Response of the Midface to Treatment with Increased Vertical Occlusal Forces

treatment and posttreatment effects in monkeys

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Posterior occlusal bite blocks of varying thicknesses inserted in seven juvenile and six adolescent monkeys resulted in changes in maxillary position and dental intrusion.

KEY WORDS: • FUNCTIONAL APPLIANCE • GROWTH • OCCLUSAL FORCE •

Since ancient times, man has frequently shown interest in changing the craniofacial morphology for cultural and esthetic purposes (Fig. 1). In recent times, considerable attention has been focused on the response of maxillary position to orthodontic and orthopedic forces applied to the maxillary teeth. Experimental work has shown that forces applied to the teeth create tensile and compressive deformations and strains in the adjacent bones (ENDO 1970, HENRY 1973, FISHER ET AL. 1976, BROUSSEAU AND KUBISCH 1977, BRANDT ET AL. 1979, KRAGT ET AL. 1979, ALTUNA 1982). Primate experiments indicate that maxillary position is changeable and the circum-maxillary sutures are affected by forces applied to the maxillary teeth. It has also been shown that the maxilla can be displaced posteriorly as well as anteriorly (DELLINGER 1973, KAMBARA 1977, NANDA 1978, JACKSON ET AL. 1979) with the use of fixed orthodontic appliances.

Previous studies of the effects of functional appliances on maxillary position have not evaluated the force levels created within the stomatognathic system by different vertical openings used in the various types of functional appliances, the significance of changes in direction of occlusal forces generated by vertical open-

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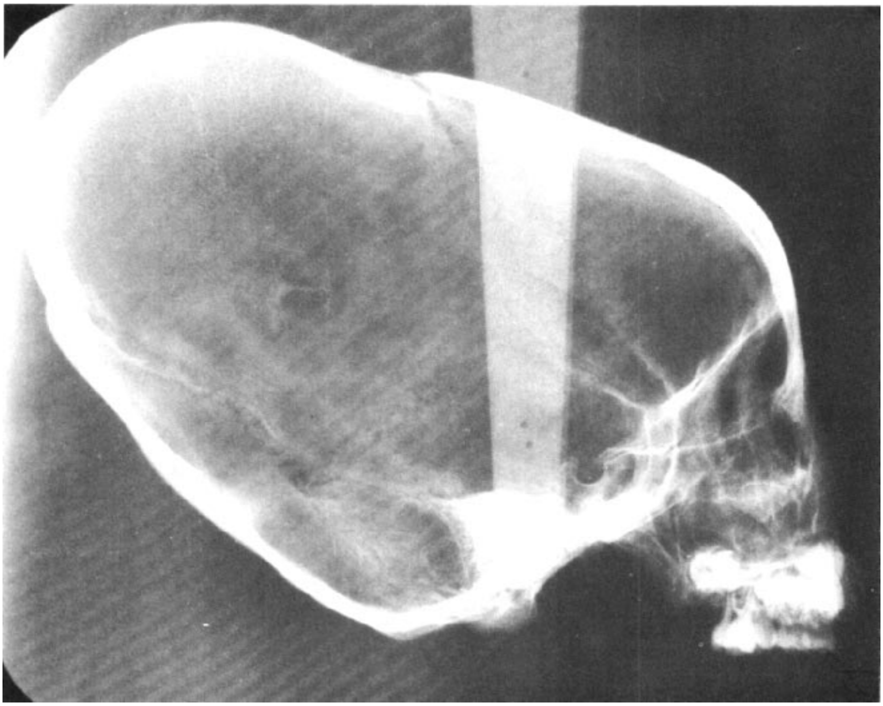

Fig. 1 **Cephalometric radiograph of human skull from Mexico which has been warped for esthetic and cultural purposes.**
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ings, and their effects on maxillary position (Harvold and Vargervik 1971, Sergl and Framand 1975, Woodside et al. 1975, McNamara 1977, Lundström and Woodside 1980, Brechtold et al. 1981).

