Cervical Retraction of the Maxillae in the Macaca Mulatta Monkey Using Heavy Orthopedic Force

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The application of cervical traction to the maxillae has been a tremendous boon to orthodontic therapy. Cervical retraction with orthodontic forces has helped tip, extrude and distally translate the maxillary teeth and to guide them to place during eruption. It has even induced distal movement of unerupted tooth buds.

Beyond this, cervical retraction has retarded the normal forward growth of the maxillae and, indeed, moved the maxillae downward and backward. This has been observed as a tipping of the anterior palate downward and backward and a retardation of the forward movement of cephalometric point A. Among the consequences of maxillary retrusion are a downward and a backward rotation of the mandible, an increase in alveolar height, and a lengthening of the face. Even more dramatically, there is evidence that orthodontic retraction has induced a downward and backward rotation of the sphenoid and posterior movement of the pterygomaxillary fissure.[3,5,8-18,20]

While orthodontic forces of 10^1 + gm magnitude have thus been extensively employed for cervical retraction, the use of orthopedic forces, 10^2 + gms, has also been employed. Such forces for the correction of anteroposterior and vertical jaw relationships were studied by Graber, Chung and Aoba[6] in Class II, Division 1 malocclusions. The success of prolonged treatment during times of greatest growth confirmed the superior ability of this type of therapy in correcting basal jaw relationships.

Using continuous cervical headgear therapy on rhesus monkeys, Sproule[19] concluded that orthopedic retraction of the maxillae was accompanied by depository remodelling at the frontozygomatic and frontomaxillary sutures. Resorptive remodelling occurred at the zygomatictemporal sutures, between the sphenoid and maxillary tuberosity, and between the sphenoid and the vomer and palatine bones. He also reported that resorption occurred on the posterior border of the ramus of the mandible as well as in the roof of the glenoid fossa and the anterior surface of the postglenoid tubercle. In a similar study on the squirrel monkey Droschl[2] showed that retractive forces on the maxillae retarded the eruptive processes of the maxillary teeth, compressed the maxillae anteroposteriorly, rotated the maxillae posteriorly around an axis near the superior border of the zygomatic process, and thrust the tuberosity against the lower wall of the orbit in the pterygopalatine fossa. He further demonstrated a downward and backward movement of the nasal bones producing a "dished in" facial profile. He concluded that orthopedic retraction of the maxillae retarded or bent the whole upper facial structure.

Little attention has been given to the application of orthopedic forces at levels of 10^3 + gms. In a clinical study

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Supported financially in part by the National Institutes of Health Grant 5S01FR05302-06.

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Haas[7] has employed retractive forces at ca 1000 to 2000 gms (2-5 pounds) to achieve dramatic results in the bodily downward and backward movement of the maxillae. No experimental scrutiny has yet been given to forces of this magnitude. If the clinical potential of this therapeutic approach is to be realized, there must be further study to confirm and extend the initial findings. The purpose of this investigation, therefore, was to further explore the changes which occur in the craniofacial complex of the postpuberal Macaca mulatta monkey when orthopedic forces of high magnitude are employed to retract the maxillae.

Materials and Methods

The Macaca mulatta monkey was selected as the experimental subject because of its anatomical and morphological similarity to man. Four postpuberal females with full permanent dentition, approximately 42 months of age and weighing 11 to 11.5 lbs., were secured and housed in the Animal Care Facility of Loma Linda University Hospital, Loma Linda, California.

The animals were randomly divided into two control and two experimental subjects. With the death of one of the experimental animals from toxemia following accidental entanglement in its restraint chair, one of the control animals was transferred to the experiment so that the final study was conducted with two experimental animals (A and B) and a control (C). "A" and "B" were treated for 351 and 209 days, respectively.

The control animal was kept in an individual cage. The experimental subjects were confined to restraint chairs. An environmental temperature of 74° was maintained to prevent the coughing, sneezing and shivering of the restrained animals which occurred when the temperature was lowered.

