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Spatial changes of the maxillofacial complex following maxillary protraction of human dry skull

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The purpose of this investigation was to study the spatial changes of the maxillofacial complex following maxillary protraction transmitted to the center of resistance of a dry juvenile human skull by a modified maxillary protraction appliance. Four dry juvenile human skulls (without mandible) with well aligned upper deciduous dentition and early mixed dentition were used as experimental samples. A modified protraction headgear was fabricated from a Delare's facemask, and following an alginate impression, an orthodontic resin maxillary splint was made for each dry skull. Protraction force level was maintained at approximately 1000gm per side for 6 hours. Cephalometric radiographs were taken pre- and post- protraction, and nine reference markers with 1.5 mm length of .017 x .025 TMA wire were placed on the right side of the skull for an accurate superimposition of serial cephalometric radiographs.

The present investigation demonstrated that vertical changes associated with an anterior displacement of the maxillary complex was observed, and the most prominent effect of protraction headgear was a counterclockwise rotation of the maxilla, that is, a forward and downward tipping around the palatomaxillary region.

Key words : Juvenile human dry skull, Modified protraction headgear, Reference marker

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Protraction of the maxillofacial complex has been thought to be particularly well suited for growing children showing severe skeletal Class III malocclusions with maxillary retrusion. Sheridan[1] stated that orthopedic effects could be achieved when heavy orthopedic force was employed, associated with the sutural morphology and physiology of the maxilla's eight articulations. Previous studies,[2-6] however, related with maxillary protraction have shown adverse effects, such as a counterclockwise rotation of the maxilla, extrusion of posterior teeth, and a clockwise rotation of the mandible. These side effects may minimize by the protraction force transmitted to the center of resistance of the maxilla. Miki[7] reported that the center of resistance in the midface of the human skull is located between the first and second upper premolars anteroposteriorly, and between the lower margin of orbitale and the distal apex of the first molar vertically in the sagittal plane. Furthermore, Hirato[8] demonstrated, in a coronal plane analysis, that the center of resistance was situated anteroposteriorly at the area between the first and second maxillary premolars. Teuscher[9] repor-ted that the center of resistance of the maxillary complex was localized at the infrazygomatic crest. Recently, Braun et al[10] reviewed more accurately than before concerning to the location of the center of resistance of the dentomaxillary complex.

Hata and associates[11] reported that protraction 5 mm above the palatal plane produces a relatively forward movement of maxilla. Some investigators[11,12] have reported that if the force was generated parallel to the occlusal plane, it would produce a counterclockwise rotation of the nasal floor at any age. Itoh et al[13] recom-mended a combination of a forward and downward vector of force for the maxillary protraction to minimize the counterclockwise rotation of the midface. Lee[14] stated, in a holographic interferometry, that protraction 20 degrees downward and 15 mm above the occlusal plane, accompanied by palatal expansion, produced a true translation of the maxillary complex. However, Nanda[12] showed that with a change in moment and direction of force, the center of rotation of the maxilla could be altered and the force variables could play an important role in the attainment of a desired directional change of midfacial bones. Some investigators[10,12,15] have reported on appliances designed to minimize these side effects.

Associated with the prediction of maxillary protraction, Melsen[16,17] mentioned the postnatal developmental stage of the palatomaxillary region. She stated that disarti-culation of the palatine bones studied was possible only in skulls representing the infantile and earliest juvenile periods. Attempted disarticulation in the later juvenile and early adolescent periods was always accompanied by fracture of the heavily interdigitated osseous surfaces.

The purpose of this investigation was to study the spatial changes of the maxillofacial complex following maxillary protraction transmitted to the center of resistance of a juvenile human dry skull by a modified maxillary protraction appliance.

MATERIALS AND METHODS

Four juvenile human dry skulls (without mandible), with well-aligned upper deciduous dentition and/or early mixed dentition, were used as experimental samples. These skulls were provided by the Department of Anatomy, College of Medicine, Ewha Womans University. Skull 1 and 2 displayed whole deciduous dentition with Hellman's dental stage IIa. Skull 3 showed that the upper first permanent molar erupted and the upper deciduous central incisors exfoliated. However, skull 4 exhibited that deciduous central incisors did not exfoliated. Postnatal development of skull 3 and 4 were Hellman's dental stage IIc.

