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THE EFFECTS OF POSTERIOR RETRACTION ON THE DISPLACEMENT OF THE MAXILLA

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Three-dimensional finite element model was made from adult skull to find desirable direction of retraction force to treat skeletal class II malocclusion. The retraction force of 400g was applied to the first molar. The direction of the force application was 23° downward, parallel, 23° upward and 45° upward to the occlusal plane. The stress distribution and the displacement within the maxilla were analyzed by three-dimensional finite element method.

The findings obtained were as follows:

1. Maxillary first molar was displaced posteriorly and inferiorly in 23° downward, parallel, 23° upward retraction but it was displaced posteriorly and superiorly in 45° upward retraction.
2. ANS, A point and prosthion were moved posteriorly and inferiorly and pterygomaxillary fissure was moved posteriorly and superiorly. Clockwise rotation of maxilla occurred when retraction force was applied.
3. The degree of clockwise rotation of maxilla was greatest when the force was applied 23° upward to the occlusal plane and was least when the force was applied 23° downward to the occlusal plane.
4. Large tensile stress appeared in maxillary first molar and alveolar bone and the infraorbital region of maxilla when the force was applied 23° downward to the occlusal plane. Tensile stress was smaller as the direction of force move upward.
5. Large compressive stress was appeared in maxillary first molar and infraorbital region in 45° upward case and large compressive stress occurred in the posterior part of maxilla as the retraction force was upward.

Key words : posterior retraction,maxilla,three-dimensional finite element method

Extraoral orthopedic appliance has been attempted to correct skeletal problems in the field of orthodontics. Maxillary headgear was used to correct the maxillary prognathism by inhibition and stimulation of skeletal growth and by changing the direction of growth[13].

Extraoral appliance was also used to move the maxillary teeth distally and to encourage the anchorage. Case[21] had recommended the use of extraoral force to correct the class II malocclusion. However, the use of cervical headgear was decreased by introduction of intermaxillary elastics[20]. Klohn[3] revived the use of cervical headgear. He stressed the guidance of growth and the conservation of mandibular anchorage made possible with the cervical gear.

Maxillary headgear can be divided into cervical pull, straight pull, oblique pull and high pull headgear. Alexander[2] insisted that the choice of appliance is determined by the amount of horizontal maxillary growth expected. The expected growth is determined primarily by the patients' age and mandibuiar plane angle. A low angle or normally growing patient is well suited for a cervical headgear. If the mandibular plane angle is between 37° -41° , the combination pull headgear is used. An angle of 42° or more requires a high pull force vector. There are two types of headgear forces. Orthodontic force is defined as a force that specifically moves the maxillary first molar distally. Orthopedic force do not move teeth individually. Instead it can inhibit maxillary sagittal growth and allow mandibular growth.

To effectively employ the extraoral force system, it is necessary to consider center of resistance, direction, force magnitude and direction[15,32,36]. Understanding the biologic effect of orthopedic appliance and the mechanics of the appliance is necessary in order to get desirable retraction effect in growing patients[31]. Quantitative analysis of application force can not be made without accurate study about the direction of force. Therefore direction of orthopedic forces is very important in controlling the balance between vertical and horizontal movements of the upper arch[29]. Photoelastic method[5,6], strain gauge method[40], laser holography[9,18,19,39] and finite element method [17,33,34,35,37,41,45] have been used as a stress analysis method because it is very difficult to measure the mechanics directly in the jaw bone.

The finite element method with the development of computer and the improvement of software can eliminate many defects of other stress analysis methods and has been used in many parts of dentistry to study mechanics of solid structure and living tissues[44].

In this study, stress distribution and displacement within the maxilla was analyzed by a 3-dimensional finite element method to determine the desirable direction of the retraction force.

MATERIALS AND METHODS

Computed tomography was taken every 2mm in adult skull of normal occlusion in order to make a finite element model of the maxillary bone & teeth. Each section was put together by mirror image to 3-dimensional coordinates and divided into three-dimensional elements. Three-dimensional gap elements were used for interproximal surfaces. Intraoral fixed appliance that splints maxillary teeth into one unit is necessary to retract the maxilla. 3-dimensional finite element was made from the first molar to first molar, which were connected into one unit to move together (Fig. 1).

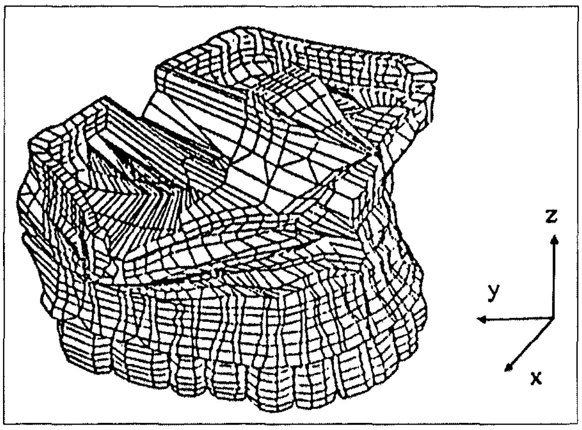

Fig.1. Schematic representation of the 3-D finite element model for the maxillary body and teeth.