The diet of each animal consisted of monkey chow biscuits, fruit supplements and water twice a day. The control animal ate and drank ad libitum while the restrained animals were fed by hand and provided with water from a 100 ml. syringe. Isoniazid (20 mgm/animal/day) was added to the water as a tuberculosis prophylactic measure.

The animals under restraint initially refused food and consequently suffered substantial weight loss. Within 14-21 days, however, they became accustomed to confinement and gradually resumed their normal eating habits. Subsequent decline in weight undoubtedly represented loss of body mass due to inactivity. To control the effects of confinement the experimental animals were periodically released and returned to their cages for 7-10 day periods of rest and relaxation. During these intervals the animals quickly regained normal strength, weight, and activity as well as their wild, native antics.

Animals subjected to experimental procedures were tranquilized with intramuscular injections of 1-(1-phenylcyclohexyl) piperidine hydrochloride (20 mgm/ml). One-half milliliter was required for a 90 minute to two hour session. Tranquilized animals were never returned to confinement until they had regained movement of their extremities and thus were assured of proper vascular flow.

Appliances

The maxillae of the experimental animals were prepared for the intraoral device by gingivectomies which assured closer adaptation of the appliance around the necks of the teeth. Alginate impressions were then taken and poured in die stone.

The appliance itself consisted of a chrome-cobalt palatal casting which included the cuspid through second molar teeth. Buccal tubes were soldered to the casting in the premolar region to receive the inner arch-bow of a Kloehn-type headgear. In addition, a stainless steel nut was soldered to the casting in the premolar and molar embrasures on each side to receive the threaded portion of a stainless steel bolt. The stainless steel bolts were inserted through buccal openings provided in the appliance and engaged the soldered nuts through holes drilled interproximally between the first and second premolar and the first and second molars on each side. This arrangement gave "monkey proof" retention of the device even during periods of freedom from confinement.

Stops were soldered to the inner bow to engage the buccal tubes of the intraoral device. The outer facebow was fitted in turn with extraoral elastics to provide the retraction force. A leather neck band lined with orthopedic foam rubber to relieve pressure was used around the cervical region of the monkey.

The lengths of the extraoral elastics were measured daily with a millimetric ruler and the weight in pounds required to stretch the elastics to the measured distance determined.

Continuous orthopedic forces of 2.5 to 5 pounds were imposed on the appliance during an initial experimental period of 60 days. Under this regimen alarming cervical decubital ulcers developed. Healing occurred with proper treatment after removal of the appliance. Thereafter retraction was resumed at a reduced load of 2.5 pounds and with daily removal of the headgear for six to eight hours. Complications did not occur under this modified program.

At the beginning and again at the end of the treatment period full upper and lower impressions were taken with an alginate material in trays fabricated from perforated copper sheeting. The impressions were poured in plaster.

Implants

Before the start of experimentation, stainless steel implants were placed over the maxillary right cuspid and below the mandibular right first premolars in all the animals.

When one of the initial experimental animals accidentally died, additional amalgam implants were placed on each side of selected craniofacial sutures in the control animal (C) and in the replacement experimental animal (B). No amalgam implants were placed in the other experimental animal because experimentation had already begun. Implantation was conducted using the sterile surgical approach and procedures of Gans and Sarnat.[4] Amalgam implants were thus located bilaterally on each side of the zygomaticomaxillary, zygomaticotemporal, premaxillomaxillary, and midpalatal sutures. Implants were also placed at prosthion and in the occipital region.

Cephalometry

Cephalometric roentgenograms were taken on the control animal (C) and the replacement experimental animal (B) at the beginning of treatment and again 160 days later.

For this purpose the tranquilized animals were supported in a restraining chair, the head positioned in custom made acrylic ear rods and the nose piece fitted. Rubber bands were used to stabilize the teeth in occlusion. As a means of insuring the identical film-object distance for each series of x-rays, measurements were made in millimeters from the film to the center of the ear rod in the frontal position and from the film to the center of the nose piece in the lateral position.

