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Original Article

Three-dimensional finite element analysis on En mass intrusion and retraction of maxillary anterior teeth with J-hook headgear

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Abstract: Objective: To study the biomechanical mechanisms of En mass intrusion and retraction of maxillary anterior teeth with J-hook headgear by three-dimensional finite element analysis. Methods: We established the three-dimensional finite element model by ANSYS 17.1 software and divided the model into two groups (A and B) according to the different location on which the force was applied: Group A, the force was applied mesial to lateral incisor; Group B, the force was applied distal to lateral incisor. The two groups were simulated En mass intrusion and retraction of maxillary anterior teeth with J-hook headgear. The force direction was maintained at 30° to the sagittal plane and 20° to 60° to the occlusal plane, which was changed every 5°. The applied force was maintained at 1.5 N. Then the displacement of maxillary anterior teeth and periodontium stress distribution were analyzed. Results: The displacement of maxillary anterior teeth was the clockwise and lingual movement with intrusion. With the increase of the traction angle, the displacement became overall retraction and intrusion, and finally the displacement became the counter-clockwise rotation with the labial movement with intrusion. And as the force was applied at 35° (A) and 45° (B), the maxillary anterior teeth showed a relatively uniform overall intrusion and retraction without rotation. Conclusions: For maxillary anterior teeth with normal lip inclination, placement of J-hook headgear mesial to lateral incisor is more conducive to the overall intrusion and retraction of maxillary anterior teeth. In addition, the traction angle should be adjusted according to individual conditions and treatment goals.

Keywords: Finite element analysis, orthodontic support, oral tractor, orthodontic gap closure

Introduction

In the orthodontic treatment, the adduction of maxillary anterior teeth is a critical stage, which requires adjustment of the position and axis inclination of the maxillary anterior teeth to obtain the best correction effect and the patient profile [1]. And the main difficulty was the control of the anterior teeth root movement, anchorage of posterior teeth and vertical position of incisor [2]. Currently, there are several therapeutic methods for adduction of maxillary anterior teeth, however, they all inevitably induce different degree of clockwise rotation of maxillary anterior teeth, thus causing lingual inclination and elongation of maxillary anterior teeth as the force always focuses on the occlusion of impedance center of teeth [3].

Previously, Park el at. had reported that using hooks with different length on anterior teeth to change the direction of traction and thus to make it near to impedance center as close as possible, the labial inclination of maxillary anterior teeth could be controlled and its whole adduction could be realized [4, 5]. As a traditional method of En mass intrusion and retraction for maxillary anterior teeth, J-hook headgear can achieve simultaneous intrusion and retraction, protect the molar support, and is relatively simple to conduct. Therefore, it is widely applied in orthodontic practice [6-9]. However, most patients can obtain good outcomes by wearing J-hook headgear, but some others are not.

Therefore, in this study, we applied the three-dimensional finite element method to simulate