Maxillary protraction appliance fabrication

Head gear

A modified protraction headgear was fabricated from a Delare's facemask, but strong enough to withstand the applied force. The attached chin-cup of the facemask was removed for the applied force to be transmitted to the maxillary complex only. The framework was then firmly anchored by means of screws around the horizontally sectioned midportion of the calvarium in the sagittal aspect (Fig 1).

Maxillary splint

Following an alginate impression, an orthodontic resin maxillary splint was made for each dry skull. It was secured with light curing resin on the maxillary teeth. The splint covered only occlusal, buccal and palatal tooth surfaces. A 0.9 mm stainless steel traction hook was embedded into the resin splint and extended anteriorly from the mesial aspect of each maxillary deciduous first molar area and 15 mm superiorly from the occlusal plane (Fig 2).

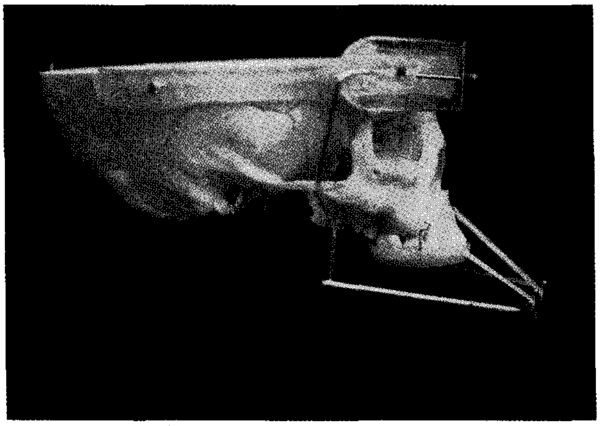


Fig. 1. Illustration of the modified protraction head gear. The traction elastic was engaged bilaterally from the anterior bar of the protraction head gear to the hook of the maxillary resin splint.

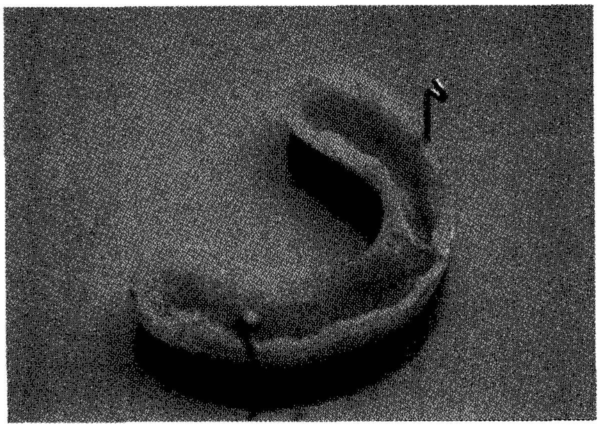


Fig. 2. A maxillary resin splint.

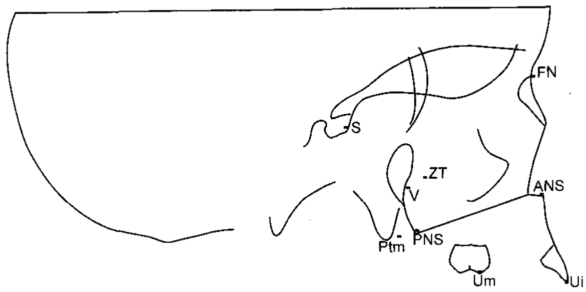


Fig. 3. Nine reference markers were placed on one side of the right zygoma adjacent to zygomaticotemporal suture(ZT), pyramidal process of the palatal bone, anterior nasal spine(ANS), posterior nasal spine(PNS), the most posterior superior point of the vomer(V), deciduous central incisor tip(Ui), mesiobuccal cusp tip of the deciduous second molar(Um), anterior wall of the sella turcica(S) and frontal bone adjacent to frontonasal suture(FN).