Posterior occlusal bite blocks are one type of functional orthodontic appliance which has been used clinically at the University of Toronto since 1962 to reduce anterior open bite associated with excessive lower anterior face height. Correction is achieved by inhibition of buccal segment tooth eruption, creating an upward and forward autorotation of the mandible or a more horizontal mandibular growth direction. The thickness of the bite blocks usually exceeds the freeway space by 3mm–4mm., although larger dimensions have been used in the past. Patients wear such appliances continuously, and are encouraged to eat with them in place. In a preliminary primate experiment, Altuna and Woodside (1977) have reported that such posterior occlusal bite blocks can create dramatic change in maxillary position as well as arrest of buccal tooth eruption.

The present study is a sequel to the above report, designed to test the effects of different vertical openings of bilateral posterior bite blocks on maxillary position of juvenile and adolescent primates. The stability of these changes in the posttreatment period is also examined.

— Material and Method —

Thirteen *Macaca fascicularis* monkeys, twelve females and one male, were used in these experiments (Tables 1 and 2). The monkeys were divided into two age groups, juvenile and adolescent, based on ages determined from the tables of Hurme and Van Wagenen(1953 and 1961) and Schultz (1969). The animals in the juvenile group were approximately 24-36 months old, and those in the adolescent group approximately 48-60 months old. Special care was taken in the selection of the monkeys for each age group so that their dentitions exhibited rather uniform stages of eruption. In the juvenile group, the permanent first molars and incisors were present and the remaining teeth were mostly deciduous teeth; in the adolescent group, all the permanent teeth were present and the molars were erupting.

Metal implants were inserted on the left side of the maxilla, on the mandible, on the midline of the cranium, and the cranial base, using the methods of Björk (1955 and 1972) and McNamara (1972),. Amalgam fillings were placed on the left maxillary and mandibular molars.

The experimental period ranged from 14 weeks to 68 weeks, with the first 14-32 weeks for each animal used as a control period. The next 18 weeks comprised the experimental period, followed by removal of the appliances and an 18-week post-experimental period. The control period for one animal was only 8 weeks long, so this control period was not included in the study.

Table 1

Juvenile Group, Age 2-3 years
Superimposition on Anterior Cranial Base Implants
Vertical and Horizontal Increments of Change
as Measured at the Posterior Maxillary Implant
Millimeters

Serial Number	Age in Years	Bite block Thickness (mm)	Time in Weeks Control	Exp.	Post Treat.	POSTERIOR MAXILLARY IMPLANT HORIZONTAL Control	Exp.	Post Treat.	VERTICAL Control	Exp.	Post Treat.
873	2-3	12.0	14	18	18	1.20	4.86	1.70	0.69	-1.69	0.64
222	2-3	8.0	14	18	18	1.38	3.03	0.41	0.23	-1.60	0.74
202	2-3	8.0	14	18	-	1.18	3.52	-	0.25	-1.88	-
50	2-3	2.0	32	18	18	2.39	0.31	1.91	1.66	-0.38	0.81
819	2-3	Control	14	-	-	0.93	-	-	0.44	-	-
819	2-3	Control	32	-	-	2.62	-	-	1.21	-	-
271	2-3	Control	14	-	-	1.37	-	-	0.76	-	-
955	2-3	Control	14	-	-	0.91	-	-	0.23	-	-

\+ indicates Forward or Downward change
— indicates Backward or Upward change

The animals were fully documented at the beginning and at the end of each period. The details of the methodology were the same as described by ALTUNA (1979).

Impressions of the maxilla and the mandible were taken with specially designed trays, and bite registrations with 2.0mm, 8.0mm, and 12.0mm thicknesses were made for each animal. The casts were fixed on an articulator and bite blocks were carved out of wax. Special care was taken to make the occlusal surfaces flat. Chrome-cobalt castings made from the waxed bite blocks were cemented to the maxillary dentition of each animal. Ligature wires were used to also tie the castings to the teeth. The appliances were equilibrated in the mouth to make sure that there was maximal contact of all the posterior teeth with the appliance. (Fig. 2)

A grid system was used to assess the changes in morphology and position of the various facial bones in respect to the cranial base. Tracings of the cranium, cranial base, midface, maxillary dentition and the metallic implants were made from all cephalographs. The tracings were then superimposed on the best fit of the anterior cranial base and the endocranial contours. The metallic implants in the cranium and the sphenoid bone were used to assist in the superimpositions, but it was not possible to use those implants in the occipital bone because of growth changes.