Paired gold discs precisely placed on the ear rods and also on the nosepiece provided a check on any variation in image size from one film series to another. All headplates were taken at 90

TABLE I
GROSS MEASUREMENTS FROM PLASTER CASTS

Measurement	*Monkey "A" (Expt.) (mm)*	*Monkey "B" (Expt.) (mm)*	*Monkey "C" (Control) (mm)*
Max. First Molar (R)	6.0	5.0	0.0
Max. First Molar (L)	7.0	5.5	0.0
Max. Primate Space (R)			
Beginning	3.5	3.0	3.0
End	5.0	4.0	4.0
Max Primate Space (L)			
Beginning	4.0	2.0	3.0
End	6.0	4.0	4.0
Mand. Primate Space (R)			
Beginning	1.5	2.0	0.75
End	1.5	2.0	0.75
Mand. Primate Space (L)			
Beginning	1.5	2.0	0.5
End	1.5	3.0	0.5
Max. Bimolar width			
Beginning	29.0	28.5	27.0
End	29.0	30.0	27.0
Mand. Bimolar width			
Beginning	24.0	22.5	21.5
End	26.0	22.0	21.5
Max. Arch Length			
Beginning	24.5	24.0	25.5
End	23.5	23.5	23.5

K.V.P., 50 M.A. and 1/12 second. The source to object distance was 60 inches.

Preparation of Material

Upon the termination of treatment the three monkeys were euthanized with a lethal intravenous solution of Euthanol-D. The intact skull of experimental animal A and the right sagittal skull halves of the other two animals were cleaned by a colony of dermestid beetles, then immersed in isopropyl alcohol and finally degreased in a solution of trichlorethylene prior to gross examination.

Meanwhile, the left sagittal skull halves of animals B and C were cut into tissue blocks with a stryker saw, grossly cleaned of soft tissue and immediately placed in 10% formalin. The tissue specimens were then ionically decalcified, embedded, cut at a thickness of 6 microns and stained with hematoxylin and eosin.

Measurements

A series of four measurements was made with a Korkhaus calipers, dividers, and a millimetric rule on the plaster casts of all three animals. Posterior movement of the maxillary first molars was measured from the tip of the mesiobuccal cusp of the maxillary first molar to the central groove of the mandibular first molar. The primate spaces were determined from the interproximal distance between the lateral incisor and cuspid of the maxillary arch and the cuspid and first premolar of the mandibular arch. The bimolar width of both arches was expressed as the distance between the central pits of the contralateral first molars. The lengths of the maxillary and mandibular arches were measured from the most anterior facial surface of the central incisors to the mesial surfaces of the first permanent molars (Table I).

TABLE II
MEASUREMENTS OF AMALGAM IMPLANTS

Measurement	*Monkey "B" (Expt.) (mm)*	*Monkey "C" (Control) (mm)*
Right ZT		
Beginning	4.75	6.5
End	3.25	7.25
Left ZT		
Beginning	5.75	7.0
End	4.0	7.5
Right ZM		
Beginning	5.0	5.5
End	4.5	5.75
Left ZM		
Beginning	4.0	6.25
End	3.75	6.5
Right PM		
Beginning	2.5	4.75
End	2.25	5.0
Left PM		
Beginning	3.5	7.25
End	3.25	8.0
Midpalatal		
Beginning	5.0	6.0
End	5.0	6.5
Bi-ZM		
Beginning	49.5	44.0
End	50.0	48.0
Pr-Ocp.		
Beginning	112.5	113.5
End	109.5	115.5

Implants

The distance between paired amalgam implants was measured on animals B and C at the time of implantation and again immediately upon sacrifice. Measurements were made directly on the skull and across the following sutures: zygomaticotemporal (ZT), zygomaticomaxillary (ZM), premaxillomaxillary (PM), bilateral zygomaticomaxillary (Bi-ZM), and midpalatal (Midpal). The distance from prosthion to occipital (Pr-Occp) was measured on a right lateral cephalogram. In every instance the distance was measured from center to center of the implants. When any implants were lost in dissection, the measurements were taken from the centers of the bony cavities (Table II).

