Facioskeletal And Dental Changes Resulting From Rapid Maxillary Expansion*

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The bones of the craniofacial complex undergo many differential changes during growth. These changes, both in the amount and in the direction of bone growth, are primarily the result of inherent and genetically controlled cellular processes. Some of the changes are probably influenced by external factors such as muscle attachments and functional activity. In addition, the growth pattern of one bone may possibly be partially controlled by the growth of adjacent skeletal structures. In general, bones react to the stress placed upon them. If the stresses are caused to change either in magnitude or in direction, then an alteration in the shape or structure of the bone or its relationship to adjacent bones can be expected as a result.

Most bones involved in the craniofacial complex are united to the contiguous bones at sutures. It is conceivable, therefore, that changes in the orientation of the bones in one region of the face may well involve sutural adjustments in remote regions.

In a previous paper[1] it was reported that rapid and strong expansion forces applied to the maxilla of the growing Macaca rhesus monkey resulted in a breakdown of the midpalatal suture. The resulting bony defect was found to be repaired during and following retention with a restoration of normal sutural morphology. As a result of the appliance therapy, the palate was also observed to be wider. An apparent tipping of the buccal segments in a lateral direction was noted. The lateral tipping occurred rapidly and the concomitant increase in palatal width suggested that it may not have been due to teeth tipping within the alveolar process. Rather, it was probably the result of a rotation of the two palatal segments around the split midpalatal suture. This type of reaction to rapid expansive forces, that is, a rotational movement away from the midpalatal suture, has been previously described in the literature.[2,3]

For this latter possibility to have occurred, a concurrent reorientation of the more remote facial bones would probably need to take place. Rapid orthopedic expansion of the maxilla under controlled experimental conditions gives an excellent opportunity for studying the effect of altering the relationship of the midline bony structures on the more remote adjustment sites. A study was designed for this purpose. The specific aims of this study were: 1) to determine if the buccal tooth movement, as a result of strong midpalatal suture expansion procedures, was "tipping" or "bodily" in nature; 2) to investigate the possibility of a rotational movement of the palatal

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processes occurring as a result of orthopedic expansion of the maxilla; and 3) to study the reactions of remote skeletal adjustment sites, namely, the facial sutures, to the rapid maxillary expansion procedures.

Method of Study

The sample consisted of five Macaca rhesus monkeys. These animals varied slightly in development but were comparable to young human beings ranging in age from seven to nine years. One animal served as a control and the remaining four monkeys were subjected to a rapid expansion of the maxillary palate using a split acrylic palate with a central expansion screw. The appliance was retained by integral bands cemented to the first and second deciduous molars, and the first permanent molars. The first experimental animal was sacrificed following four mm of expansion as measured from one molar cusp to the comparable molar cusp on the opposite side of the arch. This degree of opening took two weeks to achieve from the initial activation to the time of sacrifice. The second experimental animal was subjected to a total of six mm of expansion which was accomplished over a three-month period. The palate of the third experimental animal was expanded for three months and then retained using a "passive" retention appliance, for an additional three months, before sacrifice. In the last experimental animal, after three months of retention, the retention appliance was removed and an additional three months of postretention time was permitted to lapse before the animal was sacrificed. The above sequence gave a series of animals at various stages of expansion therapy in which the tissue reactions could be observed and compared with the control material.

Following sacrifice, decapitation, and fixation in ten per cent neutral formalin, the maxillary complex was removed from each monkey's skull and was divided transversely into blocks, approximately two and one-half millimeters in thickness. Every second block was used for histologic examination. Sections of ten micra thickness were decalcified and these sections were stained with haematoxylin and eosin. The alternate blocks were analyzed as one hundred micra thickness of undecalcified sections. The histologic examination of the midpalatal region has been reported previously.[1] In the decalcified sections the histologic reaction around the teeth was studied in an effort to determine the effect of the expansion procedure on the position of the teeth and to consider the nature of any resultant cellular activity. The sections from the alternate blocks, that is, the undecalcified sections, were subjected to an angular analysis. The individual undecalcified sections were projected at a constant magnification, ($\times$ 6), using a photographic enlarger. The projected anatomical outlines were drawn upon paper (Figure 1). Lines representing the average plane for the palatal plate on each side of the maxilla, and lines representing the long axes of the buccal teeth were constructed on each drawing. The superior angle between the two palatal lines indicated the angulation of the palatal processes of the maxilla. The inferior-medial angle between the palatal lines and the long axes of the teeth indicated the axial inclination of the buccal teeth