The sella–nasion line was drawn on the initial tracing of each series. A perpendicular to this line was then drawn

Table 2

Adolescent Group, Age 4-5 years
Superimposition on Anterior Cranial Base Implants
Vertical and Horizontal Increments of Change
as Measured at the Posterior Maxillary Implant
Millimeters

						POSTERIOR MAXILLARY IMPLANT					
						HORIZONTAL			VERTICAL		
Serial Number	Age in Years	Bite block Thickness (mm)	Time in Weeks Control	Exp.	Post Treat.	Control	Exp.	Post Treat.	Control	Exp.	Post Treat.
330	4-5	12.0	14	18	18	0.86	3.24	0.17	0.27	-0.99	0.53
483	4-5	8.0	14	18	18	0.79	3.04	0.97	0.23	-1.22	0.33
30	4-5	8.0	-	18	-	-	3.23	-	-	-1.79	-
871	4-5	2.0	32	18	18	0.73	0.60	0.23	0.34	-0.71	0.36
492	4-5	Control	32	-	-	1.14	-	-	0.36	-	-
492	4-5	Control	14	-	-	0.64	-	-	0.18	-	-
329	4-5	Control	14	-	-	0.51	-	-	0.25	-	-

+ indicates Forward or Downward change
– indicates Backward or Upward change

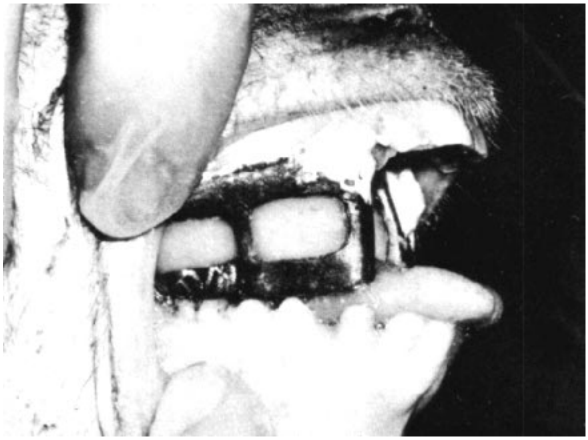

Fig. 2 Monkey with 12.0mm posterior occlusal bite block

through the sella point. The S–N horizontal and vertical lines were then transferred from the initial cephalograph to each remaining cephalograph of the series, which had been superimposed as described above. Thus, the skeletal changes were measured against the template of the initial cephalograph and the increments of change in the vertical and horizontal planes between the cephalographs were calculated by subtraction.

The same type of template was used to assess the maxillary dentoalveolar changes. In the initial tracing, a reference line was drawn on the occlusal surfaces of the maxillary dentition and a perpendicular was drawn to this line. The remaining tracings of each series were superimposed on the maxillary implants, and the occlusal reference plane and the vertical plane transferred from the initial cephalograph of the series by registering on the implants of the maxilla. Dentoalveolar changes were then measured against the template of the initial cephalograph and the increments of change in the vertical and horizontal planes calculated by subtraction.

The direction of the biting forces was assessed by the angle formed between the line drawn on the occlusal surfaces of the maxillary teeth and the occlusal plane of the bite blocks (Beta angle (β)). In addition, a line was drawn from the center of the amalgam fillings of the mandibular first permanent molars to the bifurcation point and the angle between this line and the occlusal plane was also measured (Alpha angle (α)). This measurement was taken both before and immediately after the insertion of the bite blocks (Figs. 3 and 4).

All measurements were made with an optical digitizer by the same investigator at least three different times, and the average values then used.

Inter-investigator and intra-investigator error studies to determine errors involved in measuring the distances and angles between metal implants, between metal implants and skeletal points, and between skeletal points showed a method error less than 0.3mm (Altuna 1979).

