# *An experimental study of increased vertical dimension in the growing face*

**James A. McNamara, Jr., D.D.S., Ph.D.***
*Ann Arbor, Mich.*

Increases in the vertical dimension of the face occur during normal growth, but they can also result from orthodontic intervention. Both transient and permanent alterations in bite opening have been documented as a result of various clinical procedures, such as the use of cervical headgear,[1, 2] intermaxillary elastics,[2, 3] and maxillary bite plates.[4, 5] Thompson and Brodie,[6] among others, have noted muscular alterations and have stated that when the vertical dimension is increased beyond the physiologic limits of the masticatory and facial musculature, the resting length of these muscles is restored through the resorption of underlying bone and the depression of the dentition.

Most experimental studies of bite opening have focused on the effect of bite-opening appliances on the dentoalveolar region.[7-10] Very few studies have considered adaptations elsewhere in the craniofacial complex. One such study that has is that of Sergl and Farmand[11] who, in a cephalometric study on young rabbits, reported that after placement of a unilateral bite splint, compensatory growth occurred to such an extent that the occlusion on the side opposite the splint was restored within the 9-week experimental period. The adaptations produced were not limited to the dentoalveolar region, since cranial asymmetries were evident in these animals.

In a histologic study in the rhesus monkey, Gianelly and associates[12] studied the effect of artificially produced occlusal trauma on the structure of the temporomandibular joint region. A maxillary posterior bite splint was constructed bilaterally, so that occlusal contact was possible only in the molar region. It was

This study was supported, in part, by United States Public Health Service Grants HD-02272, DE-43120, and DE-40227.

*Assistant Professor of Anatomy and Associate Research Scientist, Center for Human Growth and Development, University of Michigan.

reported that traumatic changes in the temporomandibular joint occurred, including both a flattening of the mandibular condyle and resorption in the glenoid fossa and along the posterior aspect of the articular eminence.[12] In a series of other primate studies, Breitner[13-15] investigated changes in the craniofacial region after the placement of a bite splint which was equilibrated so that no occlusal disharmony was produced. He noted the occurrence of adaptations in the dentoalveolar region, including the depression of posterior teeth, the extrusion of anterior teeth, and in one instance an alteration in occlusal relations; changes in the temporomandibular joint, in the gonial region, and along the lower border of the mandible were also noted.

These experimental studies suggest that increases in vertical dimension result in adaptations which are not limited to the dentoalveolar region but, rather, occur throughout the craniofacial complex. However, the exact qualitative nature of these changes, particularly in the maxillary region, has not been fully documented. Nor is it known at present to what degree the expression of these adaptations in the craniofacial region is quantitatively related to the amount of vertical opening. The purpose of the present study was to document craniofacial adaptations resulting from five different step-wise increases in the vertical dimension of the growing face.

## Materials and methods

Five male rhesus monkeys *(Macaca mulatta)* were used in this study. Each animal had a fully erupted deciduous dentition and erupting or erupted first permanent molars. With stages of dentitional development used as a basis for estimating age,[16] these animals were considered to be 18 to 29 months of age at the beginning of the study.

Each monkey was prepared for serial cephalometric analysis before the onset of the experiment. Tantalum implants[17] were placed in various regions of the craniofacial complex. Four to six implants were placed bilaterally in the mandible, and five implants were placed bilaterally in the maxilla. Three implants were placed in the midline of the frontal bone, and four to six pins were placed in the cranial base via an intraoral approach.[18-20] These implants made it possible to monitor growth changes within each craniofacial region and between regions.

Serial cephalometric radiographs were taken (using Kodak Type M industrial film) in a primate head holder that was specially designed for longitudinal studies on monkeys. In order to obtain a better visualization of the temporomandibular joint, two films were taken at each interval, one with the animal's mouth closed and one with the mouth open. Each film was then enlarged three times to allow for a more precise tracing of the structures of the craniofacial region.

In order to determine a baseline for normal growth in the five experimental animals, prior to the start of the experiment each animal underwent a control period ranging from 12 to 20 weeks (Table I). Data from twenty-seven untreated monkeys at the same stage of dentitional development were used for comparison.[18-20]

The experimental period lasted for 12 weeks in two animals and for 20 weeks in three animals (Table I). An increase in the vertical dimension of the face was