Establishment of 3-dimensional coordinates were as follows :

X-axis was determined at occlusal plane level in contact with upper central incisor and was established to compare buccolingually. Y-axis was perpendicular to X-axis in maxillary central incisors and was established to compare anteroposteriorly. Z-axis was perpendicular to X-axis and Y-axis and was established to compare vertically. Maxilla was consisted of compact bone and cancellous bone. Thickness of the periodontal ligaments is 0.25mm[24]. All teeth were considered as dentin substance like Jang's[38] method because the purpose of this study was to examine the movement pattern of maxillary bone by orthopedic force. Young's modules and Poisson's ratio as a physical property of material were put into computer program according to Wright's data(Table 1).

Translational and rotational movement in the direction of X, Y and Z axis were limited. The nodes in frontomaxillary suture, zygomaticomaxillary suture and anterior border of pterygomaxillary fissure were considered as fixed points. Retraction force of 400g was applied to first molar in each side. Retraction points were 4mm below mesiobuccal cusp in the first molar. Direction of retraction was parallel to sagittal plane and inclined 23° downward, parallel, 23° and 45° upward to occlusal plane(Fig. 2).

The model consist of 14,699 nodal points, 19,842 solid elements and 59,526 degree of freedom. Stress distribution and displacement property of maxilla were analyzed with ABAQUS(V 5.2) structural analytical package.

Table 1. Mechanical properties assigned to different material compounds of finite element models

Material \ Property	Young's modulus(Kg/mm^2)	Poisson's ratio
Cancellous bone	7.0 x 103	0.30
Compact bone	1.4 x 105	0.30
Peridontal ligament	7.0 x 102	0.45
Teeth (Dentin)	1.9 x 105	0.31

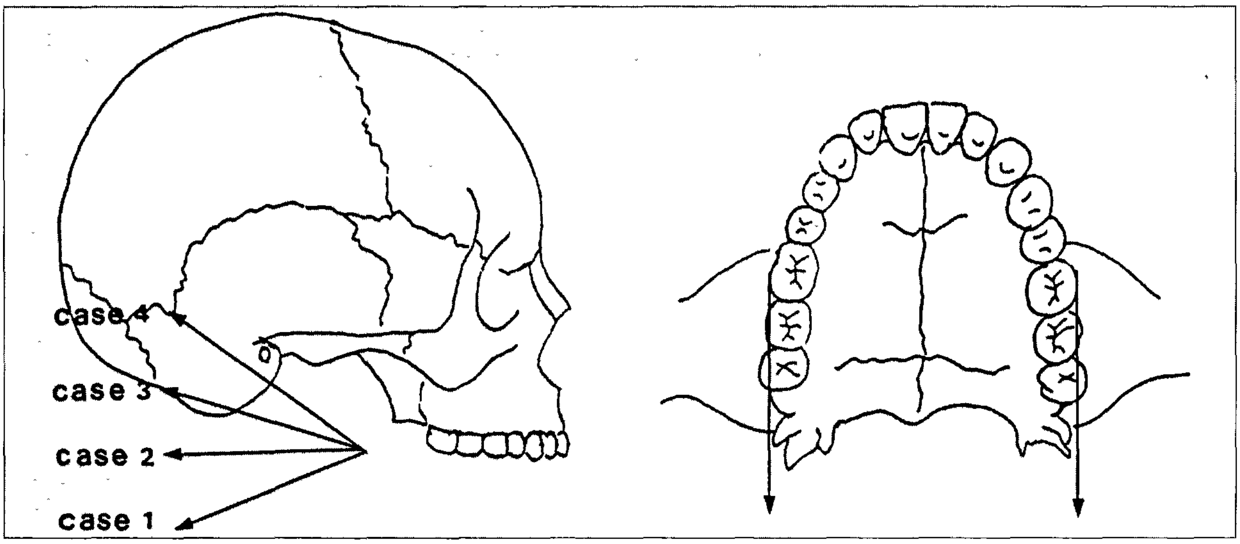

Fig. 2. Direction of force application.

Table.2 Displacement of Maxillary 1st Molar(unit: mm)

	M-B cusp tip			M-B root tip		
	X	Y	Z	X	Y	Z
23° downward	2.80x10-4	7.44x10-4	-3.69x10-4	9.43x10-6	5.51x10-5	-1.67x10-4
parallel	1.07x10-4	7.51x10-4	-2.55x10-4	1.11x10-5	5.18x10-5	-1.11x10-4
23° upward	-8.40x10-5	6.08x10-4	-1.01x10-4	1.09x10-5	4.02x10-5	-3.73x10-5
45° upward	-2.54x10-4	3.79x10-4	6.24x10-5	9.12x10-6	2.30x10-5	3.92x10-5

X ; Transverse displacement (+ : lingual,- : buccal), Y ; Sagittal displacement (+ : posterior,- : anterior),
Z ; Vertical displacement (+ : superior,- : inferior),

RESULTS

A. Displacement

1. Displacement of maxillary first molar.

Displacement by maxillary posterior retraction was greatest at the maxillary first molar. In the 23° downward force, inferior movement of the maxillary first molar was larger than other retraction forces(Table 2). Extrusion of the maxillary first molar occurred by 23° downward, parallel and 23° upward retraction and intrusion occurred by 45° upward retraction.

