

**Original Article**

## **Changes in Orthodontic Cephalometric Reference Points on Application of Orthopedic Force to Jaw: Three-Dimensional Finite Element Analysis**

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### **Abstract**

The present study investigated the effects of two orthodontic appliances on changes in the cephalometric reference planes using the three-dimensional finite element method. We simulated the use of a headgear and an orthopedic facial mask, two devices for the application of orthodontic force to the jaw. Using a finite element model of the skull, orthodontic force was applied to the maxillary first molar in a posterior or anterior direction. Changes in the maxilla, mandible and cephalometric reference planes were ascertained by the three-dimensional finite element method. The results showed that posterior force caused a slight posterior displacement and clockwise rotation of the reference planes, while anterior force caused anterior displacement and counterclockwise rotation. Since the maxilla was displaced and rotated in the same direction, the degrees of cephalometric displacement and rotation of the maxilla were smaller than the actual values.

**Key words:** Finite element method—Orthopedic force—Sphenoid bone

### **Introduction**

In clinical orthodontics, appliances are often used to apply orthopedic force to achieve skeletal improvements of the jawbone. Such appliances are used in patients during the growth period: a headgear is used for the treatment of maxillary protrusions<sup>2,15)</sup>, while a chin cap or an orthopedic facial mask is used for the treatment of mandibular protractions<sup>9,10,12)</sup>. With these appliances, orthopedic force acts on the jawbone or suture bones,

thus controlling the growth of the bone<sup>14)</sup>. The therapeutic effects of these appliances have been assessed by analyzing cephalograms<sup>11)</sup>. While orthodontic appliances have a therapeutic effect on the jawbone, they may also affect the cephalometric reference planes. To the best of our knowledge, there have been no studies investigating the effects of orthodontic appliances on the cephalometric reference planes.

Due to recent advances in computer science, the mathematical finite element method

has become widely used in the medical field, as well as in engineering<sup>16)</sup>, and this method is now being used to analyze complex structures<sup>4,6,7)</sup>. Here, by employing the finite element method, we ascertained the effect of orthodontic appliances for the application of orthopedic force to the jaw on changes in the cephalometric reference planes. By simulating the use of a headgear and an orthopedic facial mask, two such devices, we investigated the effects of anterior and posterior force applied to the maxillary first molar on the cephalometric reference planes.

## Materials and Methods

### 1. Materials and model preparation

The left half of a dry skull with normal occlusion and a dental age IVA was used for this study. The three-dimensional coordinate axes for the external maxillocraniofacial surface were determined to measure the various references points. X-ray CT was performed to obtain sagittal and frontal scans to analyze the internal structures of the skull. Based on these data, a maxillocraniofacial model was constructed.

### 2. Structural components and component properties

The maxillocraniofacial model was made from the following eight components: teeth, periodontal membrane, cortical bone, cancellous bone, sutures, synchondrosis, temporomandibular joint and masseter muscle. The model consisted of twelve bones, and the maxilla and mandible were made of cortical and cancellous bone with teeth and periodontal membrane. The head and maxillary regions were connected via sutures and synchondroses. The thickness of the sutures ranged from 0.2 to 0.5 mm, while that of the synchondroses ranged from 1 to 3 mm. These components were considered as three-dimensional solid elements. The temporomandibular joint and masseter muscle were considered as three-dimensional spring elements. The occlusal plane was a plate, and there were no

contact points between the upper and lower teeth. The teeth were positioned via the periodontal membrane, and were linked with a three-dimensional elastic beam element to simulate the use of edgewise appliances during orthodontic therapy. Figure 1 shows the entire model. The total number of nodal points and elements was 2,902 and 2,560, respectively. The material constant for each component was decided based on past studies<sup>3,8,13,16,18-20)</sup> (Table 1).

### 3. Forces and restraints (Fig. 2)

In the present study, we simulated the use of a headgear and an orthopedic facial mask.