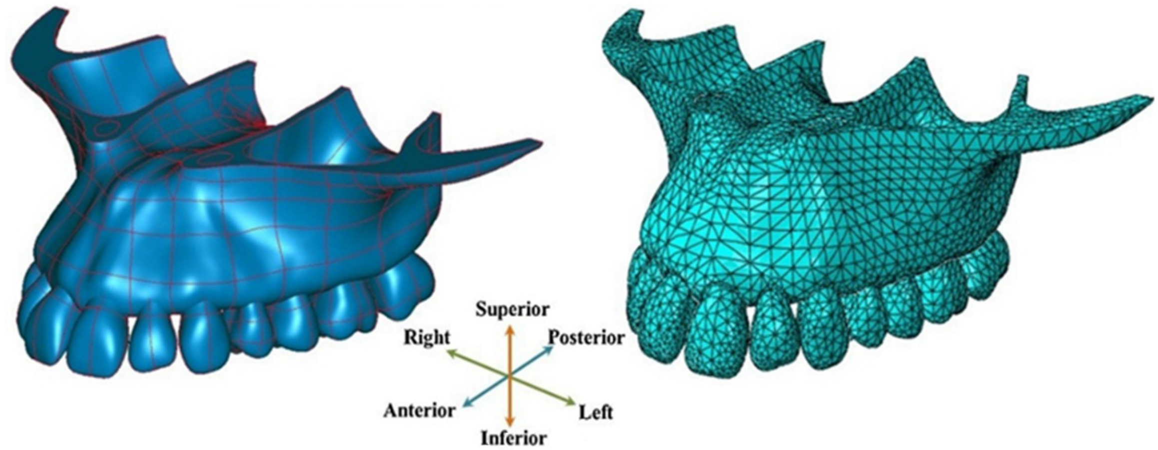

Figure 1. Lateral view of three-dimensional finite element model. Three-dimensional coordinate system: x-axis, coronal direction, from right to left; y-axis, sagittal direction, from the labial side to the lingual side; z-axis, vertical direction, from coronal direction to root. The groove width of the bracket slot is 0.56 mm*0.71 mm, the lip arch is 0.48 mm*0.64 mm, and the center of the wire is located at 4.5 mm of the gingival margin of the central incisor; stainless steel material or soft material were filled between the wire and the groove of the anterior segment or posterior segment; the mesh is automatically partitioned to generate a total of 545,454 nodes and 265,566 cells.

Table 1. Material properties of dental tissue and appliance components

Materials	Elastic Modulus (Mpa)	Poisson's ratio
Teeth	20,800.00	0.35
Alveolar bone	13,800.00	0.35
Periodontium	70.70	0.50
Stainless steel wire	177,000.00	0.35
Bracket	207,000.00	0.35
Soft filling material	30.00	0.30

the J-hook traction sites and traction directions to observe the immediate displacement trend of maxillary anterior teeth.

Materials and methods

Materials

Artificial tooth (Nissin B3-305 (32S)) was from Nissin, Japan; straight wire appliance was from Tomy, Japan; spiral CT was from Aquilion, Toshiba, Japan; Mimics 17.0 software was from Materialize, Belgium; Geomagics 12.0 software was from INUS, Korea; ANSYS 17.1 software was from ANSYS, USA.

Establishment of three-dimensional finite element model

The straight wire appliance suitable for Asian (OPA-K) was bonded to anatomic morphology artificial tooth and the wire was aligned, fixed with wax, and sculpted as maxillary anatomy according to OPA-K average standard; the angle between the maxillary incisor and the occlusal plane was 55°, which was close to the average value of population with normal occlusion [10]. Dicom data was obtained by CT scan with layer pitch 0.5 mm and imported into Mimics 17.0 software, which has high efficiency, significant accuracy, and excellent geometric similarity of three-dimensional model. The Geomagics 12.0 software was adopted for the optimizing of data regarding teeth and jaw contour points. Periodontium model with thickness of 0.25 mm was generated by Boolean logic operations, and the model of maxillary anterior teeth and its periodontium and alveolar bone was established by ANSYS 17.1 software.

The straight wire bracket and standard wire three-dimensional model was established by ANSYS 17.1 software according to the previously study [10]. The establishment of three-dimensional finite element model was shown in **Figure 1**.

In the present study, all kinds of materials and tissues in the model were considered as continuous, homogeneous, linear and isotropic elastic materials [11]. As shown in **Table 1**, the material properties of dental tissue and appliance components were listed according to the previously studies [12, 13].