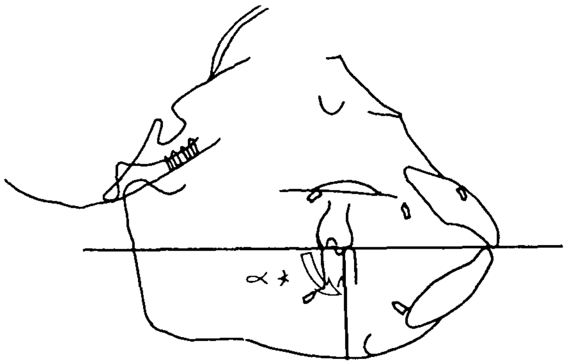

Fig. 3
α angle, measured between the axis of the lower first molar and the original occlusal plane, before insertion of the bite block

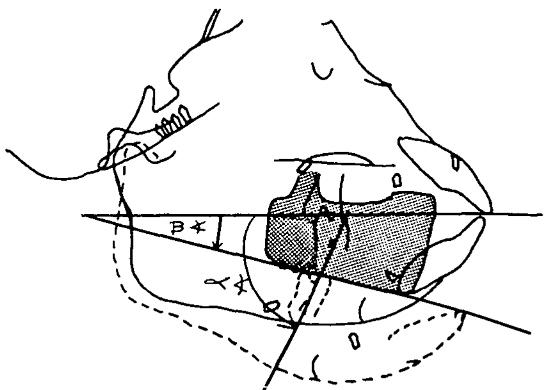

Fig. 4
β angle, between original occlusal plane and new occlusal plane of the bite block, and the α angle with bite block in place

— Results —

Skeletal Changes

The translation of the midface during normal growth was determined by measuring the changed positions of the posterior maxillary implant relative to the implants in the anterior part of the cranial base. In both the juvenile and the adolescent groups, the maxilla translated horizontally, with minimal vertical displacement (Tables 1 and 2) (Figs. 5–8)

During the 18-week experimental period, in those animals with 8.0mm and 12.0mm bite blocks, the movement of the posterior maxillary implant indicated that the maxilla was displaced in a forward and upward direction in relation to the cranial implants.

This displacement was 2 to 3 times more than seen at the end of the control period for the juvenile group, and 2 to 4 times more for the adolescent group.

Two animals, one juvenile and one adolescent, were fitted with bite blocks only 2.0mm thick. After the 18-week experimental period, the forward displacement of the maxilla in both of these animals

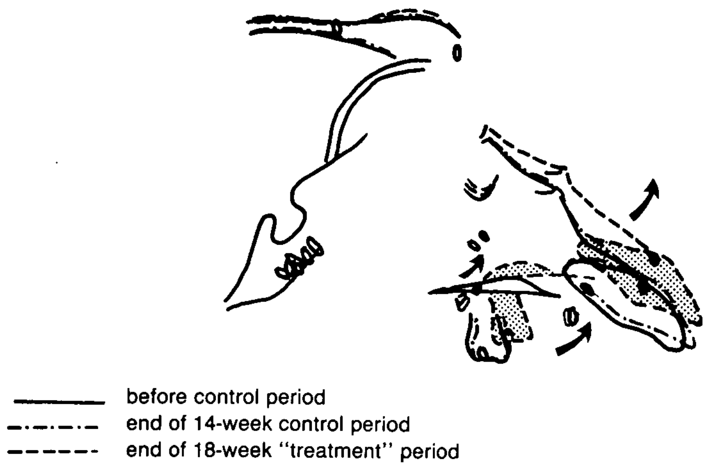

Fig. 5 Overall superimposition on the anterior cranial base implants of an adolescent animal with a 12.0mm bite block. Arrows indicate the directions of movement during the control and experimental periods.

Table 3

Juvenile Group, Age 2-3 years
Superimposition on Maxillary Implants

Vertical and Horizontal Increments of Change
as Measured at First Permanent Molar Amalgams
Millimeters

						FIRST PERMANENT MOLAR TEETH					
Serial	Age in	Bite block Thickness	Time in Weeks			HORIZONTAL			VERTICAL		
Number	Years	(mm)	Control	Exp.	Post Treat.	Control	Exp.	Post Treat.	Control	Exp.	Post Treat.
873	2-3	12.0	14	18	18	0.36	1.27	0.18	0.48	-1.35	0.81
222	2-3	8.0	14	18	18	0.33	1.20	0.45	0.21	-0.78	0.41
202	2-3	8.0	14	18	-	0.40	0.71	-	0.33	-1.61	-
50	2-3	2.0	32	18	18	0.62	0.21	0.58	0.73	-0.42	0.89
819	2-3	Control	14	-	-	0.21	-	-	0.17	-	-
819	2-3	Control	32	-	-	0.32	-	-	0.23	-	-
955	2-3	Control	14	-	-	0.21	-	-	0.19	-	-
271	2-3	Control	14	-	-	0.31	-	-	0.21	-	-