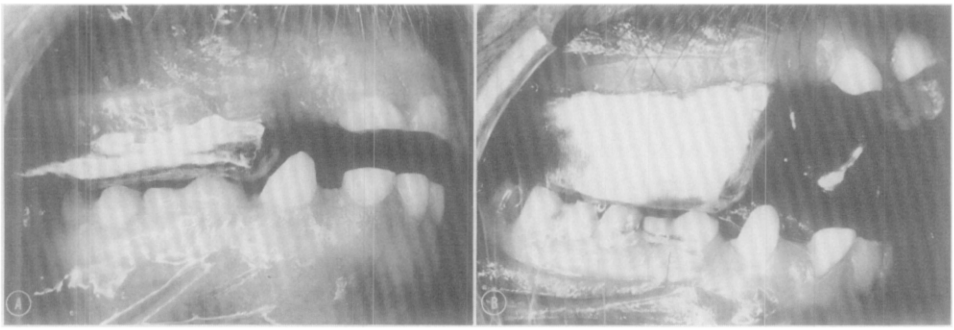


**Fig. 1.** The cast-gold bite splint used in this study. **A,** 3 mm.; **B,** 15 mm.

**Table I.** Experimental design

| *Animal* | *Bite opening (mm.)* | *Control period (weeks)* | *Experimental period (weeks)* | *Posttreatment period (weeks)* |
|---|---|---|---|---|
| A | 2 | 12 | 20 | — |
| B | 3 | 12 | 12 | — |
| C | 5 | 12 | 12 | — |
| D | 10 | 12 | 20 | 20 |
| E | 15 | 20 | 20 | 20 |

produced by opening the bite 2, 3, 5, 10, or 15 mm. (measuring from the incisal edges of the anterior teeth) by means of a cast-gold overlay which extended posteriorly from the maxillary canine teeth to the first molars (Fig. 1). The appliances were equilibrated in the mouth to allow for maximal occlusal contact of the posterior teeth.

Cephalometric radiographs were taken at the beginning of the control period, at the beginning of the experimental period, and at the end of the experimental period after the appliances had been removed (Table I). The animals in which the bite had been opened 10 or 15 mm. were followed for an additional 20-week observation period to permit the analysis of posttreatment changes.

## Results

The animals generally continued to eat and drink normally and showed a consistent weight gain after placement of the appliances. Those animals in which the bite was opened 10 or 15 mm. experienced some difficulty in chewing during the first few days, but they quickly learned to use the buccal musculature for manipulation of the bolus. No special diet was needed.

At the end of the experimental period the appliances were removed from all animals. Those animals in which the bite had been opened 2 to 5 mm. showed no measurable alteration in occlusion (Fig. 2, *A*). The animal whose bite had been opened 10 mm. demonstrated a slight lateral open-bite and an end-on molar relationship (Fig. 2, *B*). The animal in which the bite had been opened 15 mm. demonstrated a lateral open-bite and a tendency toward an end-on molar relationship (Fig. 2, *C*).

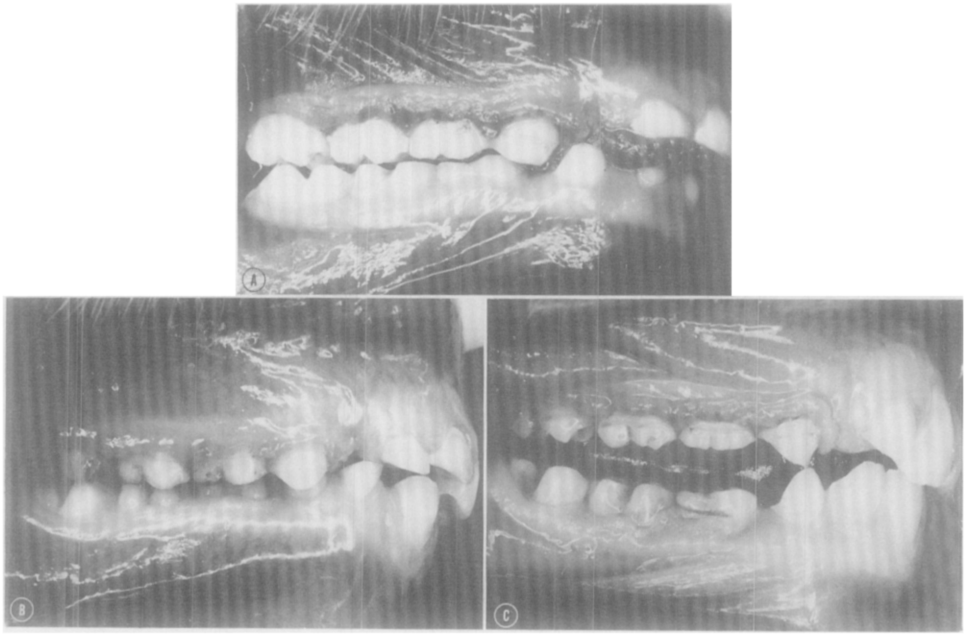


**Fig. 2.** Intraoral photographs of the occlusal relationships at the end of the experimental period. **A,** Animal with 2 mm. bite opening; **B,** animal with 10 mm. bite opening; **C,** animal with 15 mm. bite opening.