To simulate the use of a headgear, 1 kg of force was applied in the posterior direction parallel to the occlusal plane from the mesial section of the maxillary first molar. The lower region of the occipital bone, where the neck pad rests during therapy, was completely restrained, and the mid-section was symmetrical.

To simulate the use of an orthopedic facial mask, 1 kg of force was applied in the anterior direction parallel to the occlusal plane from the distal section of the maxillary first molar. The forehead and chin, where the appliance rests during therapy, were completely restrained and the mid-section was symmetrical.

### 4. Cephalometric points and analysis

Finite element analysis was carried out using ANSYS 5.1 (Swanson, distributor: Cybernet System). In order to clinically analyze the displacement of the cephalometric reference points, a two-dimensional displacement of the cephalometric points and 13 maxillary and mandibular points was determined. Then, the degree of calculated displacement was multiplied 1,000 times and applied to the trace of the normal range to indicate the changes in the reference planes. The direction of movement of the reference points and the therapeutic effects of the orthopedic forces applied to the jaw were assessed.

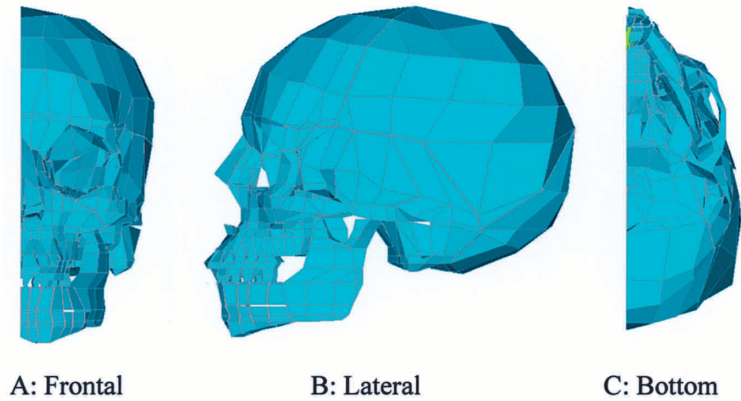


Fig. 1 Three-dimensional FEM model

Table 1 Structural components and component properties

	Young's modulus (MPa)	Poisson's ratio
Teeth	70,000	0.30
Periodontal membrane	7	0.49
Cancellous bone	7,800	0.35
Cortical bone	14,000	0.30
Sutures	7	0.49
Synchondrosis	1,400	0.40

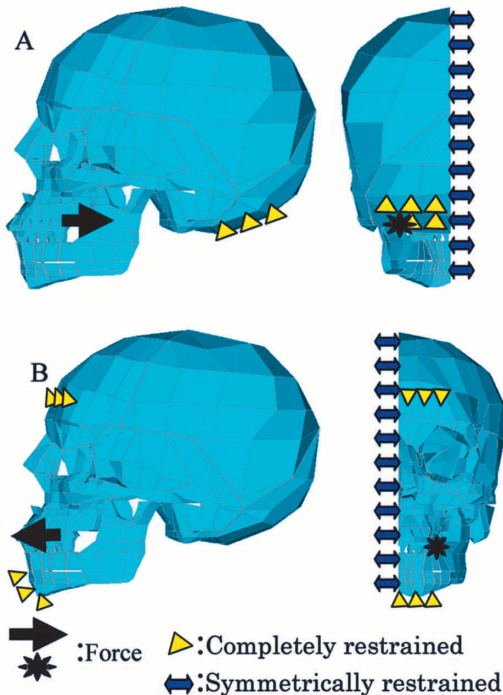


Fig. 2 Force and restraints

A: To simulate use of headgear  
 B: To simulate use of an orthopedic facial mask

## Results

### 1. Displacement of cephalometric points

#### 1) Posterior force (Table 2 and Fig. 3)

With the posterior force, the Frankfort, SN, Ba-Na(Ba-N) and palatal planes rotated clockwise, and the degree of rotation was particularly great for the Frankfort plane. Since the degree of posterior displacement for Gn was greater when compared to that of Se or Pt, both the Y and facial axes rotated in the opening direction. The degree of displacement was great for Se ( $1.47 \text{ mm} \times 10^{-3}$ ) and Or ( $1.48 \text{ mm} \times 10^{-3}$ ), and the direction of displacement was posterosuperior for Se and posteroinferior for Or.