Reference markers placement

The placement of reference markers were carried out to permit an accurate superimposition of serial cephalometric radiographs and served as reference points for measuring spatial changes. These reference markers were 1.5 mm in length and 0.5 mm in diameter of TMA wire. Nine reference markers were placed on one side of the right zygoma adjacent to the zygomaticotemporal suture, pyramidal process of the palatal bone, anterior nasal spine(ANS), posterior nasal spine(PNS), the most posterior superior point of the vomer, deciduous central incisor tip, mesiobuccal cusp tip of the deciduous second molar, anterior wall of the sella turcica and the frontal bone adjacent to the frontonasal suture(Fig 3). However, the vomer of skull 1 was absent at the beginning of experiment, therefore the reference marker was unable to be placed. The upper deciduous central incisors of skull 3 were exfoliated, therefore the positional change was not recorded.

Force application

Protraction force was delivered to the maxilla of each dry skull by engaging rubber elastic from the anterior bar of the modified head gear to the hooks of the maxillary splint.

The force level was maintained at approximately 1000 gm per side for 6 hours. The anterior bar of the modified protraction appliance was initially adjusted to direct the force 30 degrees downward to the occlusal plane. Elastic tension was checked for 6 hours to ensure that a constant force of known magnitude was being applied. Before activation, the skull was submerged for 3 hours

Table 1. Changes in displacement between reference markers measured from tracings of lateral cephalometric radiographs

Reference marker \ Samples		Skull 1	Skull 2	Skull 3	Skull 4
Sella	hori	0.00	0.00	0.00	0.00
	vert	0.00	0.00	0.00	0.00
FN suture	hori	0.00	0.10	0.00	0.05
	vert	0.00	0.05	0.00	−0.65
ZT suture	hori	1.10	2.25	0.60	0.55
	vert	0.95	1.20	0.55	3.50
Ptm	hori	2.25	0.40	1.45	2.95
	vert	1.90	0.85	1.20	4.05
ANS	hori	2.45	1.55	1.15	3.20
	vert	0.05	0	0.05	−0.05
PNS	hori	2.20	1.75	2.20	1.55
	vert	2.05	1.65	0.60	3.85
Vomer	hori		1.85	0.85	2.45
	vert		2.50	1.30	5.20
Ui	hori	2.95	3.25		4.50
	vert	0.10	0.10		−0.10
Um	hori	3.35	2.35	1.35	3.80
	vert	1.45	0.85	0.85	2.85

in a water bath that was maintained at room temperature for preventing the fracture of the friable adjacent bony structure of the dry skull. This condition was maintained during activation as well. The protraction force was applied for 6 hours, but dry skull 4 did not respond during the 6−hour period. Therefore, the protraction force was increased to 3000 gm per side for 3 hours. Following protraction, the dry skull was removed from the water bath and the elastic, maxillary splint, framework and anchoring screws were removed from each dry skull. Thereafter, the dry skull was placed on a cephalostat for taking cephalometric radiographs.

Cephalometric radiographs and superimposition

Lateral cephalometric radiographs were taken at the start of force application and at 6 or 9 hours thereafter. The radiographs were exposed at a standard object−to−tube distance unique to each dry skull. The radiographs were taken at 60 Kvp and 4 mA with an exposure time of 0.8 seconds for lateral projections. Tracings of the cephalometric radiographs were superimposed in order to evaluate spatial changes of the maxillary complex. Two base axes were drawn on the lateral cephalometric radiographs. The X−axis was drawn as a horizontal line that was the mid−calvarial line, which was drawn from the horizontally sectioned midportion of the calvarium in the sagittal plane; the Y−axis was drawn perpendicular to the X−axis on the reference marker of the anterior wall of the sella.

After the overall lateral superimposition was oriented on the X and Y−axes, the minimum distances of each landmark from the X and Y−axes were measured to assess positional changes.