Table. 3. Displacement of ANS(unit: mm)

	X	Y	Z
23° downward	-1.24x10-15	6.57x10-6	-1.17x10-5
parallel	-6.92x10-17	5.59x10-6	-1.14x10-5
23° upward	1.41x10-15	3.72x10-6	-0.92x10-5
45° upward	7.43x10-16	1.25x10-5	-0.68x10-5

Table. 4. Displacement of A point(unit: mm)

	X	Y	Z
23° downward	-3.07x10-15	2.73x10-5	-0.80x10-5
parallel	-1.52x10-16	2.61x10-5	-0.90x10-5
23° upward	3.72x10-15	2.07x10-5	-0.85x10-5
45° upward	-1.38x10-17	5.51x10-9	4.51x10-9

Table. 5. Displacement of Prosthion(unit. mm)

	X	Y	Z
23° downward	-2.59x10-15	2.11x10-5	-3.04x10-6
parallel	-1.33x10-16	2.18x10-5	-4.48x10-6
23° upward	3.22x10-15	1.91x10-5	-5.21x10-6
45° upward	6.03x10-16	1.36x10-5	-5.12x10-6

Table.6. Displacement of Pterygomaxillary fissure(unit: mm)

	X	Y	Z
23° downward	1.03x10-4	1.25x10-4	0.43x10-5
parallel	9.12x10-5	1.10x10-4	1.36x10-5
23° upward	6.47x10-5	7.73x10-4	2.07x10-5
45° upward	2.96x10-5	3.45x10-5	2.43x10-5

2. Displacement of anterior nasal spine.

The direction of displacement in anterior nasal spine was posterior and inferior. In 23° downward retraction to occlusal plane, the posterior and inferior movement was greatest and least in 45° upward retraction(Table 3).

3. Displacement of A point.

The direction of displacement of A point was posterior and inferior in 23° downward, parallel and 23° upward retraction. But in 45° upward retraction, the direction was posterior and superior(Table 4).

4. Displacement of prosthion.

The direction of displacement of prosthion was posterior and inferior. The posterior movement was great in 23° downward and parallel retraction and downward movement was great in 23° and 45° upward retraction(Table 5).

5. Displacement of pterygomaxillary fissure.
   The direction of the displacement of pterygomaxillary fissure was posterior and superior. The posterior movement was great in 23° upward retraction and superior movement was great in 45° upward retraction(Table 6).

In this study, downward movement of the anterior nasal spine and A point is least in upward retraction and great in downward retraction. The direction of displacement of pterygomaxillary fissure is backward and upward and upward displacement is great in 45° upward retraction and least in 23° downward retraction. With this result, maxillary retraction force moved the maxilla clockwisely and it is great in 23° upward retraction and least in 23° downward retraction.

B. Stress distribution.

1. Retraction in 23° downward to occlusal plane
   Maximum tensile stress was 5.19×10^{-2}kg/mm^2 at the force application point of first molar and large tensile stress appeared at the infraorbital region of maxilla and it also appeared in the alveolar process of maxillary premolars and maxillary first molar (Photo. 1A, 1B).
   Maximum compressive stress was 4.87×10^{-3}kg/mm^2 at the force application point of first molar. Large compressive stress also appeared at the upper alveolar process and the infraorbital region of maxilla(Photo. 1C, 1D).
   Displacement by retraction force was 9.54×10^{-4}mm and it was broadest and greatest at the maxillary first molar and alveolar bone.
2. Retraction in parallel to occlusal plane
   Maximum tensile stress was 5.16×10^{-2}kg/mm^2 at force application point of first molar. Large tensile stress was appeared at the alveolar process of maxillary posterior teeth and infraorbital region of maxilla(photo. 2A, 2B).
   Maximum compressive stress was 4.89×10^{-3}kg/mm^2 at the force application point of first molar. Large compressive stress was also appeared at the alveolar process of the maxillary posterior teeth and the infraorbital region of maxilla(Photo. 2C, 2D).
   Displacement by retraction was 8.53×10^{-4}mm and it was localized at maxillary first molar and alveolar process. However, its amount and range were less than 23° downward directed case(Photo. 2E, 2F).
3. Retraction in 23° upward to occlusal plane
   Maximum tensile stress was 4.74×10^{-2}kg/mm^2 at force application point of first molar. Large tensile stress appeared at the above of force application point of first molar but it was less than downward directed case or parallel directed case(Photo. 3A, 3B).
   Maximum compressive stress was 4.10×10^{-3}kg/mm^2 at the force application point of first molar. Large compressive stress also appeared at alveolar process of maxillary first molar and second molar and broad area of maxillary tuberosity and infraorbital region of maxilla(Photo. 3C, 3D).
   Displacement by retraction was 6.62×10^{-4}mm and stress appeared at the maxillary first molar(Photo. 3E,F).
4. Retraction in 45° upward to occlusal plane
   Maximum tensile stress was 4.05×10^{-2}kg/mm^2 at force application point of the maxillary first molar. Tensile stress was localized to the region of the maxillary canine and premolars(Photo. 4A, 4B).
   Maximum compressive stress was 2.67×10^{-3}kg/mm^2 at the force application point of first molar. Large compressive stress also appeared in the alveolar process of maxillary first and second molar and broad area of the maxillary tuberosity and infraorbital region of maxilla(Photo. 4C,4D).
   Displacement by retraction was 5.14×10^{-4}mm and stress was the least in four cases and it was localized to the maxillary first molar(Photo. 4E,F).
   Tensile and compressive forces were great in 23° downward case and were least in 45° upward case. Displacement was also great in 23° downward case and was least in 45° upward case.