Table 2. The displacement value of maxillary anterior teeth in Group A (× 10^{-5} mm)

Traction angle	A	B	C	D	E	F
20°	-1.62~-4.45	-1.60~-4.56	-7.45~-13.56	-7.56~-12.94	-4.56~-13.78	-4.55~-12.56
25°	-1.65~-4.30	-1.66~-4.29	-7.56~-13.50	-7.57~-13.50	-4.65~-12.50	-4.59~-11.90
30°	-1.68~-4.40	-1.68~-4.35	-7.78~-14.10	-7.77~-14.20	-4.75~-13.10	-4.71~-12.10
35°	-1.73~-4.45	-1.72~-4.43	-7.88~-14.50	-7.87~-14.50	-4.85~-13.70	-4.81~-13.50
40°	-1.77~-4.56	-1.78~-4.57	-8.10~-14.90	-8.17~-13.15	-5.15~-14.10	-5.15~-14.10
45°	-1.83~-4.61	-1.82~-4.66	-8.28~-15.10	-8.37~-13.50	-5.65~-14.70	-5.57~-14.90
50°	-2.13~-4.65	-2.12~-4.83	-8.48~-15.56	-8.37~-14.24	-5.75~-15.10	-5.81~-15.56
55°	-2.45~-4.81	-2.67~-5.15	-8.78~-16.10	-8.78~-15.90	-6.15~-15.78	-6.12~-13.14
60°	-2.63~-4.56	-3.10~-5.56	-9.10~-16.50	-9.17~-16.10	-6.45~-16.10	-6.56~-13.56

Note: A, left maxillary central incisor; B, right maxillary central incisor; C, left maxillary lateral incisor; D, right maxillary lateral incisor; E, left maxillary cuspid; F, right maxillary cuspid.

Load and constraint method

The models were divided into Group A (the force loaded in the midline between the central incisor and lateral incisor) and Group B (the force loaded in the midpoint between the lateral incisor and the cuspid) according to the load method. A force of 1.5 N was loaded on the anterior segment; direction of traction: the force direction was maintained at 30° to the sagittal plane and 20° to 60° to the occlusal plane, which was changed every 5°. Each group had nine conditions. The freedom degree of top and rear of maxilla are completely constrained.

Main indicators

1) The teeth displacement: the displacement vector was magnified 500 times and observed the displacement and rotation trend of maxillary anterior teeth from the right lateral view. 2) The stress change on periodontium: major principal stress on periodontium or alveolar bone were compared, and if the value was positive, it is compressive stress; conversely, it is tensile stress.

Results

Three-dimensional finite element analysis of displacement of maxillary anterior teeth

When the traction angle was 20°, Group A showed that the displacements of crown and root of maxillary anterior teeth were lingual movement with translation and intrusion, respectively; the Group B showed that the displacement of lateral incisor and cuspid was overall intrusion and distal translation, but the central incisor crown was lingual movement with translation; both groups showed the overall displacement in clockwise rotation.

When the traction angle was increased to 25°, Group A showed that the intrusion of crown and root of maxillary anterior teeth was increased; Group B showed that the elongation trend of central incisor disappeared; both groups showed the decreasing trend in clockwise rotation of maxillary anterior teeth.

When the traction angle was increased to 35°, Group A showed the trend of uniform displacement of maxillary anterior teeth towards posterosuperior, with small rotation tendency, which was observed in Group B when the traction angle was 45°. Therefore, the Group A was easier to obtain the overall intrusion and retraction of maxillary anterior teeth, compared with Group B.

When the traction angle was increased to 40° in Group A and 50° in Group B, maxillary anterior teeth began to demonstrate counter-clockwise rotation trend.

As the traction angle continued to be increased to 55°, both group showed that central incisor had the lip inclination trend, and the degree of rotate counter-clockwise of maxillary anterior tooth gradually increased. The displacement value of maxillary anterior teeth in Group A and B was listed in **Tables 2** and **3**.