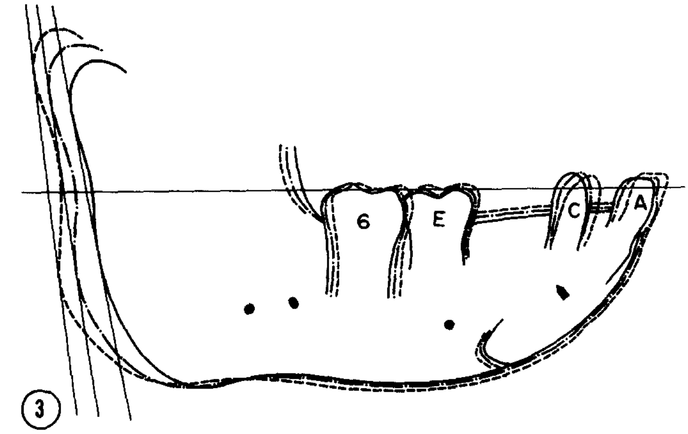
**Analysis of mandibular adaptations**

The findings in this study are most easily described by dividing the experimental animals into two groups: those animals having a bite opening of 2 to 5 mm. and those animals having a bite opening of 10 or 15 mm. Mandibular adaptations were monitored by superimposing the mandibular implants in serial cephalograms.

During the control period the mandibular growth of these animals was typical of animals at this stage of dentitional development. Growth at the condyle occurred in an upward and backward direction and the ramus was relocated posteriorly (Figs. 3 and 4). The dentition migrated in a forward and upward direction.

During the experimental period the following adaptations were observed:

*Vertical opening of 2 to 5 mm.* Few experimentally induced changes occurred in the mandibles of this group. The amount and direction of condylar growth were unaltered in the animals whose bites were opened 2 and 3 mm., as was indicated by a comparison between the control and experimental periods (Fig. 3). In the animal with a bite opening of 5 mm. the amount of vertical growth at the head of the condyle was decreased during the experimental period. This reduction in vertical growth resulted in a more posterior orientation in the direction of growth of the mandibular condyle. However, in all three animals in this group the condylar-ramus-occlusal (CRO) angle (Fig. 3) closed during both the con-



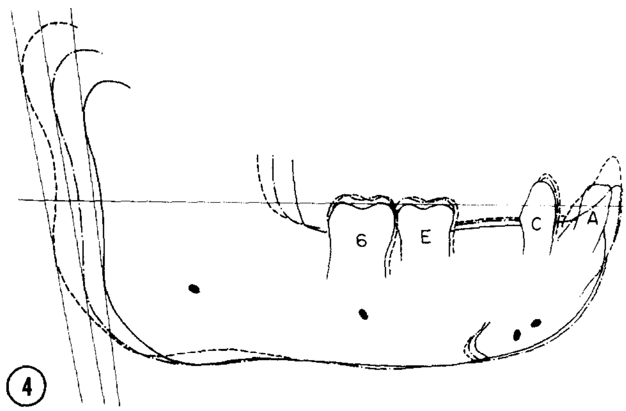
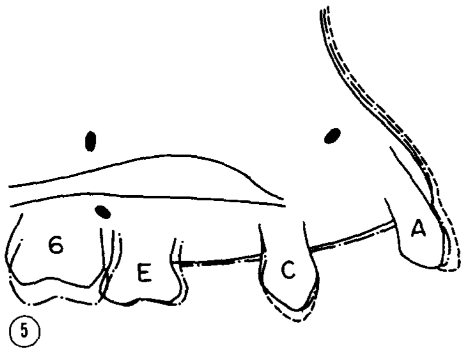




**Fig. 3.** Mandibular adaptations in the animal whose bite was opened 3 mm. This animal underwent a 12-week control period, followed by a 12-week experimental period. Note that the amount and direction of condylar growth were similar for the control and experimental periods. Note also that the angle formed by a line along the posterior border of the ramus and the posterior border of the condyle and through the occlusal plane (condylar-ramus-occlusal or CRO angle) closes during both the control and experimental periods. Also, note the lack of vertical development in buccal segments and the compensatory drifting of the dentition observed during the experimental period. Superimposition is on the mandibular implants. (Figs. 3 to 8, the solid line represents the beginning of the control period, the dashed and dotted line represents the beginning of the experimental period, and the dashed line represents the end of the experimental period. The teeth are indicated as follows: **A,** central incisor; **C,** cuspid; **E,** second deciduous molar; and **6,** first permanent molar.)

**Fig. 4.** Mandibular adaptations in the animal whose bite was opened 15 mm. This animal underwent a 20-week control period, followed by a 20-week experimental period. The most significant finding in this animal was the amount of resorption at the gonial angle during the experimental period. Condylar growth and bone deposition and resorption in other regions were relatively unaffected by the experiment. Note the inhibition of eruption of the buccal segments and the compensatory migration of the anterior teeth. Superimposition is on the mandibular implants.