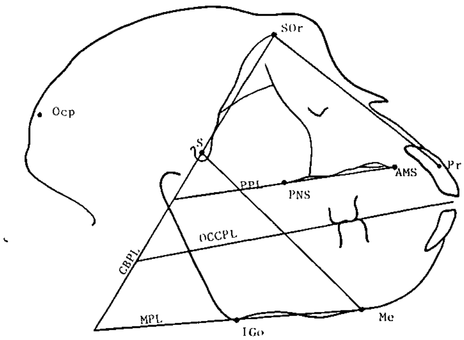

Fig. 1 Landmarks and planes employed in cephalometric analysis: Landmarks: S, sella; SOr, supraorbital; IGo, infragonion; Me, menton; PNS, posterior nasal spine; AMS, anterior maxillary spine; Pr, prosthion and Occp, occipital implant. Planes: CBPL, cranial base plane (SOr-S); MPL, mandibular plane (Igo-Me); PPL, palatal plane (AMS-PNS); OccPL, occlusal plane (line bisecting incisal surfaces and first molar cusps) and FP, facial plane (SOr-Pr).

Cephalometric Measurements

Cephalometric measurements were confined to right lateral tracings because side to side movements of the monkeys' heads made superpositioning of the P-A films impossible. A number of the cephalometric landmarks and planes used in primate studies and in orthodontics were established on tracings of the right lateral films (Fig. 1). The nature, location, and magnitude of changes were determined by superpositioning serial tracings on sella, on the implants at prosthion and occipitale, and on the palatal outlines.

Measurements of the angles between the anterior cranial base plane (SOr-S) and of other craniofacial planes were then made to reveal the effects of heavy interrupted forces to the maxillae (Table III). The gross skulls and histological slides were visually examined and also photographed.

Findings

From the longitudinal study of the plaster casts, the amalgam implants and the cephalometric tracings, to-

TABLE III

ANGULAR MEASUREMENTS FROM RIGHT LATERAL CEPHALOGRAMS

Angle	*Monkey "B" (Expt.) (degrees)*	*Monkey "C" (Control) (degrees)*
MPL		
Beginning	44.0	56.0
End	51.0	55.0
Occ PL		
Beginning	41.0	49.0
End	46.0	48.0
PPL		
Beginning	48.0	52.0
End	60.0	52.0
FP		
Beginning	82.0	83.0
End	74.0	84.0
Y Axis		
Beginning	88.0	105.0
End	97.0	106.0

gether with the comparative examination of the gross and histological specimens, it was possible to reconstruct the effects of retractive orthopedic forces on the maxillae.

Tooth Movement

First, there was marked distal movement of the maxillary cuspid, premolar and molar teeth. This was manifest in the posterior movement of the maxillary first molars in relation to the mandibular molars (Table I). It was indicated by the osteoclastic activity and distal resorption apparent in histological sections of the cuspid area. And it was grossly evident from the development of a maxillary anterior crossbite (Fig. 2), posterior crossbite and a severe Class III molar relationship.

A decided resorption of both the buccal and lingual aspects of the maxillary alveolar bone was associated with these changes. Another indirect effect of cervical retraction was a significant flaring of both the maxillary and mandibular incisors. This was reflected in the increased length of both the maxillary and the mandibular arches (Table I).

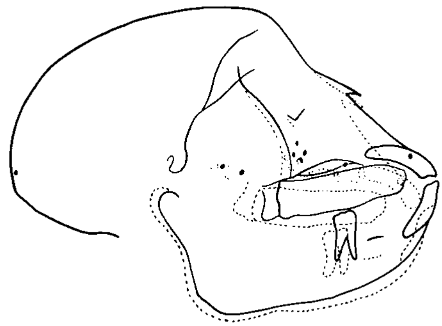

Fig. 2 Serial tracings with superposition on sella of the experimental monkey B.