RESULTS

The results of this investigation are shown in table 1, and figure 4 and 5. The sign convention used in the table is such that anteriorly or inferiorly directed movements are treated as positive. The present investigation demonstrated that vertical changes associated with an anterior displacement of the maxillary complex were observed from the superimposed tracings

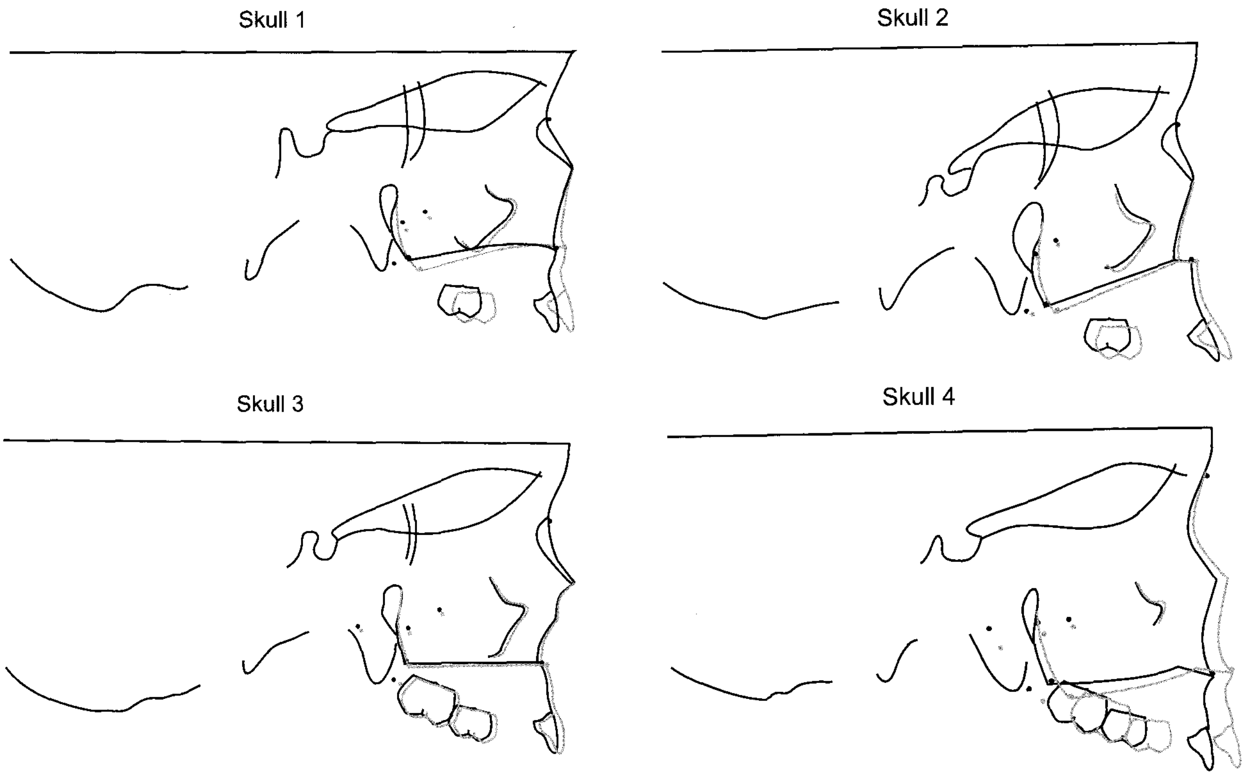


Fig. 4. Composite tracings of pre-and immediate postexperimental cephalometric radiographs of dry skulls 1, 2, 3 and 4. The black line represents preexperimental relationships; the gray line represents postexperimental relationships.

Fig. 5. Pre- (A) and immediate postexperimental (B) lateral cephalometric radiographs of skull 1. An arrowhead in the B indicates disarticulation of the pterygomaxillary fissure area.

of pre-and immediate postexperimental lateral cephalometric radiographs.

It can be seen that the most prominent effect is a counterclockwise rotation of the maxilla, that is, a forward and downward tipping around the palato-maxillary region.

Anterior wall of the sella turcica

Positions of the reference markers showed no changes in the pre- and post- experimental cephalometric radiographs of all skulls.

Frontal bone adjacent to frontonasal suture

The reference markers remained in the same positions during the entire experimental period in skull 1 and 3, and showed a minimal change of horizontal and vertical displacement in skull 2 and 4. However the reference maker of skull 4 moved superiorly, which was different from skull 2.