DISCUSSION

Many attempts to retract the maxilla by orthopedic force have been done to correct skeletal class II malocclusion[21)]. Retraction of maxilla was possible by extraoral orthopedic force in experimental animals [10,11,16)]. Droschl[11)] induced midface deficiency in

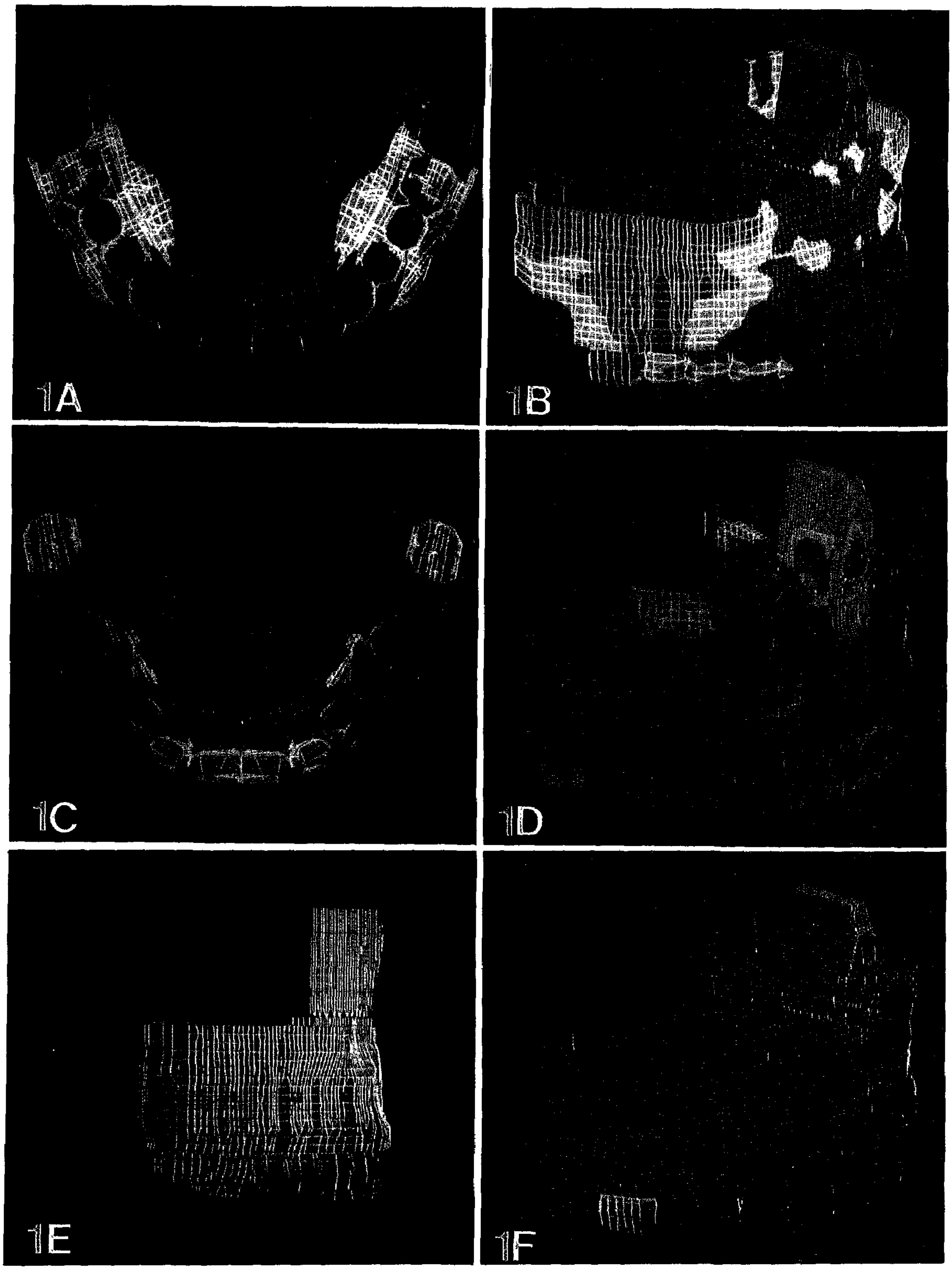

Photo. 1A, 1B Maximum principal stress when 23° downward force was applied.
Photo. 1C, 1D Minimum principal stress when 23° downward force was applied
Photo. 1E, 1F Displacement of maxilla when 23° downward force was applied.