#### 2) Anterior force (Table 2 and Fig. 4)

With the anterior force, the Frankfort, SN, Ba-N and palatal planes rotated counterclockwise, and the degree of rotation was particularly great for the palatal plane. Both Se and Pt were displaced in the anterior direction, and both the Y and facial axes rotated in the opening direction. As was the case with the

Table 2 Displacement of cephalometric points

		Posterior force			Anterior force		
		Sagittal	Vertical	Absolute value	Sagittal	Vertical	Absolute value
Cephalometric reference points	Se	1.34	0.60	1.47	-0.80	-0.32	0.86
	N	0.62	-0.46	0.77	0.01	0.14	0.14
	Po	0.74	0.33	0.81	-0.31	-0.10	0.33
	Or	1.18	-0.90	1.48	-0.58	0.65	0.87
	Ba	0.53	0.73	0.90	-0.35	-0.46	0.58
	Pt	0.90	0.23	0.93	-0.44	-0.32	0.54
Maxilla	Ans	2.42	-0.22	2.43	-1.75	1.87	2.56
	Pns	2.34	0.50	2.39	-1.70	-0.50	1.77
	Point A	2.52	-2.07	3.62	-2.04	2.32	3.09
Mandible	Pog	2.16	-0.70	2.27	0.00	0.00	0.00
	Go	2.29	0.52	2.35	-0.04	0.11	0.12
	Gn	2.33	-0.64	2.42	0.00	0.00	0.00
	Point B	1.98	-0.69	2.10	-0.11	-0.33	0.35

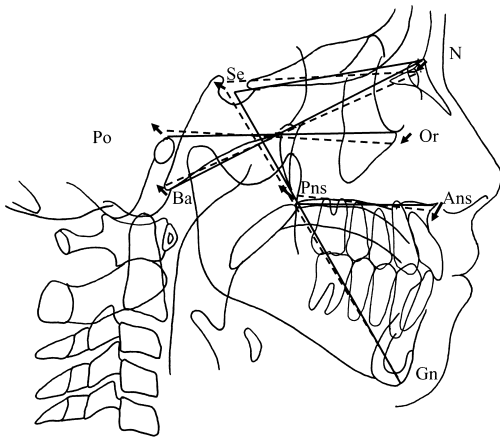


Fig. 3 Displacement of cephalometric points by posterior force

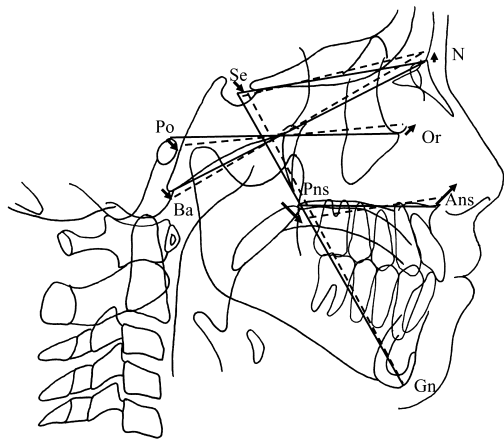


Fig. 4 Displacement of cephalometric points by anterior force

posterior force, the degree of displacement was high for Se and Or, but it was about half when compared to that with the posterior force.

## 2. Displacement of skull due to posterior and anterior forces (Table 2)

### 1) Posterior force

The posterior force displaced the maxilla in the posterior direction, and due to the posterior displacement and elongation of the first molar, the mandible rotated in the posteroinferior direction. The degree of dis-

placement was particularly great for the A point ( $3.62 \text{ mm} \times 10^{-3}$  in the posteroinferior direction).