+ indicates Forward or Downward change
− indicates Backward or Upward change

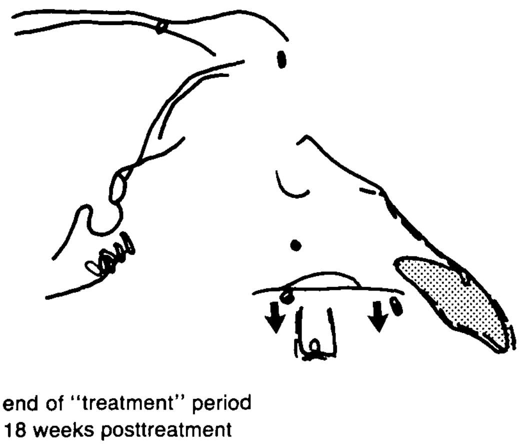

Fig. 6 Overall superimposition on the anterior cranial base implants of an adolescent animal during the post-experimental period, after the removal of the 12.0mm bite block.

Table 4

Adolescent Group, Age 4-5 years
Superimposition on Maxillary Implants
Vertical and Horizontal Increments of Change
as Measured at First Permanent Molar Amalgams
Millimeters

Serial Number	Age in Years	Bite block Thickness (mm)	Time in Weeks Control	Exp.	Post Treat.	FIRST PERMANENT MOLAR TEETH HORIZONTAL Control	Exp.	Post Treat.	VERTICAL Control	Exp.	Post Treat.
330	4-5	12.0	14	18	18	0.18	1.14	0.15	0.13	-2.31	1.18
483	4-5	8.0	14	18	18	0.35	0.60	0.23	0.30	-2.52	1.09
30	4-5	8.0	-	18	-	-	0.64	-	-	-1.91	-
871	4-5	2.0	32	18	18	0.21	0.15	0.25	0.32	-0.35	0.46
492	4-5	Control	14	-	-	0.19	-	-	0.16	-	-
492	4-5	Control	32	-	-	0.36	-	-	0.28	-	-
329	4-5	Control	14	-	-	0.15	-	-	0.38	-	-

+ indicates Forward or Downward change
− indicates Backward or Upward change

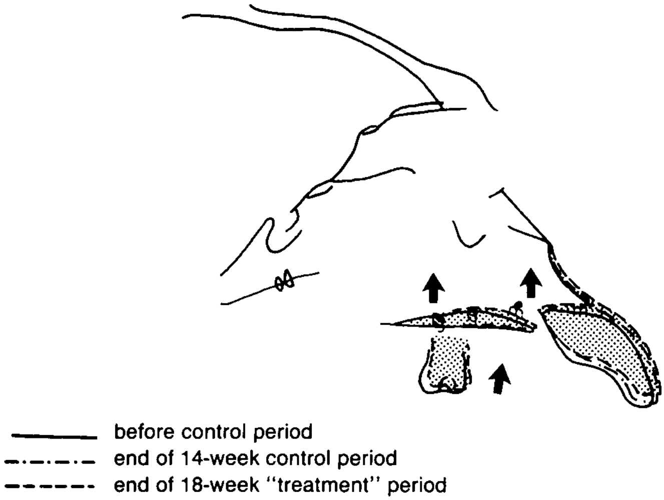

Fig. 7 Overall superimposition on the anterior cranial base implants of an adolescent animal with a 2.0mm bite block. Arrows indicate the directions of movement during the control and experimental periods.