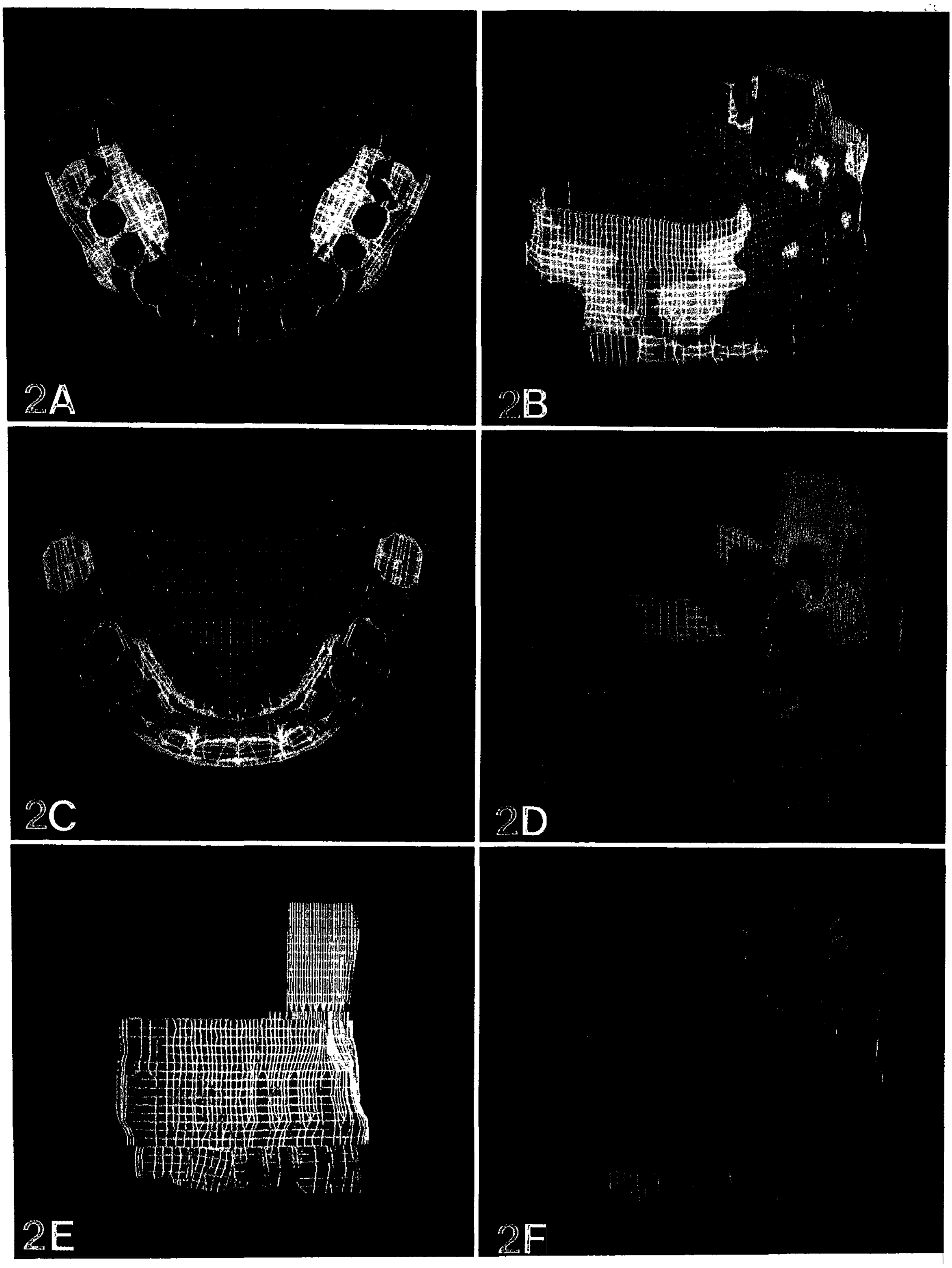

Photo. 2A, 2B Maximum principal stress when parallel force was applied.
Photo. 2C, 2D Minimum principal stress when parallel force was applied.
Photo. 2E, 2F Displacement of maxilla when parallel force was applied.