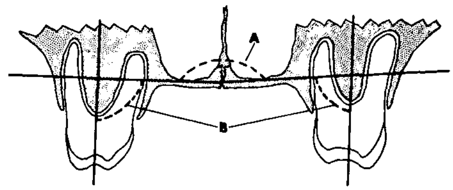

Fig. 1 The projected anatomical outlines with the corresponding lines representing the average plane for the palatal plate (A) and the long axes of the buccal teeth (B).

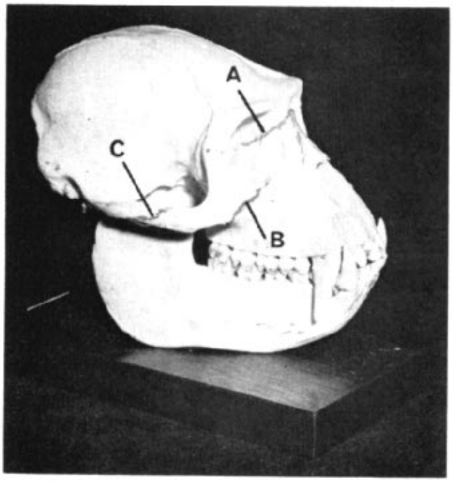

Fig. 2 A monkey skull depicting the facial sutures studied: A. nasal suture, B. maxillary-zygomatic suture, C. zygomaticotemporal suture.

relative to the palate.

Mean values were obtained for the anterior sections which were taken from the region of the incisive foramen, and for the sections derived from the flatter, more posterior part of the hard palate. A statistical analysis was performed upon these data to determine the significance of any difference occurring between the control and the experimental animals. It was hoped that, by using this technique, it would be possible to identify any rotation of the palatal processes around the midpalatal suture region resulting from the expansion procedure. Also, the relationship of the axial inclination of the buccal teeth to the palatal lines would indicate whether tooth movement occurring as a result of maxillary expansion was essentially "tipping" or "bodily" in nature.

In order to ascertain if the splitting of the midpalatal suture resulted in any compensatory bone changes in other parts of the facial skeleton, selected sutural regions were dissected and prepared for histological examination. The regions studied were: the frontonasal complex of sutures, the maxillary zygomatic suture, and the zygomaticotemporal suture (Figure 2). As nearly as possible, decalcified sections, ten micra in thickness, were prepared from each specimen at right angles to the plane of the suture. Also, tissue blocks for each suture were oriented and cut in a similar direction for each animal. The serial sections cut through each block were examined in an effort to determine if the sutures did or did not react to the palatal expansion.

Results

A. *Histologic Examination*

The histological examination of the supporting structures of the teeth in the control animal showed an essentially normal picture for the mixed dentition period. The periodontal membrane was noted to be regular in width around each tooth with the principal fiber bundles running in the directions usually considered to reflect an adaptation to normal functional stress (Figure 3). The surface of the alveolar bone was smooth in contour and was observed to be well organized. The cellular elements of the periodontal membrane showed the usual distribution of fibroblasts, cementoblasts and osteoblasts.

The strong expansion forces used in the experimental animals to dislocate the midpalatal suture seemed to have considerable effect on the supporting structures of the buccal teeth. In the first experimental animal, sacrificed after two weeks of orthodontic expansion, the periodontal membranes of these teeth were found to be stretched on the palatal aspect. The periodontal membranes were observed to be disorganized and to contain cell-free zones on the buccal side. The alveolar bone surface was irregular and scalloped and showed many areas of bone resorption. These changes were fairly uniform along the full length of the roots, sug-