Maxillary Movement

In contrast to the normal downward and forward movement consistently observed in the control animal, there was a definite downward and backward movement of the maxillary base in the experimental animals. This movement was manifest in an increased maxillary primate space (Table I), and in the diminished distances measured across the zygomaticotemporal and zygomaticomaxillary sutures (Table II). Downward and backward movement of the maxillae was particularly evident from the serial cephalometric tracings superimposed on sella, on the implants and on the palatal outlines (Figs. 2-7). Increases in the angles of the occlusal plane and the palatal plane with the cranial base also signified a downward movement of the maxillae (Table III). The marked increase in the palatal plane angle probably represented a rotation of the anterior portion downward and of the posterior portion upward.

Further evidence for the downward and backward movement of the maxillae was also evident from a sliding of the zygomaticotemporal sutures over one another, from closure of the pterygomaxillary fissure and the impingement of the third molars on the pterygoid plates.

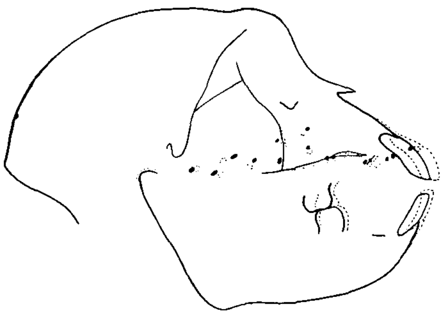

Fig. 3 Serial tracings with superposition on sella of the control monkey C.

Compensatory Movements

The movement of the maxillary teeth and of the maxillary base induced adaptive changes in other segments of the craniofacial complex. While there was no distal movement of the mandibular posterior teeth with respect to the mandibular primate space (Table I), there was a marked downward and backward movement of the mandible itself. This was observed on the cephalometric tracings superpositioned on sella (Figs. 2, 3). It was also seen in an increase of the mandibular plane angle and of the Y axis (Table III).

Downward and backward rotation of the mandible was also evident upon gross inspection of the skulls by the depression of the coronoid processes below the zygomatic arch and the slight forward displacement of the condyles. Pressure upon the condyle was manifested by slight resorption of its superior surface and at the insertion of the lateral pterygoid muscle.

Posterior movement of the premaxilla was detected by the diminished distance from prosthion to occipitale (Table II). The decrease in the facial plane angle also indicated posterior movement of the premaxilla (Table III). Superpositioning the cephalometric tracings on sella and on the implants at prosthion and occipitale generally showed a downward as well as backward movement of the premaxilla (Figs. 2, 4, 6). These changes were visualized as a flattening of the facial profile from the nasal opening to the maxillary incisors.

Superpositioning the tracings on the implants showed that the maxillary segment with the appliance moved posteriorly more than prosthion on the premaxilla (Fig. 4). Diminished movement of the premaxilla was also indicated by the increase in maxillary primate space and the lengthening of the maxillary arch (Table I).

The retractive force imposed on the malar bones was reflected in the diminished implant distance across the zygomaticomaxillary and the zygomaticotemporal sutures (Table II) and the sliding of the zygomaticotemporal sutures over one another. It was also suggested by the increased concavity of the lower borders of the zygomatic arches and the marked adaptive increase in bizygomatic width despite a stable midpalatal suture.

Fig. 4 Serial tracings with superposition on the implants of the experimental monkey B.

Fig. 5 Serial tracings with superposition on the implants of the control monkey C.

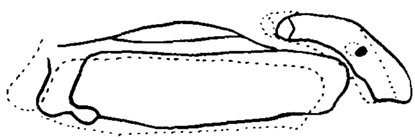

Fig. 6 Serial tracings with superposition on the palate of the experimental monkey B.

Fig. 7 Serial tracings with superposition on the palate of the control monkey C.

Downward and backward movement of the nasal bones also occurred as an adaptive change.

Nonmovement of the Cranial Base

Despite an increase in vascularity and in osteoclastic activity at craniofacial sutures in the experimental animals, there was no evidence of change in the anterior craniofacial base. Most significantly, there was no evidence for movement either in the pterygoid processes or the body of the sphenoid itself. Rather the impingement of the tuberosity on the pterygoid plates induced marked osteoclastic activity and resorption both in the tuberosity and through one area of the plate.