The stress change on periodontium during maxillary anterior teeth displacement

When traction angle was 35° in Group A, the maximum principal stress on periodontium

Table 3. The displacement value of maxillary anterior teeth in Group B (× 10^{-5} mm)

Traction angle	A	B	C	D	E	F
20°	-1.15~-6.45	-1.10~-6.56	-3.95~1.85	-3.96~1.94	-1.15~4.15	-1.15~4.16
25°	-1.13~-6.30	-1.08~-6.49	-3.86~-1.75	-3.87~-1.78	-1.09~4.07	-1.08~4.09
30°	-1.11~-6.20	-1.06~-6.35	-3.78~-1.60	-3.77~-1.50	-1.05~4.05	-1.06~4.06
35°	-1.09~-6.05	-1.04~-6.12	-3.68~-1.50	-3.65~-1.40	-1.02~4.03	-1.05~4.04
40°	-1.07~-5.76	-1.02~-5.97	-3.55~-1.45	-3.57~-1.35	-0.09~3.99	-1.01~4.02
45°	-1.05~-5.65	-1.00~-5.66	-3.48~-1.40	-3.47~-1.27	-0.07~3.87	-0.08~3.99
50°	-1.03~-5.45	-0.75~-5.43	-3.42~-1.26	-3.35~-1.24	-0.05~3.75	-0.07~3.86
55°	-1.02~-5.21	-0.67~-5.25	-3.28~-1.17	-2.78~-1.19	-0.03~3.97	-0.05~3.88
60°	-1.01~-5.05	-0.66~-5.16	-3.10~-1.05	-2.67~-1.10	-0.02~3.77	-0.03~3.56

Note: A, left maxillary central incisor; B, right maxillary central incisor; C, left maxillary lateral incisor; D, right maxillary lateral incisor; E, left maxillary cuspid; F, right maxillary cuspid.

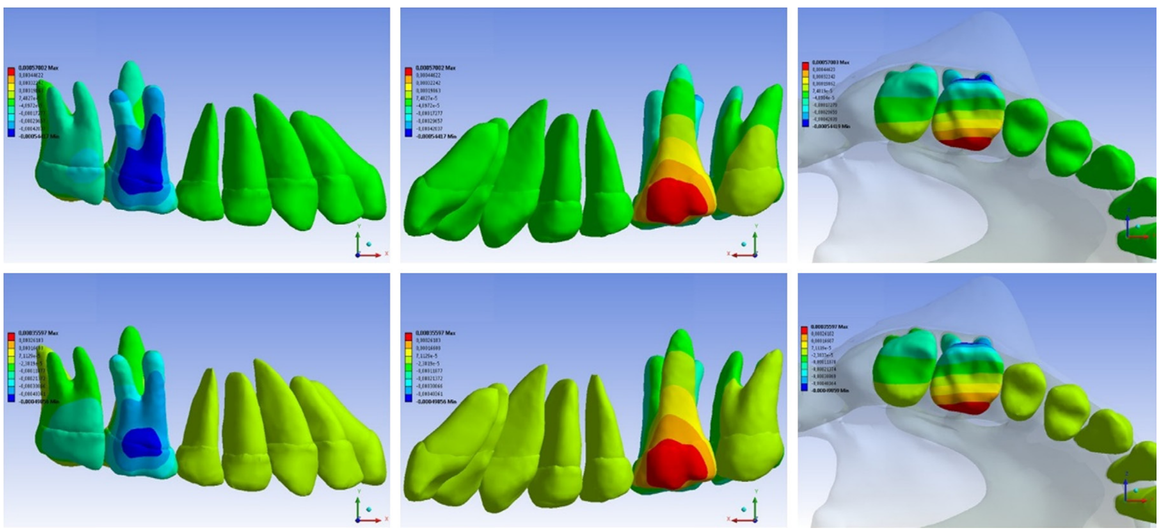

Figure 2. The stress distribution on periodontium. Top: applied mesial to lateral incisor at 35° (Group A); Bottom: applied distal to lateral incisor at 45° (Group B).

(7,737 Pa) was located at the mid-neck of the labial side of lateral incisors, while minimum principal stress on periodontium (-5,078 Pa) was located at the apex of the lingual side of central incisor.