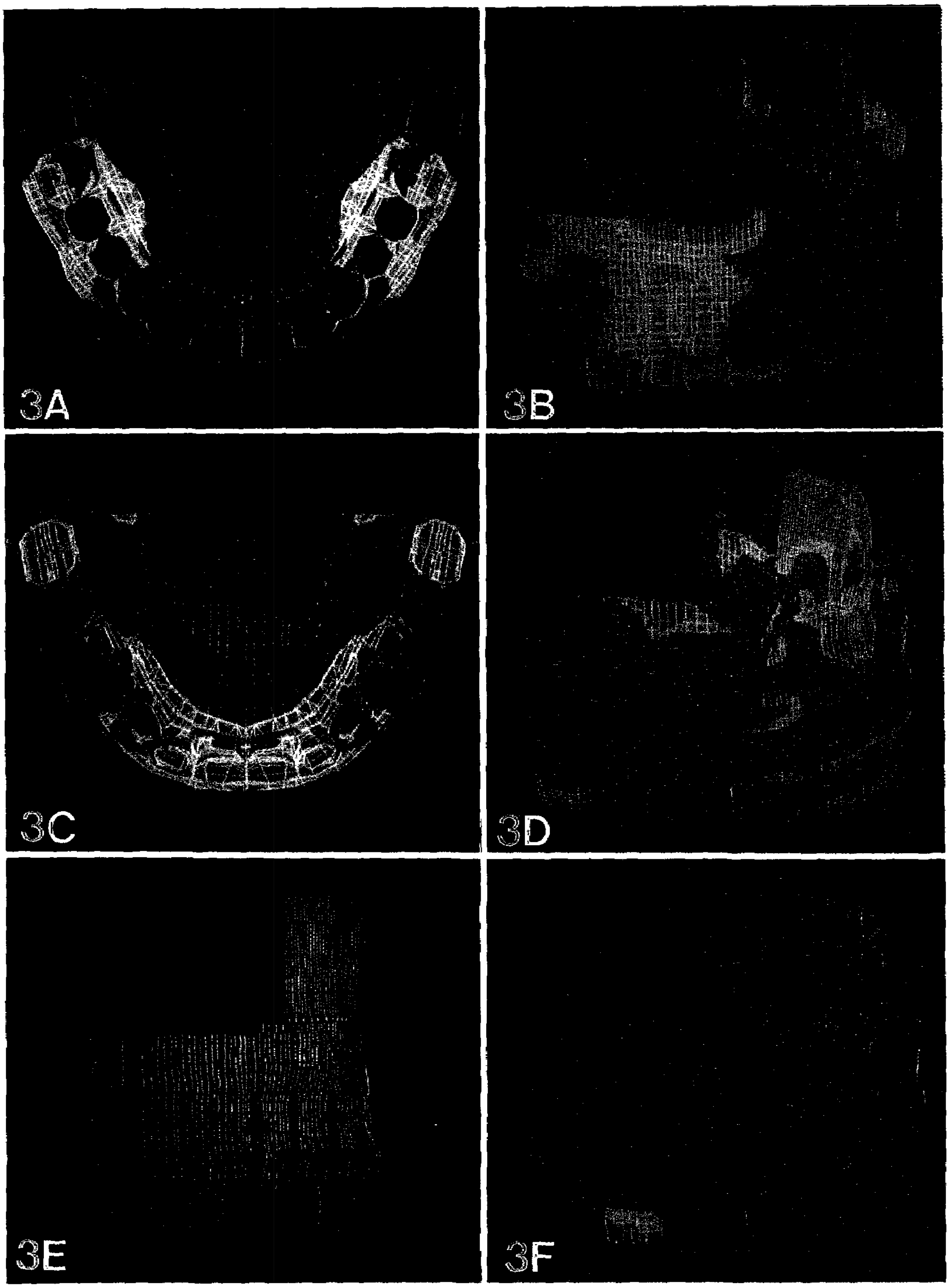

Photo. 3A, 3B Maximum principal stress when 23° upward force was applied.
Photo. 3C, 3D Minimum principal stress when 23° upward force was applied.
Photo. 3E, 3F Displacement of maxilla when 23° upward force was applied.