### 2) Anterior force

The anterior force markedly displaced the maxilla in the anterosuperior direction, while the mandible was slightly displaced in the inferior direction. As was the case with the posterior force, the degree of displacement was particularly great for the A point ( $3.09 \text{ mm} \times 10^{-3}$  in the anterosuperior direction).

## Discussion

### 1. Study methods

Various biomechanical studies have been conducted to analyze the initial reactions of the skull to orthopedic force. Due to recent advances in computer science, the accuracy of model simulation has improved. Since it is now possible to analyze large models, complicated maxillocraniofacial models have been constructed. The model in the present study was accurate, and included almost all of the bones that make up the jaw, face and cranium, connected via sutures and synchondroses.

In the present study, we simulated the use of a headgear and an orthopedic facial mask, two devices that apply orthopedic force to the jaw during the growth period for treatment of maxillary protractions and underdeveloped mandibles, respectively. Although different amounts of force are used in different patients, 1 kg of posterior or anterior force was applied to the maxillary first molar, because the purpose of the present study was to compare changes.

As far as the restraints were concerned, with the posterior force, the posterior region of the occipital bone was completely restrained, because the neck pad of a cervical headgear is placed in this area. Also, since the model only consisted of the left side of the skull, the mid-section was symmetrical. With the anterior force, as the facial mask of a maxillary anterior traction appliance is fixed to the forehead and chin, these two areas were completely restrained, and the mid-section was symmetrical.

### 2. Simulation

In clinical orthodontics, diagnosis is based on lateral cephalograms. In cephalograms, different angles are measured in relation to various reference planes. In general, the Frankfort, SN and Ba-N planes are used, and these planes are considered mostly unchanged. In the present simulation study, we analyzed the effects of orthopedic forces on these reference planes.

The results showed that, with posterior

force, the Frankfort, SN and Ba-N planes rotated clockwise. In clinical settings, when posterior force is applied to the first molar, the maxilla rotates in the posteroinferior direction, as the center of resistance is in a superior direction<sup>1,2,6,7,15</sup>. The results of the present study are in agreement with those of previous reports. Since the reference planes rotated in the same direction as the maxilla, the cephalometric rotation of the maxilla was smaller than the actual rotation. In case of the mandible, Se was displaced in the posterosuperior direction. However, since Gn was displaced in the posteroinferior direction to a greater degree, the Y-axis rotated clockwise, thus agreeing with the findings obtained in clinical settings.

With an anterior force, the Frankfort, SN and Ba-N planes rotated counterclockwise. In general, a maxillary anterior traction appliance rotates the maxilla in the anterosuperior direction<sup>4,5,9,10,12,17</sup>, and the results of the present study are in agreement with those of previous reports. Therefore, as was the case with the posterior force, the cephalometric rotation of the maxilla was smaller than the actual rotation. In the case of the mandible, Se was displaced in the anterior direction, and because Gn was fixed, the Y-axis opened, thus agreeing with the findings obtained in clinical settings.

The present study investigated the initial reactions of the reference planes on lateral cephalograms to the application of orthopedic forces. The measurements were greatly magnified to ascertain the direction of the initial changes. The degree of displacement at the areas that made up the reference planes was slight, but the degree of displacement of the maxilla and mandible was about three times greater. Therefore, while the effects of orthopedic forces applied to the jaw on the reference planes are not marked, when assessing pure skeletal movements, it is necessary to keep in mind that cephalometric data are not absolute data.

## Conclusions

By simulating the use of a headgear and an orthopedic facial mask, we analyzed the effects of orthodontic force applied to the maxillary first molar in the anterior and posterior directions on the cephalometric reference planes by the three-dimensional finite element method. Based on the initial reactions, the results were as follows:

1. With a posterior force, the Frankfort, SN and Ba-N planes were displaced in the posterior direction and rotated clockwise. The degree of rotation was particularly great for the Frankfort plane. Also, the same findings applied to the palatal plane, and as a result, the degrees of cephalometric displacement and rotation of the maxilla were lower than the actual values.