Zygomatic bone adjacent to the zygomatic-otemporal suture

During the experimental period, the positions of the reference markers moved antero-inferiorly in all dry skulls. The range of horizontal movement was from 0.55 mm (skull 4) to 2.25 mm (skull 2), and the range of vertical movement was from 0.55 mm (skull 3) to 3.50 mm(skull 4). Skull 1, 2 and 3 corroborated the cep-halometric findings. Most apparent was the enormous amount of displacement created in skull 4, which differed considerably from the other three dry skulls. The main reason was related with the three fold higher level of protraction force and extended duration applied in skull 4. Therefore, the zygomaticotemporal suture separated completely in skull 4 as shown in figure 5.

Pyramidal process of the palatine bone

The reference marker moved antero-inferiorly in all dry skulls relative to the superimposed reference lines. A macroscopic finding was separated, particularly in skull 4, when compared with the other three skulls. The greatest change of the pyramidal process of the palatine bone in skull 4 was measured to be 2.95 mm anteriorly and 4.05 mm inferiorly. Therefore the pterygomaxillary fissure of dry skull 4 was disarticulated completely as shown in figure 5.

Anterior nasal spine (ANS)

There was a change in the anterior nasal spine of all-dry skulls during the experimental period. Spatially, the reference marker moved anteriorly ranging from 1.15 to 2.45 mm and slightly inferiorly ranging from 0 to 0.05 mm in skull 1, 2 and 3. However the greatest change was observed in skull 4, which was 3.20 mm anteriorly and 0.05 mm superiorly.

Posterior nasal spine (PNS)

A superior tipping of the palatal plane anteriorly and an inferior tipping posteriorly were observed in each dry skull. The posterior nasal spine showed a change in dry skulls 1, 2 and 3, ranging from 1.75 to 2.20 mm anteri-orly and from 0.60 to 2.05 mm inferiorly. However, skull 4 showed a change of 1.55 mm anteriorly and 3.85 mm inferiorly.

Vomer

The displacement of the vomer demonstrated a similar pattern as in PNS and the pyramidal process of the palatine bone. The reference marker also moved anteroinferiorly, however, the amount of vertical change was greater than the horizontal change seen in skulls 2, 3 and 4. However, skull 4 showed a severe inferior displacement of 5.20 mm greater than anterior displacement of 2.45 mm.

Incisor tip

The anterior displacement of skulls 1, 2 and 4 ranged from 2.95 to 4.50 mm. Skulls 1 and 2 showed an inferior displacement of 0.10 mm, however, skull 4 was moved superiorly 0.10 mm.

Molar cusp tip

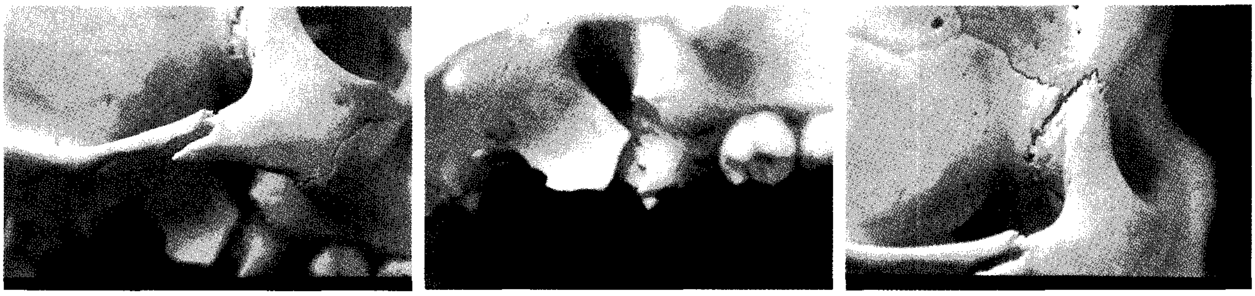
Displacement of the mesiobuccal cusp tip of the second deciduous molar ranged from 1.35 to 3.35 mm anteriorly, to 0.85 to 1.45 mm inferiorly in skulls 1, 2 and 3. However, skull 4 showed a greater displacement of 3.80 mm anteriorly and 2.85 mm inferiorly.