Discussion

The craniofacial movements induced in this study were generally more marked than those observed clinically since the experimental forces were heavier, applied longer, and imposed on smaller areas. Nevertheless, the absence of inflammatory reaction in any of the areas examined histologically indicates that the experimental forces were well within biological tolerance.

The generalized resorption of bone at the craniofacial sutures observed in this study emphasized the far-reaching impact of cervical retraction of the maxillae. Unlike the findings of Sproule[19] the frontomaxillary and zygomaticofrontal sutures showed very active resorption in this investigation (Figs. 8, 9). This difference could stem from his use of growing animals and a more vertical component of force from headgear therapy.

Previous suggestions[17,20] that retraction of the maxillae moves the pterygomaxillary fissure posteriorly at the expense of the pterygoid plates was not confirmed by this study. Rather, retrusion of the maxillae was accompanied by closure of the pterygomaxillary fissues and resorption of both the tuberosity and of the pterygoid plates. The possible harmful effects of moving the maxillae too far posteriorly and thus impinging on vital structures in the pterygopalatine fossa must be considered in clinical therapy.

The report of increased resorption in the roof of the glenoid fossa and the anterior surface of the postglenoid tubercle[19] could not be confirmed by this study. The relative inactivity in this region, in fact, challenges the claims of altered condylar patterns resulting from cervical retraction of the maxillae.

Summary and Conclusions

Heavy, interrupted orthopedic forces were employed for the cervical retraction of the maxillae in two Macaca mulatta monkeys. The nature, location and magnitude of resultant movements and remodelling were studied with the help of plaster casts, amalgam implants, lateral cephalometric tracings, and of gross and microscopic study of the skulls themselves.

The principal effect of the retractive force was a marked downward and backward rotational movement of the maxillae which carried the maxillary teeth into posterior crossbite and a severe Class III molar relationship. Posterior movement of the tuberosity entirely closed the pterygomaxillary fissure so that the tuberosity impinged upon the pterygoid plates.

Like the maxillae, the mandible, premaxilla, and nasal bones also moved downward and backward. These changes increased the vertical dimension of the face and diminished it hori-

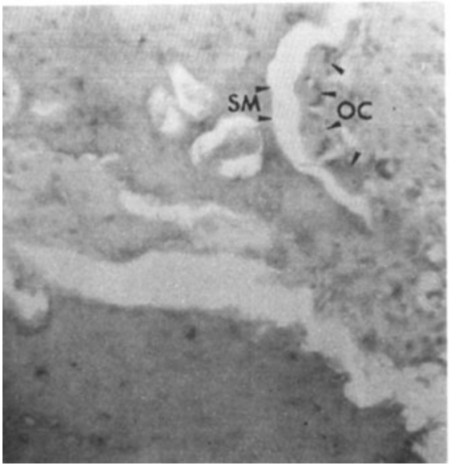

Fig. 8 A photomicrograph of a coronal section through the frontozygomatic suture of the experimental monkey B. Note osteoclasts (OC) and cupping at the suture margin (SM).

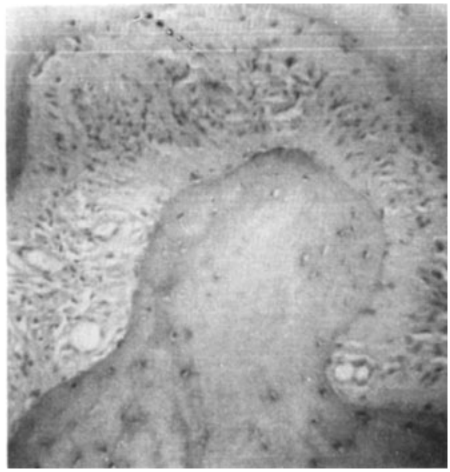

Fig. 9 A photomicrograph of a coronal section through the frontozygomatic suture of the control monkey C. This suture demonstrates normal activity.

zontally leaving a flattened facial profile from the nasal opening to the maxillary incisors.