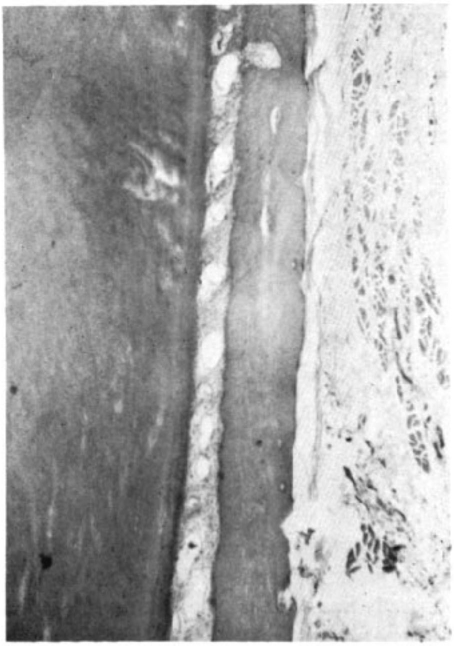

Fig. 3A Photomicrograph (x40) showing normal supporting structures of the teeth in the control animal.

gesting that tooth movement was largely "bodily" in nature (Figure 4). In general, the bone reaction was noted to be confined to the bone immediately adjacent to the periodontal membrane. No tooth was found to have lost any section of the buccal plate. Since the buccal plate was very thin, and buccal segments were expanded four mm in the two-week period, the bulk of the expansion must have taken place at the midpalatal suture region. Similar, but more extensive changes were observed to have occurred in the buccal bone of the second experimental animal which was sacrificed after three months of maxillary expansion. In this animal sections of many teeth showed almost complete remodelling of the buccal plate and extensive areas of local bone resorption (Figure 5). New bone deposition was noted on the palatal side. Bone reaction extended along the full length of the roots, again suggesting

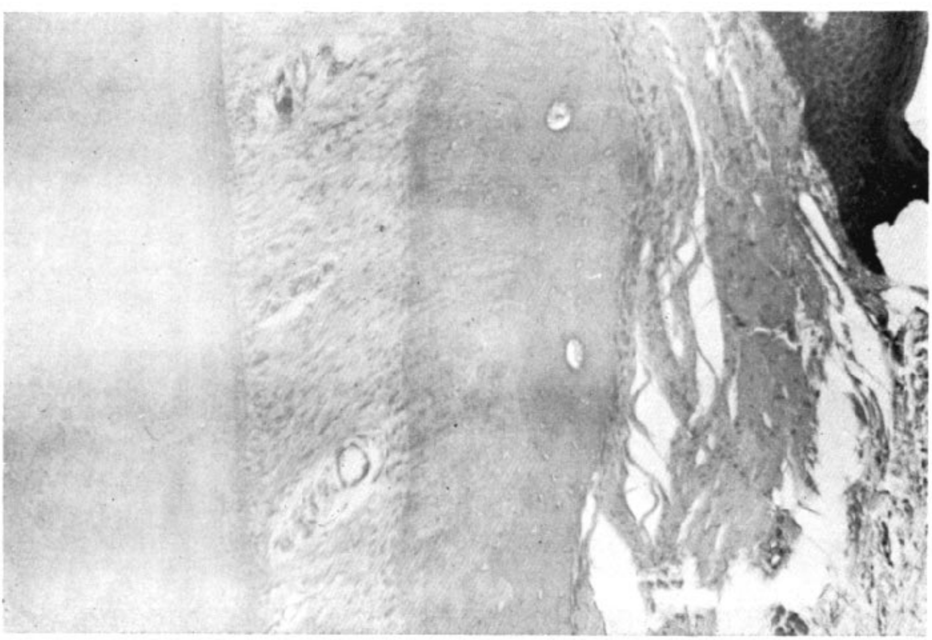

Fig. 3B High power (x100) photomicrograph showing normal periodontal membrane fibers and alveolar bone contour.

Fig. 4A Photomicrograph (x40) showing disruption of periodontal membrane due to rapid expansion.

that "bodily" tooth movement had predominated. The periodontal membrane fibers and cellular elements were less severely disrupted than observed in the first experimental animal. This finding indicated that after three months of expansion, the dental supporting structures had reacted and were adjusting to the expansion forces. Small, isolated areas of cementum resorption were noted on some teeth.