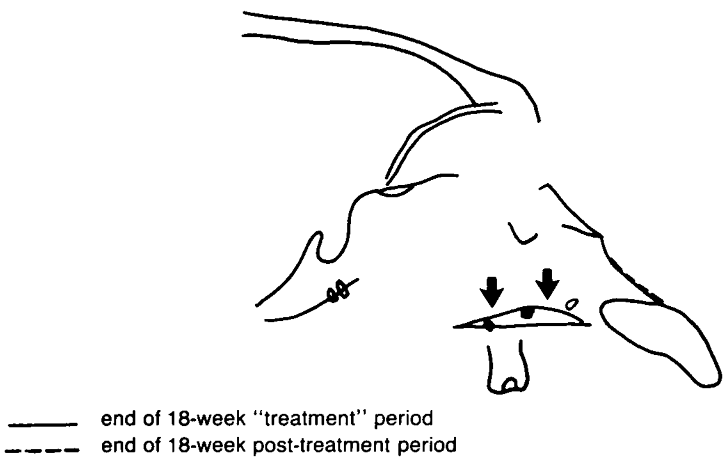

Fig. 8 Overall superimposition on the anterior cranial base implants of an adolescent animal during the post-experimental period, after the removal of the 2.0mm bite block.

was less than that recorded after the 14-week control period.

The bite blocks were removed at the end of the 18-week experimental period in three juvenile and three adolescent animals. In the following 18 weeks, the growth that took place was documented and the stability of the changes resulting from the wearing of the bite blocks was assessed. During the experimental period, the maxilla was displaced in an upward direction. In the posttreatment period, the growth was once again in a downward and forward direction. After the 18-week posttreatment period, the vertical displacement, as measured at the posterior maxillary implants relative to the cranial base implants, was almost twice as much as that observed during the 14-week period for most of the animals.

Maxillary Dentoalveolar Changes

During the 14-week control period, there was a downward and forward migration of the maxillary first molars. This forward migration was minimal in both groups (Tables 3 and 4).

During the 18-week experimental period, the maxillary first permanent molar was intruded or its eruption inhibited in all experimental animals. This intrusion was greatest in the adolescent group and least in the juveniles. The intrusion was least in the group with 2.0mm bite blocks and it was largest in the groups with 8.0mm and 12.0mm bite blocks.

The mesial movement of the maxillary first permanent molars in the groups with 8.0mm and 12.0mm bite blocks was 1 to 3 times more during the experimental period than during the control period. In the group with 2.0mm bite blocks, the mesial movement of the maxillary first permanent molars was proportionately less.

During the 18-week posttreatment period, the maxillary first permanent molars were extruded more than that which was observed during the 14-week control period.

Direction of Biting Forces

Before the insertion of the bite blocks, the observed direction of the biting force was primarily in a vertical direction (β 0°, α 85°–92°). The 8.0mm and 12.0mm bite blocks added a horizontal component to the biting force (β 9°–14°, α 50°–75°) (Figs. 3 and 4). The insertion of the 2.0mm bite block brought about no noticeable change in the direction of the biting force (β 1°, α 85°–89°).

— Discussion —

The authors are aware that there are inherent limitations in the application of findings from primate studies to human therapy. In spite of these limitations, nonhuman primates provide the best available model for the investigation of the effects of some orthodontic appliances. With the help of cephalometrics, histology and electromyography, the results can provide a clearer understanding of the basic biological principles underlying the etiology of malocclusion.

The results of this study show that maxillary position is highly plastic and easily changed by the forces created by the insertion of posterior occlusal bite blocks of varying thickness in both juvenile and adolescent animals. Those with 8.0mm and 12.0mm bite blocks showed 3 to 6 times more forward maxillary translation relative to the cranial base than was observed during the control period (Figs. 5 and 6).

In addition, the usual downward growth of the maxilla was redirected upward in a rotational manner, with the upward displacement of the anterior segments larger than that seen in the posterior segments. Upward vertical displacement of the maxilla has been reported in clinical patients with the Milwaukee brace (THORS 1964, ALEXANDER 1966) and in animal experiments with posterior occlusal bite blocks (SERGL 1975, MCNAMARA 1977, HURME 1953). The results of this study support the above findings.

In contrast to the above findings and the work of others, the animals wearing 2.0mm bite blocks showed less forward maxillary translation in the experimental period than during the control period, while in the vertical plane the normal downward growth of the maxilla was changed to an upward direction (Figs. 7 and 8) This difference in maxillary response to different levels of vertical opening of the jaws indicates that the direction of occlusal force delivery may influence maxillary position. With the insertion of bite blocks, ranging from 8.0mm to 12.0mm in thickness, an anterior component is added to the occlusal forces. However, in the animal wearing a 2.0mm bite block, the direction of occlusal forces is not changed by the appliance.