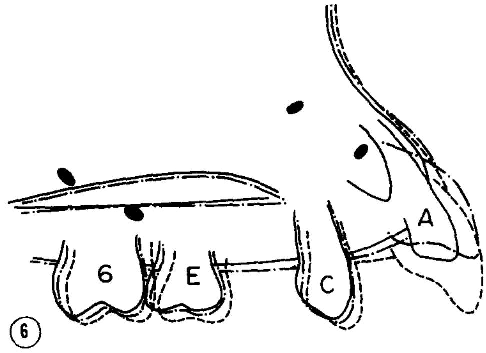




**Fig. 5.** Maxillary adaptations in the animal with the 3 mm. bite opening. Note the inhibition of eruption of the buccal segments and the slight compensatory migration of the anterior teeth during the experimental period. The first molar completed its eruption into occlusion during the control period. Superimposition is on the maxillary implants.

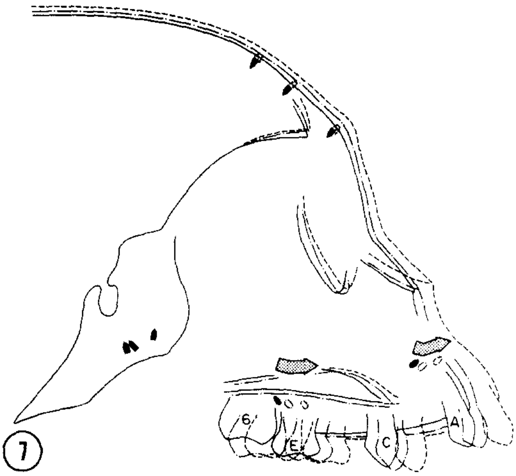
**Fig. 6.** Maxillary adaptations in the animal with the 15 mm. bite opening. The downward and forward migration of the buccal segments was not inhibited in this animal. Compensatory tooth migration, particularly of the central incisors, was evident during the experimental period. The permanent central incisors erupted during the control period. Superimposition is on the maxillary implants.

trol and experimental periods, indicating that no increase in the rate of posterior growth occurred at the head of the condyle relative to the other parts of the mandible. Normal bone deposition was observed along the lower border of the mandible and in the symphyseal region in both the control and experimental periods. In addition, there was no change in the rate of either bone deposition along the posterior border of the ramus or bone resorption along the anterior border of the ramus.

The effect of the appliance on the mandibular dentition was primarily restricted to a reduction in the amount of vertical migration of the buccal segments (Fig. 3). In addition, limited compensatory changes were observed in the canine and incisor region as a result of the placement of the appliance. These adaptations usually resulted in a slight forward migration of the lower canines and a slight upward migration of the lower incisors.

*Vertical opening of 10 and 15 mm.* Condylar growth in the two animals in this group was not altered during the experimental period. No significant increases or decreases in either the amount or the direction of condylar growth were noted, although the CRO angle remained constant rather than decreasing during the experimental period (Fig. 4). The most significant skeletal adaptation in the mandible occurred in the remodeling of the gonial region. The gonial region normally has an irregular remodeling pattern; however, in the animal with the 15 mm. bite opening, bone resorption occurred to a much greater extent than is usually observed during normal growth.

An inhibition of eruption of the buccal segments occurred during the experimental period in this group (Fig. 4). However, it should be noted that, even



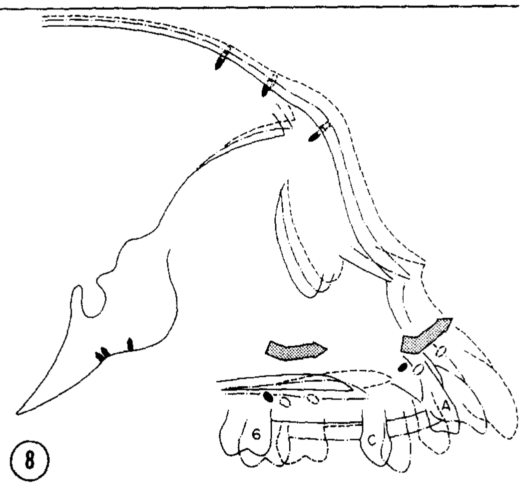




**Fig. 7.** Displacement of the maxillary complex in the animal whose bite was opened 3 mm. Note the downward and forward movement of the maxillary and premaxillary implants during the control period. During the experimental period the premaxillary implant was displaced forward and upward while the maxillary implant was displaced only in a forward direction. The movement of the implants during the control and experimental periods is indicated by the change in direction of the arrows. Note also the upward and forward displacement of the palatal outline during the experimental period. Superimposition is on the implants in the cranial base and upon the outline of the endocranial surface of the orbital roof.