The third experimental animal, sacrificed after three months of retention, and the fourth experimental animals, sacrificed following retention plus three months after removal of retention, showed progressive improvement in the tissues of the supporting structures. The periodontal membranes of the third experimental animal showed an almost normal fiber distribution and cell population, while the alveolar bone was only slightly more irregular than normal. Much evidence of recent alveolar bone formation was apparent. The final ex-

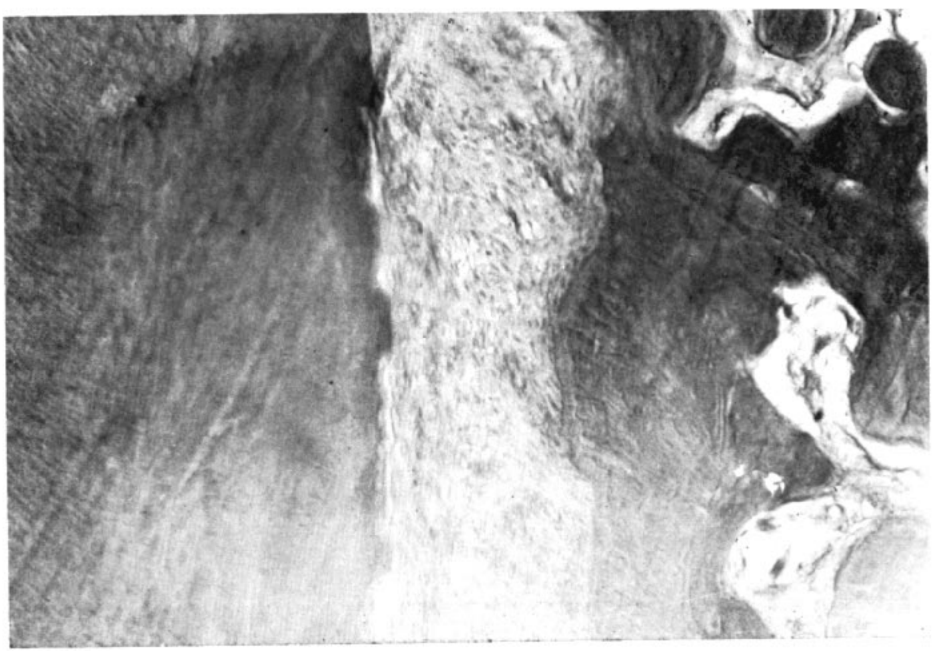

Fig. 4B High power (x100) photomicrograph showing the periodontal membrane disorganized and the scalloped and irregular surface of the alveolar bone.

perimental animal showed continued adjustment toward "near normal" dental supporting structures (Figure 6). However, even after retention and a three-months postretention period, the tissue had not returned completely to normal. The deposition of bone on the palatal side of the roots reinforced the suggestion that the earlier tooth movement had been "bodily" rather than a "tipping" in nature.

In summary, the histological study of the teeth and supporting structures showed that tooth movement in a buccal direction resulted from the application of strong lateral expansion forces. This tooth movement was found to be largely of the "bodily" type. It seemed from the clinical and x-ray records that the buccal teeth had been *tipped* laterally as a result of expansion. However, from the foregoing histologic examination, this interpretation did not seem feasible. Therefore, it was con-

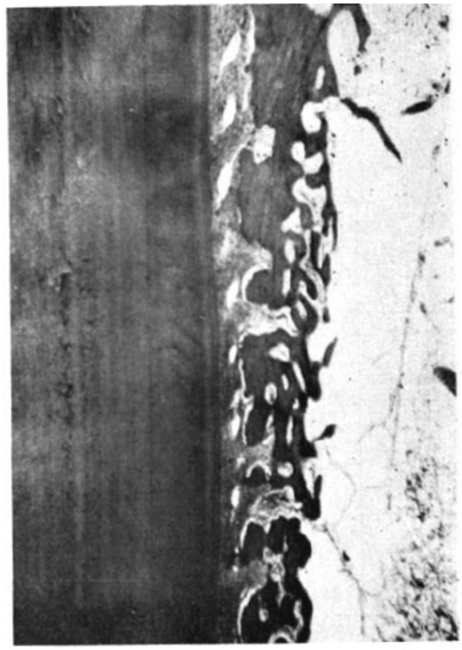

Fig. 5A Photomicrograph (x40) showing that the reaction extends the full length of the root.

