembled.

Setting of material properties, definition of boundary constraints and load mode as well as generation of CAE model

The material in the model for the experiment included teeth, parodontium, mandibular bone, bracket, arch wire and micro-implant anchorage. Since the tooth initial displacement and parodontium stress were analyzed in the experiment, the influence of the tooth structure enamel, dentin, dental pulp cavity and cementum as well as alveolar bone structure cancellous bone and compact bone substance on experiment results was ignored. Therefore, the teeth and alveolar bone were set as homogeneous structure in the experiment. Therefore, material tooth, parodontium, mandibular bone, bracket, arch wire and micro-implant anchorage were hypothesized as isotropic and continuously homogeneous line elastomers in the experiment [10]. Material deformation is tiny. The mechanical property parameters of different materials (namely elasticity modulus and Poisson's ratio) are shown in the following table.

![Figure 1. Model I: implant embedding direction and facies ossea form an angle of 30° (The depth of implant in the bone is 6mm).](image1)

![Figure 2. Model II: implant embedding direction and facies ossea form an angle of 80° (The depth of implant in the bone is 6mm).](image2)
TABLE 1. The mechanical property parameters of different materials.

<table>
<thead>
<tr>
<th>Item</th>
<th>Elasticity modulus MPa</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth</td>
<td>20000</td>
<td>0.33</td>
</tr>
<tr>
<td>Parodontium</td>
<td>0.667</td>
<td>0.45</td>
</tr>
<tr>
<td>Alveolar bone</td>
<td>2000</td>
<td>0.30</td>
</tr>
<tr>
<td>Titanium</td>
<td>106.4</td>
<td>0.34</td>
</tr>
<tr>
<td>Bracket and buccal tube</td>
<td>206000</td>
<td>0.30</td>
</tr>
<tr>
<td>Arch wire</td>
<td>176000</td>
<td>0.30</td>
</tr>
</tbody>
</table>

All parts in the experiment underwent grid partition, tetrahedron four-node units are adopted in all parts of the model, and two models were divided into 216672 nodes and 776029 units totally.

The model mandibular bone bottom and processus condyloideus part were fixed. Therefore, the model displacement and rotation are limited in all directions. In model I, slide bar was simulated to apply 150g force and push mandibular second molar distalization. In model II, 150g, 200g, 250g, 300g, 350g and 400g force was respectively applied to pull mandibular 3-7 group-teeth for malor distalization.

A precise coordinate system should be established in order to facilitate data recording and analyzing. In the experiment, the dentition movement trend at horizontal direction was set as X axis (positive in bistant direction and negative in mesial direction); dentition movement trend to sagittal direction was set as Y axis (positive in the lingual side and negative in the lingual side); dentition vertical direction movement trend was set as Z axis (positive upward; negative downward).

In the experiment, mesio-incisal angle, disto-incisal angle and root tip of incisor tooth, mesio-incisal angle, disto-incisal angle and root tip of lateral incisor tooth, mesio-incisal angle, disto-incisal angle and root tip of canine teeth, hypoconid, tongue apex and root tip of the first anterior molar, hypoconid, tongue apex and root tip of the second anterior molar, mesiobuccal apex, hypoconid, hypoconid, distolingual apex, mesiolingual apex, mesial root tip and distal root tip of the first molar, mesiobuccal apex, mesiolingual apex, hypoconid, distolingual apex and root tip of the second molar were regarded as reference points for analysis. (Shown in the following figure).

Figure 3. CAE model.

Figure 4. Observation points of all teeth.
RESULT

Mandibular second molar displacement tendency during model I stress

In model I displacement tendency was shown as follows when 150g force was applied on mandibular second molar at the horizontal direction.

The above table shows initial displacement at the horizontal upward direction during application of 150g horizontal thrust on mandibular second molar: hypoconid>mesiobuccal apex>distolingual apex>mesiolingual apex>root tip, initial displacement value of dental crown and tooth root is positive; initial displacement at sagittal upward direction: hypoconid>mesiobuccal apex>distolingual apex>mesiolingual apex, root tip initial displacement has opposite direction to dental crown; initial displacement at vertical direction: mesiolingual apex>mesiobuccal apex>distolingual apex>hypoconid.

Mandibular second molar displacement tendency during force application on model II

In model II, when 150g, 200g, 250g, 300g, 350g and 400g force was respectively applied, displacement tendency of mandibular second molar at horizontal direction is shown as follows:

Figure 5. Initial displacement value of middle mandibular second molar in model I.