DISCUSSION

The anterior extraoral forces applied to the center of resistance of the maxillofacial complex were transmitted through the maxilla and related midfacial bones, resulting in the translation of the maxilla. During extraoral traction, the influence of sutural morphology and resistance to the movement on the displacement of the maxilla has been demonstrated by laser holography.[18-20] Lee[14] stated that the response of the maxillary complex when protracted 20 degrees downward and 15 mm above the occlusal plane, accompanied by palatal expansion, appeared as typical circular fringe patterns. The center of each fringe pattern can be further described as located laterally at approximately 63% of the distance from the crista gali axis to the inferior border of the zygomaticomaxillary suture bilaterally, and approximately 13% of the distance from the zygoma-ticomaxillary axis to the inferior border of the orbit. This indicates that a true translation of the maxilla occurred. These studies reveal, however, only the initial displace-ment of the maxilla as seen in dry adult skulls after application of a force system.

The spatial change of the maxillary complex has been described in numerous consecutive experimental cephalometric studies.[4,12,21,22] However, these studies do not show translation of the maxillary complex. This means that the protraction forces applied parallel to the occlusal plane from either the molars or the premolars caused a counterclockwise opening rotation of the maxilla. In this investigation, even though the protraction 30 degrees downward and 15 mm above the occlusal plane were transmitted to the center of the resistance of the maxillary complex, the maxillary complex showed a counterclockwise rotation rather than translation. These results were consistent with the findings of Itoh and associates[13] and others[4,30] who tested in vitro, and Nanda[12] and Ishii[31] who examined primate animals. However, this viewpoint was based on pure geometry, considering the maxilla as a free body movable in space and not necessarily considering the resistance in the different sutures surrounding the maxilla.

The area of the articulation surfaces of the palato-maxillary region is considerably larger than the surfaces of the fronto- naso- and zygomatico-maxillary suture. It can be explained by the magnitude of the sutural area in the posterior part of the maxilla as compared to the more simple sutures connecting the maxilla with the frontal, nasal, and zygomatic bones. It is, therefore, suggested that the center of resistance of the maxillary complex may change during postnatal development, such that a shift toward the more complicated sutural area takes place from the juvenile to the adolescent period. Elder and Tuenge[23] felt that the medial pterygoid plate, vomer, and pyramidal processes of the palatine bones were forced against the inferior surface of the posterior sphenoid, creating a buckling of the cranial base at the still patent spheno-occipital and mids-phenoidal synchondroses. Melsen[16] noted that the comple-xity of the contact surfaces was expressed as an index between the shortest distance and the length of the two bone surfaces, the palatal and pterygoid bone surfaces, involved in the suture. A complete strai-ght suture would thus have a complexity index of 2. During the early period of postnatal development, the suture of the palatomaxillary region allows the palatine bone to move relatively freely in relation to the maxilla and pterygoid process. In the infantile stage, when the palatine bone is separated from the adjacent bones by a wide fissure containing loose connective tissue, a pronounced forward displacement of the maxilla can be obtained with protraction force. In the juvenile period, all articulating surfaces between the palatine bone and adjacent bones were irregular. The disarticulated bones revealed a more intimate contact between the maxilla and the palatine bone than in the infantile stage. Several investigators[24,25] stated that the protraction of the maxillofacial complex will be more effective at an early age where optimal response can be expected. Baik[26]



A B C

Fig. 6. Dry skull 4 showing the zygomaticotemporal process completely disarticulated(A). The pterygomaxillary fissure was also completely disarticulated(B), however, zygomaticofrontal suture was nearly disarticulated(C).