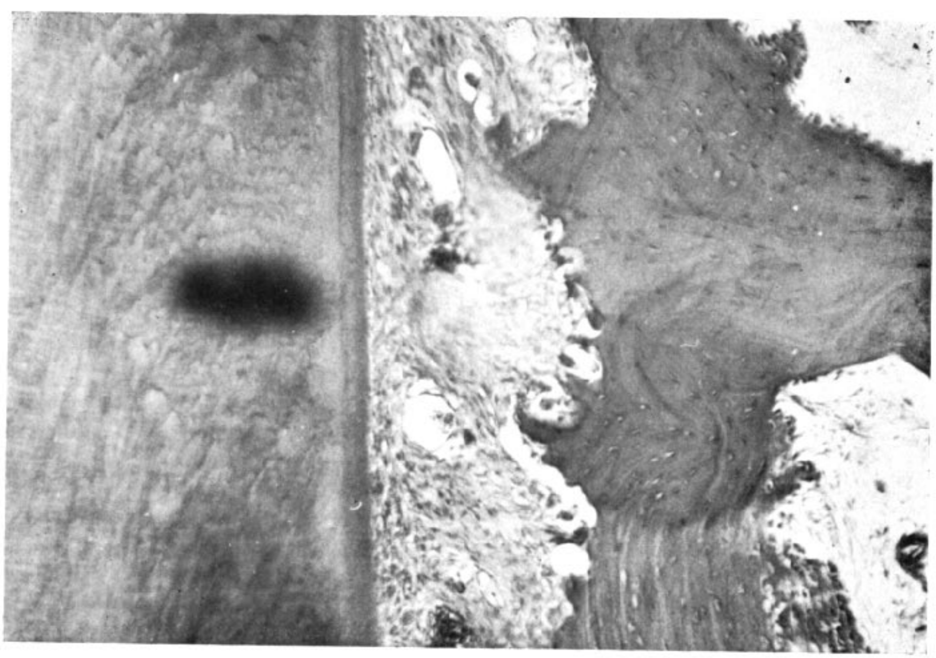

Fig. 5B High power photomicrograph (x100) revealing remodelling of buccal plate and extensive areas of local bone resorption.

Fig. 6A Photomicrograph (x40) showing continued adjustment toward a normal periodontium.

sidered possible that the palatal processes, the alveolar processes, and the teeth may have rotated, as a unit, around the disrupted midpalatal suture.

B. *Biometric analysis of the palatal processes and buccal teeth*

The results of measuring the angle between the two palatal lines and between these lines and the long axes of the buccal teeth on enlarged projections of the undecalcified sections (Figure 1), are shown in Table 1. It will be noted that sections were grouped into those taken from near the incisive foramen and from those situated more posteriorly.

From the biometric analysis it can be seen that no significant differences or trends were found between the control and the experimental animals when the inclinations of the buccal teeth, relative to the palatal lines, were analyzed. The maintenance of a relatively constant angle between the palatal lines and the

Fig. 6B High power photomicrograph (x100) showing continued adjustment toward a normal periodontium.

TABLE 1
SHOWING PALATAL ANGULATION AND INCLINATION OF BUCCAL TEETH

Animal	Region of Palate Studied	Angulation of Palatal Processes (in degrees.) Mean	S.D.	Inclination of Buccal Teeth to Palate (in degrees.) Mean	S.D.
Control	Near Incisive Foramen	249.9	9.4	123.4	13.3
	Posterior to Foramen	185.4	7.2	87.6	12.6
First Experimental	Near Incisive Foramen	230.3*	6.3	229.1	10.1
	Posterior to Foramen	180.4	9.5	91.2	7.8
Second Experimental	Near Incisive Foramen	217.0*	10.1	119.3	10.2
	Posterior to Foramen	175.5*	8.5	89.7	5.4
Third Experimental	Near Incisive Foramen	243.3	12.6	127.5	6.8
	Posterior to Foramen	173.6*	6.5	84.0	7.2
Fourth Experimental	Near Incisive Foramen	241.8	5.2	127.1	8.9
	Posterior to Foramen	182.4	10.8	89.7	7.8

* Difference between this figure and the corresponding value for the control animal significant at the 0.01 level of confidence.

long axes of the teeth suggests that the buccal teeth were not tipped buccally as a result of the expansion therapy. This finding complements the previous observation, based on the histological examinations, that the tooth movement was "bodily" rather than "tipping" in nature.