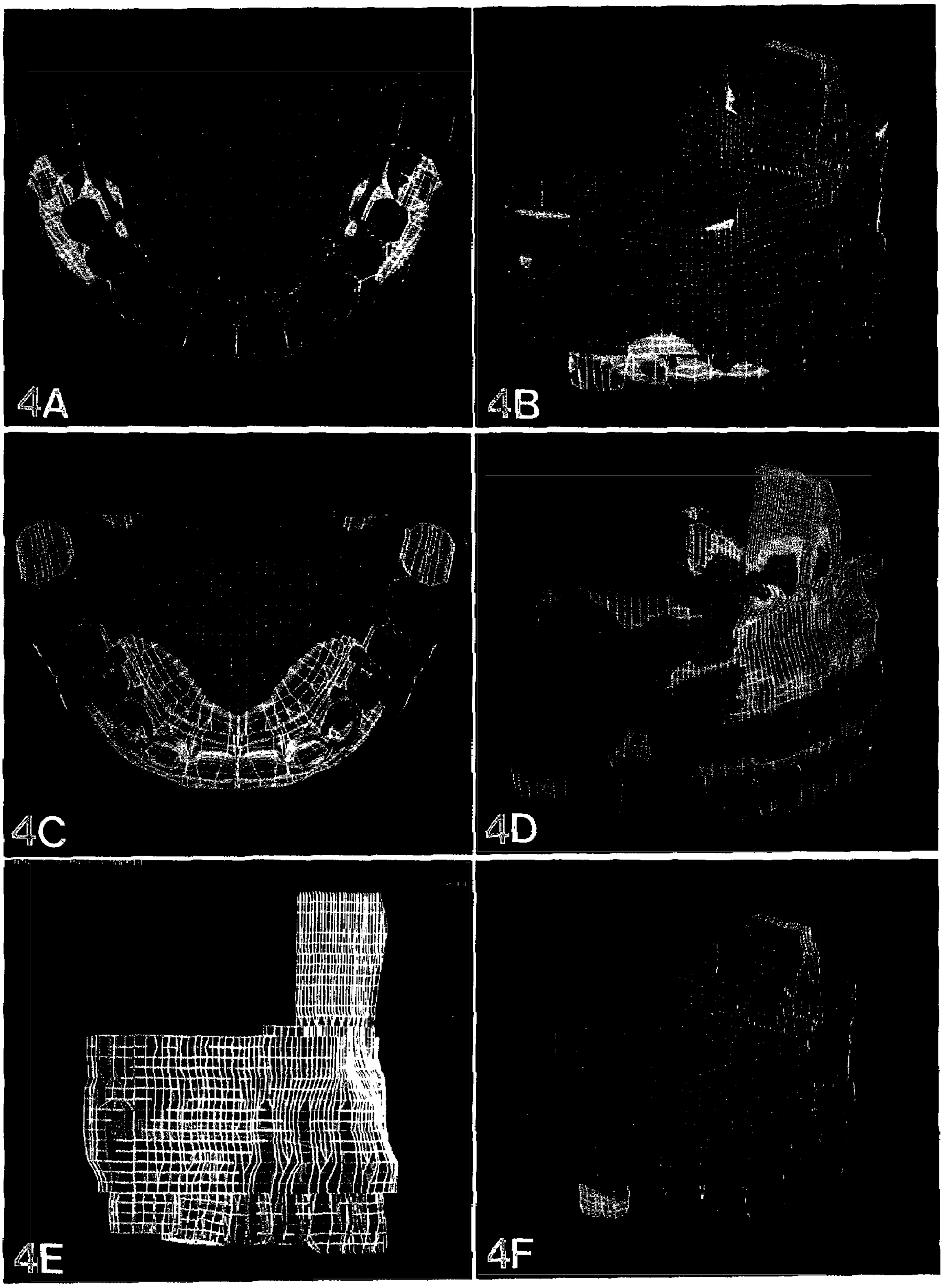

Photo. 4A, 4B Maximum principal stress when 45° upward force was applied.
Photo. 4C, 4D Minimum principal stress when 45° upward force was applied.
Photo. 4E, 4F Displacement of maxilla when 45° upward force was applied.

growing monkey by application of 100gm force in each side. Deformation of bone has been practiced in different societies for centuries. The well known deformation is Chinese girls results in a permanent change in the shape of the foot[31]. Foster[12] and Alexander[1] reported on the effects of Milwaukee brace employed for the treatment of young patients with poliomyelitis or scoliosis. They demonstrated that the mandible was rotated upward and forward around the condyle. The evidence from experimental and pathological studies affirms that it is possible to modify the size, shape and position of the maxilla and the mandible by orthopedic mechanical forces. Bluehеr[3] analysed the effect of cervical headgear treatment by cephalometric analysis. He reported that SNA angle decreased gradually and SNB angle did not change or slightly decreased and have some bite opening effect. The recognized variables in a study of this type primarily concern the patient. There are wide variations of growth activity related to age, of tissue responses to orthodontic pressures and of individual . patient cooperation. Numerous clinical studies have shown that the forward movement of the maxilla can be inhibited by maxillary retraction headgear[8]. Mcnamara and Bruden[21] reported that the direction of force can be altered, depending upon the place of attachment of the anchoring unit. A highpull headgear is used in individuals in whom increases in vertical dimension are to be minimized or avoided.

It is important to study the effect of orthopedic force biologically in vivo and to analyze the force mechanics and stress distribution of force qualitatively for understanding of force system : force magnitude, direction, application point, duration[15]. Orthopedic force is delivered to maxilla and adjacent bones through the maxillary teeth and morphology and position of facial bones could be changed. But it is difficult to predict those changes because of complexity of suture between maxilla and adjacent bones. Various experimental methods have been used to examine those changes of morphology and position[22,23]. Photoelastic method, strain gauge, holography and finite element methods are used for stress analysis of effect of maxillary protraction on maxillofacial skeleton.

Photoelastic method can be used to measure the stress of complex tissue like oral tissue by modeling according to apparatus. This method has an advantage that can determine the area and amount of stress concentration area of model. But only relative stress difference from adjacent point rather than the amount of stress is examined and it is impossible to compare two states simultaneously. It is not easy to make models and to do experimental work[5,6,14]. Strain gauge method is used to measure the amount and direction of stress by attaching the strain gauge. Stress and displacement can be measured at any point. It cannot be attached to small area and stress analysis on that area is impossible because there is limitation to make it very small[41]. Holography method can measure the micromovement of 0.5 micro meter at any surface condition and has no problem in determining the fixed point. But experimental condition is difficult and internal change cannot be examined[18,19,39].