**Fig. 8.** The displacement of the maxillary complex in the animal whose bite was opened 15 mm. This animal underwent a 20-week control period and a 20-week experimental period. Note the downward and forward movement of the maxillary and premaxillary implants during the control period. During the experimental period the maxillary complex was displaced forward and upward, as indicated by the movement of the implants. Note also the superior and forward repositioning of the palatal outline and the forward movement of the buccal segments during the experimental period. Superimposition is on the implants in the cranial base and on the outline of the endocranial surface of the orbital roof.

with a 15 mm. bite opening, no intrusion of the lower buccal segments was observed. Compensatory tooth migration in the anterior region was also noted. This resulted in a vertical migration of the teeth in the canine and incisor regions.

**Analysis of maxillary adaptations**

The amount of localized bone deposition and resorption and the movement of the maxillary dentition relative to the maxilla were monitored by superimposing tracings on implants within the maxillary region. During the control period, the five experimental animals exhibited patterns of growth which were typical of juvenile monkeys (Figs. 5 and 6). Minimal downward and forward migration of the buccal segments occurred. A slightly greater downward and forward movement of the canine and incisor regions was evident. Deposition of new bone occurred to a greater extent in the anterior portion of the maxilla, particularly in the region adjacent to the roots of the upper incisor teeth.

During the experimental period the following adaptations were observed:

*Vertical opening of 2-5 mm.* Since the appliances were cemented on the canines, deciduous molars, and first permanent molars (a process which effectively splinted these teeth together as a single unit), it was expected that little movement would be evident in these structures. In the three animals in this group, the buccal segments remained stable without any appreciable downward or forward movement (Fig. 5). However, compensatory tooth movement was observed in the anterior region, where an increase in the vertical migration of the upper incisors was observed, apparently as a result of the open-bite created by the appliance. The areas of normal bone deposition in the anterior region of the maxillary complex were unaffected.

*Vertical opening of 10 and 15 mm.* Downward and forward migration of the buccal segments was observed in these two animals (Fig. 6). There was no intrusion of the posterior teeth. The amount of compensatory tooth migration in the anterior region was also increased. The upper incisors migrated inferiorly, again in an apparent attempt to close the open-bite. This anterior migration was accompanied by localized bone remodeling of the adjacent alveolar areas (Fig. 6).

**Analysis of maxillary displacement**

In order to monitor the amount and direction of the displacement of the maxillary complex relative to cranial structures, tracings were superimposed on implants in the cranial base, in the frontal bone, and on the outline of the inferior portion of the endocranial surface of the orbital roof. During the control period, the five experimental animals demonstrated normal patterns of midfacial development. The maxillary complex grew in a downward and forward direction, as indicated by the movements of the premaxillary and maxillary implants (Figs. 7 and 8). The movements of these implants also indicated the slight counterclockwise rotation of the maxillary complex that occurred during normal growth.

During the experimental period, the following adaptations were observed:

*Vertical opening of 2 to 5 mm.* In contrast to the previously described findings within the mandible and maxilla, significant adaptations were observed in the displacement of the maxillary complex in this group of animals. Downward migration of the maxillary complex was reduced during the experimental period, and the expression of this growth was more anterior in direction. There was an upward and forward displacement of the premaxillary implant in all of the animals, which accentuated the counterclockwise rotation observed during the control period. The normal downward displacement of the palate was also reversed during the experimental (Fig. 7).

The normal downward and forward movement of the maxillary dentition relative to the cranial structures was also altered. The downward migration was inhibited while the maxillary dentition moved more anteriorly (Fig. 7). The anterior teeth were displaced in a slightly upward direction.

*Vertical opening of 10 and 15 mm.* The two animals in this group experienced alterations in maxillary displacement similar to those observed in the other three animals in the study, but the expression of these changes was more dramatic in the animals in which the bite had been opened to a greater extent. The amount of anterior maxillary displacement was two to three times as great as that occurring during the control period (Fig. 8). In addition, the normal downward displacement of the maxillary complex was reversed, that is, there appeared to be an upward displacement of the nasomaxillary complex. This was especially evident in the anterior portion of the maxillary complex, where the premaxillary implant had been displaced superiorly.

An increase in the amount of the forward movement of the upper buccal segments was also evident in these animals (Fig. 8). The amount of forward displacement was so great in the animal whose bite was opened 10 mm. that, upon appliance removal, an end-to-end relationship of the maxillary and mandibular dentitions resulted (Fig. 2).