2. With an anterior force, the Frankfort, SN and Ba-N planes were displaced in the anterior direction and rotated counterclockwise. Since the palatal plane rotated in the same fashion, the degrees of cephalometric displacement and rotation of the maxilla were lower than the actual values.

These findings suggest that orthopedic force slightly affects the cephalometric reference planes, and that when assessing pure skeletal movements, it is necessary to keep in mind that cephalometric data are not absolute data.

## References

- 1) Aono H, Hiranuma Y, Kohgo A, Yamamoto Y, Sumida H, Kawamoto T, Goto H (1986) Experimental study of the behavior of craniofacial bone sutures under external force. *Bull Josai Dent Univ* 15:313–329. (in Japanese)
- 2) Brandt HC, Shapiro PA, Kokich VG (1979) Experimental and postexperimental effects of posteriorly directed extraoral traction in adult *Macaca fascicularis*. *Am J Orthodont* 75:301–317.
- 3) Dymont ML, Syngé JL (1935) The elasticity of the periodontal membrane. *Oral Health* 25: 105–109.
- 4) Fukumoto K (1997) Biomechanical study of deformation on the craniofacial complex by maxillary protraction—Analysis by three dimensional finite element method—. *Shikwa Gakuho* 97:149–166. (in Japanese)
- 5) Irie M, Nakamura S (1975) Orthopedic approach to sever skeletal Class III malocclusion. *Am J Orthodont* 67:377–392.
- 6) Jinushi H (1992) A dynamic study of the effect on the maxillofacial complex by face bow— Analysis by three dimensional finite element method—. *Shikwa Gakuho* 92:771–814. (in Japanese)
- 7) Katada H (1989) A study of internal reaction on the maxilla by orthopedic force— Analysis by three dimensional finite element method—. *Shikwa Gakuho* 89:1339–1384. (in Japanese)
- 8) Katura M (1959) Study of the human tooth strength. *J Kyoto Pref Univ Med* 66:207–219. (in Japanese)
- 9) Kragt G, Duterloo HS (1982) The initial effects of orthopedic forces: A study of alterations in the cranio-facial complex of a macerated human skull owing to high-pull headgear traction. *Am J Orthodont* 81:57–64.
- 10) Mermigos J, Clemens AF, Andreasent G (1990) Protraction of the maxillofacial complex. *Am J Orthodont* 98:47–55.
- 11) Merrifield LL, Cross JJ (1970) Directional forces. *Am J Orthodont* 57:435–464.
- 12) Nanda R, Hickory W (1984) Zygomaticomaxillary suture adaptation incident to anteriorly-directed forces in rhesus monkeys. *Angle Orthodont* 54:199–210.
- 13) Okikura M, Atumi K (1964) The physical characteristic of the raw body tissue. *Strides of Medicine* 51:276–283. (in Japanese)
- 14) Proffit WR (1986) *Contemporary Orthodontics*, pp.199–219, The CV Mosby Company, St Louis.
- 15) Suzuki T (1982) Experimental study of the deformation of maxillary complex loaded by orthopedic forces measurement by three axial strain gages. *Shikwa Gakuho* 82:469–502. (in Japanese)
- 16) Tamatu Y (1994) A measurement of local elastic modulus of labial and buccal compact bone of human mandible. *Jpn J Oral Biol* 36:306–329. (in Japanese)
- 17) Tanne K, Matsubara S (1996) Association between the direction of orthopedic headgear force and sutural responses in the nasomaxillary complex. *Angle Orthodont* 66: 125–130.
- 18) Tateishi T, Shirasaki Y, Kimura S, Ogawa K (1980) The viscoelasticity of the compact bone and strength. *Transactions of the Japan Society of Mechanical Engineers* 46:97–115. (in Japanese)

- 19) Tuda K (1957) Study of the bend and the impact strength of the human cortical bone. J Kyoto Pref Univ Med 61:1001-1025. (in Japanese)
- 20) Yokoo S (1952) The compression test of the cancellous bone. J Kyoto Pref Univ Med 51:273-276. (in Japanese)

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