and Merwin et al,[27] however, reported that a similar skeletal response could be obtained when maxillary protraction was started either before age 8(5 to 8 years) or after age 8 (8 to 12 years). Kapust and his coworkers[5] have reported that although early treatment may be most effective, facemask therapy can provide a viable option for older children as well. Namely, the younger age groups (4 to 7 and 7 to 10 years) appeared to have responded better to treatment; accordingly, the 10 to 14 year age group still demonstrated significant treatment effects, indicating that orthopedic change does occur in older children. However, the 10 to 14 year age group did reveal less orthopedic change than might be expected in the younger age groups to achieve correction of the malocclusion, showing a significantly greater negative convexity, a more severe Class III molar relationship, and a slightly longer treatment time than the two younger age groups. Melsen[16] reported that with increasing age the palatine bone increased the extension of the contact surfaces with the adjacent bones, the maxilla, and the pterygoid process of the sphenoid bone. This indicates that a pronounced variability existed among individuals within the same developmental stage. In this investigation, the results of the response were different in each skull even though they were of the same developmental dental stage. The displacement seen in skull 1 was greater than that in skull 2. Skull 3, which was Hellmans' IIc stage, showed greater change than skull 2, that was stage IIa. Skull 3 and 4 were the same developmental dental stage, however, the response at the beginning of the experiment was totally different. In particular, skull 4 did not respond in the first trial. After increasing the traction force and extending the traction time, it exhibited greater counterclockwise rotation than the other three skulls, with an irreversible fracture of an adjacent bony structure(Fig 6). This is in agreement with the findings of several other in vivo studies[28,29]. From these observations, it might be suggested that despite the anterior extraoral forces applied to the center of resistance of the maxillary complex, counterclockwise rotation of the maxilla was shown in all dry skulls. Furthermore, although a downward protraction force vector decreased this effect, the downward pull would also cause extrusion of the maxillary posterior teeth, which might lead to an alteration of the position of the mandible. Even though the vertical force component counteracts the adverse rotation of the maxilla, it may affect the mandibular position to a greater degree by extruding the upper posterior teeth. Jackson and coworkers[21] have relied on tooth-borne splints for the application of extraoral force and have reported undesirable dental tipping and extrusion. However, in the present investigation, extrusion of all upper teeth was not observed because the teeth of the dry skull were immobilized to the alveolar sockets by curing the resin before activation.

CONCLUSIONS

To obtain an effective movement of the maxillary complex without rotation, the center of resistance of the maxilla should be localized. However, although the extraoral protraction force was transmitted through the center of resistance of the maxilla, the maxilla still demonstrated a counterclockwise rotation that is unavoidable in facemask treatment. On the contrary, it seems to indicate that clinicians should be using it in Class III deep overbite cases in which an increase in lower face height will be beneficial. Despite a limited sample size, this investigation shows that the maxillary protraction may be more effective at an early age and that individual variability exists within the same developmental stage of the palatomaxillary region.

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국문초록

건조 두개골에서 상악의 전방 견인후 상악 안면 복합체의 공간 변화에 관한 연구

전윤식, 최장우, 최승은, 이성근

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이 연구의 목적은 유년기 건조 두개골에서 상악골 전방 견인 장치로 상악골의 저항중심을 지나는 힘을 가했을 때, 상악골 복합체의 공간 변화를 평가하기 위함이다. 유치열기 혹은 초기 혼합 치열기로 추정되는 건조 두개골 4구를 사용하여 Delare의 facemask로 modified protraction headgear를 제작하였으며, 각각의 두개골에서 알지네이트 인상을 채득한 후 상악 스플린트를 제작하였다. 전방 견인력을 편측 당 1000gm씩 6시간 가하였다. 전방견인 전과 후 측모 두부방사선사진을 촬영하였으며 정확한 중첩이 가능하도록 1.5mm 길이의 .017 x .025 TMA wire를 사용하여 9개의 reference marker를 두개골 우측에 위치 시켰다.

본 연구를 통해 상악골 전방 견인시 상악골 복합체의 전방 이동과 더불어 수직적 변화를 관찰할 수 있었으며, protraction headgear의 주된 효과는 상악골의 반시계 방향의 회전, 즉 구개상악부(palatomaxillary region)의 전하방 경사 이동에 의한 것임을 알 수 있었다.

주요 단어 : 건조 두개골, Modified protraction headgear, Reference marker