### Posttreatment adaptations

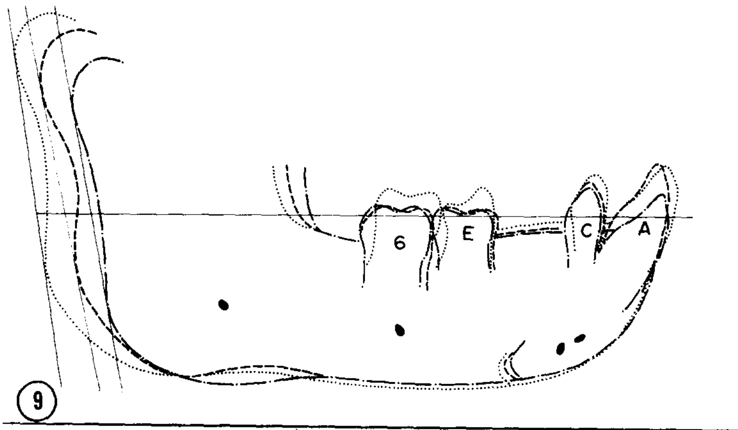
The appliances were removed from the animals with 10 and 15 mm. bite openings at the end of the experimental period. These monkeys were then followed for a 20-week observation period, during which time no type of retention device was used.

*Mandibular adaptations.* The changes that occurred in the mandible during the posttreatment period were primarily dentoalveolar in nature. Because of the lateral open-bite created by the appliance, the lower buccal segments were extruded during the 20-week posttreatment period (Fig. 9). Compensatory tooth movement also occurred in the anterior region.

Skeletal growth in the mandible was relatively unaffected. There was no change in either the amount or the direction of growth at the mandibular condyle. However, there was a reversal of the resorptive pattern that occurred in the gonial region during the experimental period. This may have been due to the re-establishment of the vertical dimension after appliance removal.

*Maxillary adaptations.* As in the mandible, the principal adaptations in the maxillary region were dentoalveolar in nature. As bite closure took place during the posttreatment period, there was a slight extrusion of the buccal segments, as well as an upward tipping of the central incisors.

*Maxillary displacement.* The normal downward and forward displacement



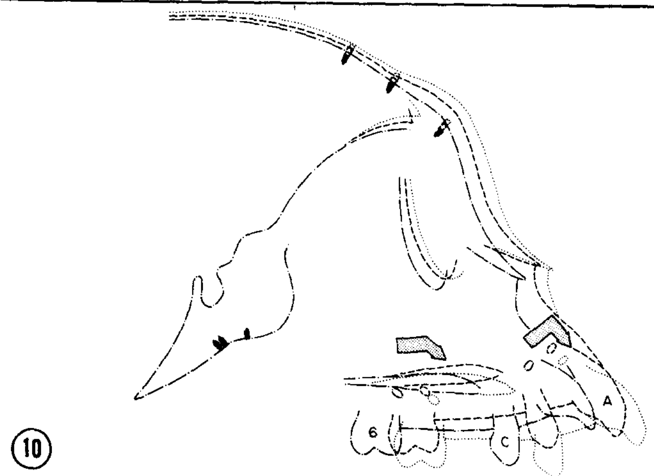




**Fig. 9.** Mandibular adaptations during the experimental and posttreatment periods in the animal with the 15 mm. bite opening. The resorption of bone in the gonial region was reversed during the posttreatment period. An upward and forward movement of the buccal segments occurred during the posttreatment period, presumably in response to the lateral open-bite created by the appliance during the experimental period. (In Figs. 9 and 10, the dotted and dashed line represents the beginning of the experimental period, the dashed line represents the end of the 20-week experimental period, and the dotted lines represents the end of the 20-week posttreatment period.)

**Fig. 10.** Maxillary displacement of the animal with the 15 mm. bite opening during the experimental and posttreatment periods. The maxillary complex was displaced downward and forward during the posttreatment period, in a direction which approximated that observed during the control period. The palatal outline moved downward and forward, as did the teeth in the buccal segment. Compensatory adaptations were also observed in the anterior teeth. Superimposition is on the implants in the cranial base and on the outline of the endocranial surface of the orbital roof.

of the maxilla relative to the cranial base and cranial floor structures resumed during the posttreatment period (Fig. 10). The amount of *forward* migration of the maxillary and premaxillary implants was similar to that observed during the control period; the amount of *downward* migration of these implants was greater than during the control period, presumably in response to the relative upward

**Fig. 11.** Intraoral photograph of the occlusal relationship of the animal with the 10 mm. bite opening 20 weeks after appliance removal.

displacement of these implants during the experimental period. The upward displacement of the palate observed during the experimental period was also reversed during the posttreatment phase.

Dentoalveolar adaptations that occurred during this posttreatment period included a downward and forward movement of the buccal segments, a downward and slightly forward movement of the canines, and a forward movement of the anterior teeth. In the animal with the 10 mm. bite opening the amount of forward movement during this period maintained the end-on molar relationship that was observed at the end of the experimental period (Fig. 11). However, the differential eruption of teeth allowed for the re-establishment of a Class I molar relationship in the animal with the 15 mm. bite opening.

## Discussion

Results of this study indicate that, when the vertical dimension of the face is altered, significant structural adaptations occur throughout the craniofacial complex. These adaptations are not limited to a single region or area, and they appear to be dependent on the amount of bite opening. The region of the face most affected by changes in vertical dimension appears to be the maxillary complex and its relationship with cranial structures; the sutural system that exists between the maxillary complex and the cranial base and cranial floor appears to be the area in which adaptations occur most readily. Adaptations occurred in the displacement of the maxillary complex in all five of the experimental animals observed in this study, even when the amount of bite opening was as little as 2 mm.