Figure 6. Initial displacement value of middle mandibular second molar on axis X in model II.
The above table shows that when the force value was increased from 150g to 250g, the initial displacement value of mandibular second molar was increased gradually. When the force value was higher than 250g, the displacement value was gradually reduced. When the force value was 400g, the initial displacement value of mandibular second molar was low. In addition, the initial displacement directions of dental crown and tooth root were opposite at the X axis.

**Maximum Von-mise stress of parodontium of all teeth during model II stress**

The parodontium stress distribution of all teeth under different force values is shown as Figure 7.

The above data show that the maximum stress of parodontium was mainly concentrated in canine teeth. The maximum stress value of parodontium in all teeth was increased with force value increase. Lee proposed that the maximum stress undertaken by the parodontium was 26Kpa [11]. When the force value was smaller than 300g, the maximum stress value of the parodontium in all teeth was smaller than the maximum stress level undertaken by the parodontium. When the force value was higher than 300g, the maximum stress value of the canine teeth parodontium was larger than 26Kpa.

**DISCUSSION**

Finite element method was firstly applied to aviation industry in 1956. In 1973, Theresher [12] and Farah used the finite element method in the oral cavity field for the first time. Japanese scholar Takahashi [13] analyzed and studied dental inclination, torsion and parodontium under different loading conditions in 1980. It is the first application of finite element method in the field of orthodontics. Finite element software can be used for accurately simulating various material properties [14] and analyzing the stress strain applied on the organism. It has been proved that the finite element method can solve a series of problems from foundation to clinic [15].

In the experiment, when 150g horizontal force was applied for pushing malor distalization of mandibular second molar, horizontal initial displacement is shown as follows: hypoconid > mesiobuccal apex > distolingual apex > mesiolingual apex > root tip. It shows that the tooth malor distalization process is inclination movement.
accompanied with lingual reverse. It indicates that large dimension stainless steel mode can be applied as far as possible in clinic for molar malor distalization. Initial displacement at sagittal upward direction: root tip initial displacement is opposite to dental crown direction. It is obvious that the molar malor distalization is accompanied with tooth tongue inclination, the posterior area coverage is also increased accordingly. In clinic, orthodontic doctors resist the side effect through expanding the arch wire. Initial displacement at vertical direction: mesiolingual apex > mesiobuccal apex > distolingual apex > hypoconid. The tooth malor distalization is accompanied with tooth elongation. In addition, dental crown mesial elongation is prominently higher than that in the distal part. Therefore, vertical growth patient is not suitable for applying the mode in molar malor distalization.

In the experiment model II, the implant is embedded into the mandibular external oblique line zone, force is directly added to the mandibular canine teeth from the implant for experimenting malor distalization of 3-7 group-teeth at the same time. Patients with crowded situation in the mandibular anterior region can be arranged into a line after gap is obtained, thereby avoiding tooth to-and-fro movement. Sugawara, etc. [21] proposed that the ratio of tooth root and dental crown at horizontal direction, vertical director or close bistal direction during tooth movement is regarded as inclination ratio. If the inclination ratio is smaller than 25%, the movement mode of the tooth belongs to inclination movement. In the experiment, when 150g horizontal thrust is applied to the second molar (model I), the inclination ratio at the horizontal direction is 16%, and the movement mode of the tooth is inclination movement. When force is applied in the mode of group-teeth malor distalization, the inclination ratio of the mandibular second molar under the force of 150g, 200g, 250g, 300g and 350g is 40.7%, 44.8%, 52%, 37.3% and 35.3% at the horizontal direction. Since the dental crown and tooth root initial displacement directions are opposite during application of force 400g, and the displacement value is small, the value is not counted. The above data show that the movement mode of the second molar during application of model II force application mode is close to overall malor distalization.

In previous studies, the most suitable orthodontic force for pushing single-tooth malor distalization was 150g [19, 20], therefore 150g was used for pushing mandibular second molar malor distalization in the experiment II. However, the studies on mandibular 3-7 group-teeth malor distalization were rare. There was no clear data about the most suitable related orthodontic force. In the experiment, maximum stress of parodontium was mainly concentrated in canine teeth, especially canine teeth mesial tooth neck because the force is directly applied on the canine teeth. When the force value was smaller than 250g, the maximum stress value of the parodontium in all teeth was smaller than the maximum stress undertaken by the parodontium (26Kpa [11]). When the force value was larger than 300g, the maximum stress value of canine teeth parodontium was higher than 26Kpa. Therefore, when implant anchorage was utilized for mandibular 3-7 group-teeth malor distalization, orthodontic force should be below 300g. When the force value was 250g, the second molar initial displacement value was the maximum, and the maximum dental inclination ratio was 52%. Therefore, 250g was orthodontic force, which was the most suitable for 3-7 group-teeth malor distalization.
REFERENCES

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