These results show that the direction of occlusal forces is an important factor in change in maxillary position, and this should be taken into consideration in functional appliance treatment planning. Some orthodontic appliances used on patients during the course of orthodontic treatment may change the direction of the occlusal forces delivered to the jaws. This change should be analyzed in each individual case prior to the placement of functional appliances.

The results of this study also indicate the importance of the vertical distance between the maxillary teeth and the circum-maxillary sutures and the cranial base. In monkeys, the circum-maxillary sutures are nearer to the maxillary first permanent molars than they are in humans; therefore, forces applied to the maxillary teeth are much more directly transmitted to the sutures. On the other hand, according to BJÖRK AND SKIELLER (1976), the maxillary molars in man at the age of 13 are almost 12.0mm to 14.0mm further away from the cranial base and the circum-maxillary sutures than they were at the age of 7 to 8 years. One might speculate then that the chances of affecting the circum-maxillary sutures may be better in younger subjects.

Histological analysis showed that the midfacial complex was displaced anteriorly by sutural modifications in growing and in young adult animals. At the end of the 18-week experimental period, the fibers in the zygomatico-temporal and the zygomatico-frontal sutures of the experimental animals showed some isolated areas of hyalinization, but there was no ankylosis of the sutures. These results support the findings of KAMBARA (1977) AND NANDA (1978).

There was a marked difference between the juvenile and adolescent animals in the amount of buccal tooth intrusion achieved with the bite blocks. The juvenile animals showed arrest of tooth eruption and slight intrusion, while the older animals showed extensive intrusion of buccal teeth in both arches. This difference between the two age groups is probably due to two factors —

First, inhibition of eruption in animals where the teeth are normally erupting rapidly produces a relative intrusion and minimizes the need for actual intrusion.

Second, the maxillary translations may occur more rapidly in the younger animals, thus relieving the dentoalveolar region of the large occlusal forces.

The 18-week post-experimental period showed clearly that the maxillary translations which occurred during the experimental period were not reversed, indicating that a chronic environmental impact to the maxilla can produce a dramatic change in maxillary position which is not subsequently reversed (Figs. 6 and 8).

The findings show that manipulation of the vertical dimension can be an important factor in the achievement of mesiodistal occlusal changes, and this should be taken into consideration in functional appliance therapy. The use of posterior occlusal bite blocks resulted in dramatic skeletal changes in the anteroposterior and vertical position of the maxilla, with the direction of these changes varying with different vertical openings.

— Conclusions —

- Maxillary position in both young and adolescent monkeys is highly plastic in response to forces generated by alterations in the facial and masticatory neuromuscular system.
- Maxillary displacement in response to placement of thick posterior occlusal bite blocks occurred in both vertical and horizontal planes. It was rotational in nature, with the anterior portion displaced more than the posterior portion.
- The intrusion of buccal teeth with use of thick posterior occlusal bite blocks occurs more readily in mature animals, whereas the insertion of such bite blocks in growing animals results in inhibition of eruption with relative intrusion.
- A chronically applied environmental impact to the maxilla can create change in maxillary position which is stable following removal of that impact.

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References

Alexander, R., 1966. The effects on tooth position and maxillo-facial vertical growth during scoliosis treatment with the Milwaukee brace: An initial study. *Am. J. Orthod.* 52:161-189.

Altuna, G., and Woodside, D. G., 1977. Die Auswirkung von Ausbissblocken in Oberkiefer bei Macaca rhesus (Vorlaufige Ergebnisse), *Fortschr. Kieferorthop.* 38:391-402.

Altuna, G.

1979. The effects of excess occlusal force on the eruption of the buccal segments and maxillary and mandibular growth direction in the Macaca monkey, M. Sc. thesis, University of Toronto, Toronto, Canada.

1982. Measurement of the strains in the alveolar bone, Unpublished preliminary experiment.

Björk, A.

1955. Facial growth in man studied with the aid of metallic implants, *Acta. Odont. Scand.* 13:9-34.

Björk, A., 1972. Personal communication.

Björk, A., and Skieller, V., 1976. Postnatal growth and development of the maxillary complex, in *Factors Affecting the Growth of the Midface*, McNamara, J. A., Jr., ed., Monograph 6, Craniofacial Growth Series, Center for Human Growth and Development, The University of Michigan, Ann Arbor.