Although the severity of its expression depended on the amount of bite opening, the manner in which this adaptation was expressed is uniform. When the vertical dimension of the face was increased through the placement of the appliance, the downward vector of this displacement was impeded and in some cases even reversed, so that an upward displacement of the maxillary complex resulted. Moreover, displacement of the maxillary complex appeared to gain an additional anterior component, so that by the end of the experiment the maxilla was in a more forward position than it would have been without experimental intervention. The forward displacement of the maxillary complex resulted in an alteration in the occlusal relationship, particularly in the animal with the 10 mm. bite opening, where an end-to-end molar relationship was produced. In a related experiment, a similar alteration in occlusal relationship in one adult monkey was observed by Breitner.[14]

It can be assumed that a severe bite opening, which causes the mandible to function in a partially rotated position, produces a change in the vector of forces generated by the masticatory musculature. The opening of the bite produces muscular forces which have a more anterior vector and thus may be responsible for a more forward displacement of the maxillary complex. It is interesting to note that the forward displacement of the maxillary complex was maintained in the two animals that were followed for a 20-week posttreatment period. During this period, there was a more normal rate of downward and forward displacement. However, a greater downward displacement of the maxillary complex occurred during the posttreatment period, presumably in an attempt to overcome the upward displacement that occurred during the experimental period. Although the altered molar relationship produced during the experimental period in the animal whose bite was opened 15 mm. was reversed during the posttreatment phase, this was due to dentoalveolar adaptation rather than skeletal changes in the maxillary complex. The end-to-end occlusal relationship in the animal with the 10 mm. bite opening was maintained during the posttreatment period.

The growth of the mandible was relatively unaffected by the experiment. The only significant finding was that a degree of localized bone resorption occurred in the area of the gonial angle in those animals in which a large bite opening was produced. This resorption along the lower border of the mandible may have been a response to the stresses produced by the associated musculature, which was elongated by the placement of the appliance. Since muscles which have been elongated seek to return to their original resting length, it can be postulated that muscle shortening could occur, in part, as a result of the migration of the muscle at the muscle-bone interface. This migration of muscle may have resulted in the occurrence of bone remodeling at the gonial angle. The findings obtained during the posttreatment period, that is, the fact that the pattern of remodeling in the gonial angle was reversed after appliance removal, tend to support this proposition.

Most previous experimental studies of alterations in vertical dimension have considered the effect of such procedures on the dentition and associated dentoalveolar structures.[7-10] These studies have reported various alterations in dentoalveolar structures, including a widening of the periodontal membrane, loosening of teeth, resorption of alveolar bone, dentin, and cementum, and tooth intrusion. Although there were obvious dentoalveolar adaptations observed in the present study, the amount of these adaptations was minimal when compared to the various skeletal adaptations, particularly those in the maxillary complex. The vertical migration of the dentition was inhibited by the placement of the appliance; however, even in the animals in which extreme bite opening was produced, no significant intrusion of the buccal segments was observed. The mesial migration of the upper buccal segments was observed only in those animals in which severe bite openings had been produced, and the extent of dentitional migration in the maxilla was not nearly so great as the displacement of the whole maxillary complex relative to the cranial base.

The extrapolation of the findings of this study to clinical treatment in man must be made with caution. There are obvious differences in the growth and configuration of the craniofacial complex in the monkey and in man.[20, 21] The monkey, for instance, demonstrates a more anterior development of the nasomaxillary complex; the amount of muzzle development, however, is not as great in the juvenile animals used in this study as it is in adolescent and adult monkeys.[20]

The results of this study indicate that any increase in the vertical dimension of the face, even as little as 2 mm., results in an alteration in craniofacial growth. Thus, other procedures which cause an opening of the bite (for example, bite plate or posterior bite splint therapy) probably have their primary effect in the maxillary region. This effect is not so obvious in clinical patients as it is in a controlled experimental study, partially because the amount of relative bite opening is not as great as that produced in an experimental situation. Also, changes in maxillary position are often masked by difficulties in cranial base superimposition in which the "best fit" method of superimposition on cranial base structures is used.

It may be hypothesized that modifications of the bite-opening appliances used in this experiment can be used in certain clinical situations. For example, the increased forward displacement of the maxillary complex may be effected by the use of posterior bite splints, particularly in a Class III patient with a deficiency in the maxillary complex. This redirection of the forces of the muscles of mastication may result in a forward displacement of that region. It may also be postulated that such bite-opening appliances may be useful in cases of open-bite in which the inhibition of eruption of the posterior teeth and the extrusion of the upper and lower incisors is desired.