In the finite element method used in this study, the shape and size of model can be made as true object. Model of complex elastic body consisted of various material also can be made and accurate measurement of internal stress according to grouping is easy. Border condition of model is changed easily and it is possible to analyze the stress distribution of the whole structure and to compare the change simultaneously before and after displacement. So finite element method has been used widely to analyze the stress distribution[41] and displacement in maxilla and mandible by orthopedic force and in tooth and alveolar bone by orthodontic force[17,38] and to analyze the growth of facial skeleton. ABACUS package that is currently revised computer program is used in this study to make 3-dimensional finite elements model of the maxillary teeth and maxilla with proper number of finite elements model by CAD system. Efforts should be given to make optimal finite element model in spite of this improvement.

It is desirable to apply the orthopedic force early before the end of growth of maxillofacial skeleton for maxillary protraction . But there is few information about physical property of each structure of infant skull. The purpose of this study is mechanical analysis in maxilla according to direction of retraction. This study was projected for analysis of stress distribution and displacement in adult skull according to Miura's[24] report using strain gauge method in which there is no difference in stress distribution between infant and adult skull. Load force in this study is 400g that is widely used orthopedic force in practice[21].

Jacobson[15] reported that the inclination or steepness of the line of action can be varied and is dependent upon the origin of the force and the point of attachment of the force. He insisted that high pull headgear will tend to intrude molars, whereas cervical headgear will extrude these teeth and application of maximum distal force to molars with minimal intrusion or extrusion is achieved by horizontal pull extraoral assemblies. In this study, the distal movement of maxillary first molar crown occurred in all cases. The amount of distal movement is least in 45° upward retraction case and great in parallel retraction case. This is coincident with the result of Jacobson that maximum distal movement is achieved by horizontal pull headgear. In this study, retraction force induce downward and backward movement of the maxillary first molar, anterior nasal spine, A point and prosthion in 23° downward, parallel and 23° upward retraction cases except 45° upward retraction case. 45° upward retraction force induced upward and backward movement in the maxillary first molar and A point. 45° upward force induced upward and downward movement of the anterior nasal spine and prosthion. Downward movement of anterior nasal spine was great in 23° downward directed case and least in 23° upward directed case.

Boecler et al[4] reported that the direction of extraoral force application influence the palatal plane, occlusal plane and mandibular plane. Cervical force tipped the palate downward anteriorly, opened the mandibular plane angle and encouraged increased vertical development. In this study, in parallel directed case to occlusal plane, the amount of posterior and inferior rotation of anterior nasal spine, A point and prosthion was less than downward directed retraction although the difference was not large. Clockwise rotation of the maxilla was also occurred in parallel directed case. In 23° upward directed case to occlusal plane, clockwise rotation of the maxilla also occurred and the amount was larger than downward directed and parallel directed case. Posterior and inferior rotation of the anterior nasal spine, A point and prosthion also occurred though the amount of it was smaller than downward directed and parallel directed retraction. Posterior displacement of the pterygomaxillary fissure was greatest and intrusion of it was larger than downward directed and parallel directed retraction. In 45° upward directed retraction to occlusal plane, the anterior nasal spine and prosthion rotated posteriorly and inferiorly. Posterior movement of A point is least and intrusion occurred in 45° upward case. Pterygomaxillary fissure rotated posteriorly and superiorly. Clockwise rotation also occurred in 45° upward case (Table 2-6).

Further studies may be necessary to verify the results in vivo and to complement insufficiency of data of physical and mechanical analysis by finite element method because of the anatomical complexity and specificity of growth pattern of the maxilla.

CONCLUSION

Three-dimensional finite element model was made from adult skull to find desirable direction of retraction force to treat skeletal class II malocclusion. The retraction force of 400g was applied to the first molar. The direction of the force application was 23° downward, parallel, 23° upward and 45° upward to the occlusal plane. The stress distribution and the displacement within the maxilla were analyzed by three-dimensional finite element method.
The findings obtained were as follows:

1. Maxillary first molar was displaced posteriorly and inferiorly in 23° downward, parallel, 23° upward retraction but it was displaced posteriorly and superiorly in 45° upward retraction.
2. ANS, A point and prosthion were moved posteriorly and inferiorly and pterygomaxillary fissure was moved posteriorly and superiorly. Clockwise rotation of maxilla occurred when retraction force was applied.
3. The degree of clockwise rotation of maxilla was greatest when the force was applied 23° upward to the occlusal plane and was least when the force was applied 23° downward to the occlusal plane.
4. Large tensile stress appeared in maxillary first molar and alveolar bone and the infraorbital region of maxilla when the force was applied 23° downward to the occlusal plane. Tensile stress was smaller as

the direction of force move upward.

5. Large compressive stress was appeared in maxillary first molar and infraorbital region in 45° upward case and large compressive stress occurred in the posterior part of maxilla as the retraction force was upward.

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