When traction angle was 45° in Group B, the maximum principal stress on periodontium (7,175 Pa) was located at the mid-neck of the labial side of cuspid, while minimum principal stress on periodontium (-25,676 Pa) was located at the apex of the lingual side of lateral incisor.

The stress change on periodontium under the above two conditions was relatively small and the stress distribution was relatively uniform compared with other 18 conditions. See **Figure 2**.

Discussion

Since 1980, finite element method has begun to applied in odontoplasty as Shan et al. firstly used two-dimensional finite element model to study the inclination and twisting of teeth and the stress within pericementum [14]. Finite element method would not damage the integrity of subjects and can be recycle; moreover, it can analyze materials with different properties in the same model and precisely simulate the structure of subjects [15]. Currently, finite element method has been widely used in various area regarding odontoplasty, such as micro-implant anchorage, maxillary protraction, adduction front teeth, etc. [10, 16, 17]. Especially, the biological similarity of the model is remarkably increased and the meshing is more and more subtle, which provide sound theoretical foundation for biomechanics of orthodontics. The position of maxillary anterior teeth has a great effect on the beautiful degree of maxillofacial region [18]. Patients with gummy smile are commonly in orthodontics, whose upper incisors need to be lower, however, the occur of pendulum effect is easily observed when their front teeth were adducted, resulting in the elongation of front teeth and severe incompetent lips [1]. Therefore, there needs stress for indentation when adduction of front teeth. While, J-hock can provide force for adduction as well as indentation, which is a hot-spot in the orthodontics researches.

In theory, as the force passes through the impedance center of a rigid object, the object will have a global translation and its hindered position will produce a uniform stress. However, in our study, the instantaneous displacements of six maxillary anterior teeth after J-hook loading were not absolutely uniform, and the instantaneous displacement of the teeth on both sides of the traction site was relatively larger. The reason may be as follows. On the one hand, it is not accurate to estimate the displacement tendency of a group of teeth using periodontium stress distribution. As previously studies had indicated that only when the J-hook traction angles were 65°-75° or 45°-55°, the periodontium stress distributions of central incisor and lateral incisor were relative uniform, suitable for intrusion of corresponding teeth [19]. But, the above traction angle is difficult to achieve in the clinical practice. On the other hand, studies have proved that J-hook force will gradually dispersed to adjacent teeth after displacement of teeth on both sides of the traction site, resulting in the overall movement of maxillary anterior teeth [20]. Therefore, our study analyzed the experimental results based on the displacement tendency of the six maxillary anterior teeth rather than individual tooth.

Orthodontic force loading site directly affects the displacement of the teeth. The major factor affecting the displacement tendency is the relative relationship between the direction of traction and the center of impedance of a group of teeth. In this study, we found that in both group, when the J-hook traction angles were 35° and 45°, respectively, the traction force was close to the impedance center of six maxillary anterior teeth; therefore, compared with Group B, a relatively small traction angle can enable the traction force through the anterior segment impedance center in Group A, indicating that for maxillary anterior teeth with normal lip inclination, J-hook loading mesial to lateral incisors is easy to obtain the overall intrusion and retraction of maxillary anterior teeth, which was consist of previous report [21].

The main acting point of J-hock is forepart of dental arch, which can lower the height of overgrown teeth and phatnoma. Our results showed that in the two groups, when the J-hook traction angle was small, the traction force passed below the impedance center of the anterior segment, causing maxillary anterior teeth to rotate clockwise with elongation and lingual inclination, suggesting that J-hook does not definitely cause intrusion of maxillary anterior teeth. Therefore, the direction of traction should be adjusted according to individual conditions and treatment goals.

In conclusion, for maxillary anterior teeth with normal lip inclination, placement of J-hook headgear mesial to lateral incisor is more conducive to the overall intrusion and retraction of maxillary anterior teeth, when compared with loading the force on distal to lateral incisor. Meanwhile, the traction angle should be adjusted according to individual conditions and treatment goals.

Disclosure of conflict of interest

None.

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