## Summary and conclusions

Five juvenile rhesus monkeys were used in an experiment designed to study the structural adaptations in the craniofacial complex that resulted from increases in vertical dimension. The bite was opened 2, 3, 5, 10, or 15 mm. by means of cast bite splints cemented on the maxillary arch. Adaptations were monitored in these animals by means of serial cephalometric radiography with metallic implants.

The results of this study indicate that any change in the vertical dimension of the face results in specific structural adaptations throughout the craniofacial complex. The most significant adaptation occurred in the maxillary region, in which the normal downward displacement of this region was decreased and the anterior displacement was increased. Adaptations were less evident in the mandible, except in those animals in which a severe bite opening was produced; resorption in the region of the gonial angle was evident. Dentitional adaptations were of secondary importance.

This study demonstrates that the maxillary complex is a very plastic structure which responds to changes in bite opening and altered muscle length. The clini-

cian should be aware of the changes that result from various alterations of vertical dimension to make sure that these changes are not antagonistic to his over-all treatment goal. He may also take advantage of these changes when designing treatment strategies for certain clinical cases.

The author thanks Ms. M. C. McBride and Ms. Jody Ungerleider for their technical assistance on this project.

**REFERENCES**

1. Creekmore, T. D.: Inhibition or stimulation of the vertical growth of the facial complex, its significance to treatment, Angle Orthod. **37**: 285-297, 1967.
2. Ricketts, R. M.: The influence of orthodontic treatment on facial growth and development, Angle Orthod. **30**: 103-133, 1960.
3. Schudy, F. F.: Vertical growth versus anteroposterior growth as related to function and treatment, Angle Orthod. **34**: 75-93, 1964.
4. Lewis, P. D.: Vertical dimension, AM. J. ORTHOD. **37**: 522-533, 1951.
5. Sleichter, C. G.: Effects of maxillary bite plane therapy in orthodontics, AM. J. ORTHOD. **40**: 850-870, 1954.
6. Thompson, J. R., and Brodie, A. G.: Factors in the position of the mandible, J. Am. Dent. Assoc. **29**: 925-941, 1942.
7. Glickman, J., and Weiss, L. A.: Role of trauma from occlusion in initiation of periodontal pocket formation in experimental animals, J. Periodontol. **26**: 14-20, 1955.
8. Itoiz; M. E.: Carranza, F. A., and Cabrini, R. L.: Histologic and histometric study of experimental occlusal trauma in rats, J. Periodontol. **34**: 305-315, 1963.
9. Waerhaug, J., and Hansen, E. R.: Periodontal changes incident to prolonged occlusal overload in monkeys, Acta Odontol. Scand. **24**: 91-105, 1966.
10. Wentz, F. M., Jarabak, J., and Orban, B.: Experimental occlusal trauma imitating cuspal interferences, J. Periodontol. **29**: 117-127, 1958.
11. Sergl, H. G., and Farmand, M.: Experiments with unilateral bite planes in rabbits, Angle Orthod. **45**: 108-114, 1975.
12. Gianelly, A. A., Ruben, M. P., and Risinger, R.: Effect of experimentally altered occlusal vertical dimension on temporomandibular articulation, J. Prosthet. Dent. **24**: 629-635, 1970.
13. Breitner, C.: Further investigations of bone changes resulting from experimental orthodontic treatment, AM. J. ORTHOD. **27**: 605-632, 1941.
14. Breitner, C.: The tooth supporting apparatus under occlusal changes, J. Periodontol. **13**: 72-80, 1942.
15. Breitner, C.: Alteration of occlusal relations induced by experimental procedure, AM. J. ORTHOD. **29**: 277-289, 1943.
16. Hurme, V., and Van Wagenen, G.: Basic data on the emergence of permanent teeth in the rhesus monkey *(Macaca mulatta)*, Proc. Am. Philo. Soc. **105**: 105-116, 1961.
17. Björk, A.: The use of metallic implants in the study of facial growth in children: Method and application, Am. J. Phys. Anthropol. **29**: 243-254, 1968.
18. McNamara, J. A., Jr.: Neuromuscular and skeletal adaptations to altered orofacial function, Monograph No. 1, Craniofacial Growth Series, Center for Human Growth and Development, Ann Arbor, 1972, The University of Michigan.
19. McNamara, J. A., Jr., and Graber, L. W.: Mandibular growth in the rhesus monkey *(Macaca mulatta)*, Am. J. Phys. Anthropol. **42**: 15-24, 1975.
20. McNamara, J. A., Jr., Riolo, M. L., and Enlow, D. H.: The growth of the maxillary complex in the rhesus monkey *(Macaca mulatta)*, Am. J. Phys. Anthropol. **44**: 15-26, 1976.
21. Enlow, D. H.: A comparative study of facial growth in *Homo* and *Macaca*, Am. J. Phys. Anthropol. **24**: 293-307, 1966.