Movement of facial elements posteriorly against an unyielding anterior cranial base imposed a number of other compensatory changes. These included generalized resorption at the craniofacial sutures and sliding of the sutures upon each other. They also involved mutual resorption of the maxillary tuberosity and of the pterygoid plates together with remodelling and lateral extension of the malar bones.

Tolerance of the animals and of the localized tissues for these intensive forces suggests a significant role for this form of therapy. Clinical application, however, should be tempered by judicious concern for the vital structures of the pterygomaxillary fissure which could be impinged or strangulated by excessive retrusive force.

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Bibliography

1. Björk, A.: Facial growth in man studied with the aid of metallic implants, *Acta Odontol. Scand.*, 13:9-34, 1955.
2. Droschl, H.: The effect of heavy orthopedic forces on the maxilla in the growing Saimiri sciureus (squirrel monkey), *Am. J. Orthod.*, 63:449-461, 1973.
3. Epstein, W. N.: Analysis of changes in molar relationships by means of extra-oral anchorage (head-cap) in treatment of malocclusion, *Angle Orthod.*, 18:63-69, 1948.
4. Gans, B. J. and Sarnat, B. G.: Sutural facial growth of the Macaca rhesus monkey: A gross and serial roentgenographic study by means of metallic implants, *Am. J. Orthod.*, 37:827-841, 1951.
5. Graber, T. M.: Extra-oral force—facts and fallacies, *Am. J. Orthod.*, 41:490-505, 1955.
6. Graber, T. M., Chung, D. D. B., and Aoba, J. T.: Dentofacial orthopedics versus orthodontics, *J. Am. Dent. Assoc.*, 75:1145-1166, 1967.
7. Haas, A. J.: Palatal expansion: Just the beginning of dento-facial orthopedics, *Am. J. Orthod.*, 57:219-255, 1970.
8. King, E. W.: Cervical anchorage in Class II, Division 1 treatment, *Angle Orthod.*, 27:98-104, 1957.

9. Klein, P. L.: An evaluation of cervical traction on the maxilla and the upper first permanent molar, *Angle Orthod.*, 27:61-68, 1957.
10. Kloehn, S. J.: Guiding alveolar growth and eruption of teeth to reduce treatment time and produce a more balanced denture and face, *Angle Orthod.*, 17:10-33, 1947.
11. ———: Orthodontics—force or persuasion, *Angle Orthod.*, 23:56-65, 1953.
12. Moore, A. W.: Observations on facial growth and its clinical significance, *Am. J. Orthod.*, 45:399-423, 1959.
13. Oppenheim, A.: Biologic orthodontic therapy and reality, *Angle Orthod.*, 6:153-183, 1936.
14. Poulton, D. R.: The influence of extraoral traction, *Am. J. Orthod.*, 53: 8-18, 1967.
15. Ricketts, R. M.: The influence of orthodontic treatment on facial growth and development, *Angle Orthod.*, 30:103-133, 1960.
16. Ringenberg, Z. M. and Butts, W. C.: A controlled cephalometric evaluation of single-arch cervical traction therapy, *Am. J. Orthod.*, 57:179-185, 1970.
17. Sandusky, W. C.: Cephalometric evaluation of the effects of the Kloehn type of cervical traction used as an auxiliary with the edgewise mechanism following Tweed's principles for correction of Class II, Division 1 malocclusion, *Am. J. Orthod.*, 51:262-287, 1965.
18. Sassouni, V.: Dentofacial orthopedics: A critical review, *Am. J. Orthod.*, 61:255-269, 1972.
19. Sproule, W. R.: Dentofacial changes produced by extraoral cervical traction to the maxilla of the Macaca mulatta: A histologic and serial cephalometric study (abst.), *Am. J. Orthod.*, 55:531-532, 1969.
20. Wieslander, L.: The effect of orthodontic treatment on the concurrent development of the craniofacial complex, *Am. J. Orthod.*, 49:15-27, 1963.