Brandt, H. C., Shapiro, P. A. and Kokich, V. G., 1979. Experimental and post-experimental effects of posteriorly directed extraoral traction in adult Macaca fascicularis, *Am. J. Orthod.* 75:301-17.

Brechtold, H., Glaiber, W., Kiegele, E., Rheinheimer, R., Rosch, D., Rosch-Tozzi, F., Straub, H., and Wagenmann, J., 1981. Veranderungen im Fernröntgenbild nach der Behändlung von Klasse II/1 Fallen mit dem Aktivator oder mit aktivatorahe Lichen Geraten, *Fortschr. Kieferorthop.* 42:375-85.

Brousseau, M. and Kubisch, G. W., 1977. Continuous versus intermittent extraoral traction: An experimental study, *Am. J. Orthod.* 71:607-21.

Dellinger, L. E., 1973. A preliminary study of anterior maxillary displacement, *Am. J. Orthod.* 63:509-16.

Endo, B., 1970. Analysis of stresses around the orbit due to masseter and temporalis muscles respectively. *J. Anthrop. Soc. Nippon* 78(4):251-66.

Fisher, J. L., Godfrey, K., and Stephens, R. I., 1976. Experimental strain analysis of infant, adolescent and adult miniature swine skulls subjected to simulated mastication forces. *J. Biomechanics* 9:333-38.

Harvold, E. P., and Vargervik, K., 1971.Morphogenetic response to activator treatment, *Am. J. Orthod.* 60:478-89.

Henry, L. H., 1973. Craniofacial changes induced by 'orthopedic forces' in the Macaca mulatta rhesus monkey, M.S.D. thesis, University of Manitoba.

Hurme, V. O., and Van Wagenen, G.

1953. Basic data on the emergence of deciduous teeth in the monkey (Macaca mulatta). *Proc. Am. Philo. Soc.* 97:291-315.

1961. Basic data on the emergence of permanent teeth in the rhesus monkey (Macaca mulatta). *Proc. Am. Philo. Soc.* 105:105-40.

Jackson, G. W., Kokich, V. G., and Shapiro, P. A., 1979. Experimental and post-experimental response to anteriorly directed extraoral force in young Macaca nemestrina. *Am. J. Orthod.* 75:318-33.

Kambara, T., 1977. Dentofacial changes produced by extraoral forward force in the Macaca irus. *Am. J. Orthod.* 71:249-77.

Kragt, G., Ten Bosch, J. J., and Borsbooe, P. C. F., 1979. Measurement of bone displacement in a macerated human skull induced by Orthodontic Forces: A holographic study. *J. Biomechanics* 12:905-10.

Lundström, A., and Woodside, D. G., 1980. Individual variation in growth direction expressed at the chin and the midface. *Eur. J. Orthod.* 2:65-79.

McNamara, J. A., Jr.

1972. *Neuromuscular and skeletal adaptations to altered orofacial function,* Monograph 1, Craniofacial Growth Series, Center for Human Growth and Development, the University of Michigan, Ann Arbor.

1977. An experimental study of increased vertical dimension in the growing face. *Am. J. Orth.* 71:382-95.

Nanda, R., 1978. Protraction of maxilla in rhesus monkeys by controlled extraoral forces. *Am. J. Orthod.* 74:121-41.

Schultz, A. H., 1969. Growth and Development, in *The Anatomy of the Rhesus Monkey,* Hartman, C. G., and Straus, W. L., Jr., eds., New York.

Sergl, H. G. and Framand, M., 1975. Experiments with unilateral bite planes in rabbits. *Angle Orthod.* 45:108-14.

Thors, O., 1964. Compression of facial sutures by external pressure demonstrated by the implant method. *Eur. Orthod. Soc. Rep.* 40:221-32.

Van Ness, A. L., 1978. Implantation of cranial base metallic markers in non-human primates. *Am. J. Phys. Anthrop.* 49:85-90.

Woodside, D. G., Reed, R. T., Doucet, J. D., and Thompson, G. W., 1975. Some effects of activator treatment on the growth rate of the mandible and position of mid-face, *Transactions of the Third International Orthodontic Congress* 459-80. C. V. Mosby Co., St. Louis.