The statistical analysis of the angulation of the palatal processes to each other (Table 1) showed that this angle was significantly greater in the sections obtained from the experimental animals than was found in the sections of the control animal. This finding indicates that the palate was flattened with the midpalatal aspect of the palatal plate seeming to rotate about the midpalatal suture. A composite diagram of the control and the second experimental monkey (sacrificed after three months of expansion) is shown in Figure 7, and demonstrates the upward and outward swinging of the lateral aspects of the maxilla relative to the central portion.

For this amount of skeletal change to have taken place, a considerable degree of reorganization of the arrangement of the bones of facial complex would be required. The facial sutures were considered to be the most likely sites to demonstrate such adjustments.

C. *Changes in the facial sutures*

In the control animal all of the sutures examined were typical of those present during periods of active bone

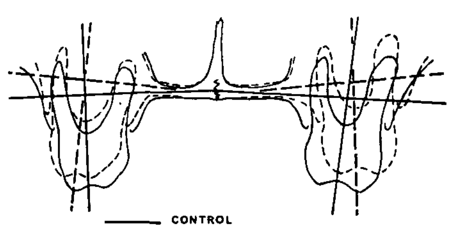

Fig. 7 Biometric analysis: typical superimposition of control and experimental material with appropriate lines drawn.

Fig. 8A Photomicrograph (x40) of normal nasal suture.

Fig. 8B High magnification (x400) showing smooth outline of bone surface.

growth. An example of a suture in the frontonasal region is shown in Figure 8 revealing typical interdigitating sutural bony processes separated by fibrous connective tissue. The bone surfaces were found to be smooth in outline with slight appositional and remodelling processes in evidence. This general sutural histology was observed in the frontonasal complex of sutures, the maxillary-zygomatic suture and the zygomaticotemporal suture. The different sutures studied varied in their morphology and cellular activity depending upon their location.

In the animal sacrificed after two weeks of expansion the sutures of the frontonasal complex showed an increase in cellular activity and evidence of bone remodelling (Figure 9). In this sutural region the histological reaction to the expansion procedures was not marked, but was sufficient to indicate that sutural adjustments were taking place. A study of the maxillary-zygomatic and zygomaticotemporal sutures showed some increased activity when compared with the comparable sutures in the control animal. However, this increased activity was very slight and was well within the range of individual variation. Therefore, it might be stated that while the nasal complex of sutures was found to react to the expansion procedures after two weeks, the other facial sutures studied showed little evidence that they were also adjusting.

All three sutural areas studied in the second experimental animal (sacrificed after three months of expansion) were found to be in a marked state of reorganization. In the nasal complex, for example (Figure 10), the sutural connective tissue was abnormally wide and showed an abnormally great number of osteoblasts and osteoclasts to be present. This tissue was also hypervascularized. The sutural bony processes were lined, in many places, by masses of new bone

Fig. 9A Photomicrograph (x40) of nasal suture following two weeks of palatal expansion.

Fig. 10A Photomicrograph (x40) showing abnormally wide connective tissue.

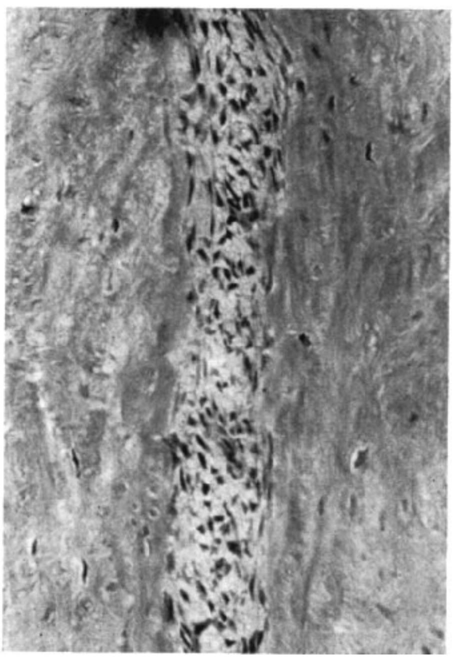

Fig. 9B Higher power (x400) revealing increased cellular activity.

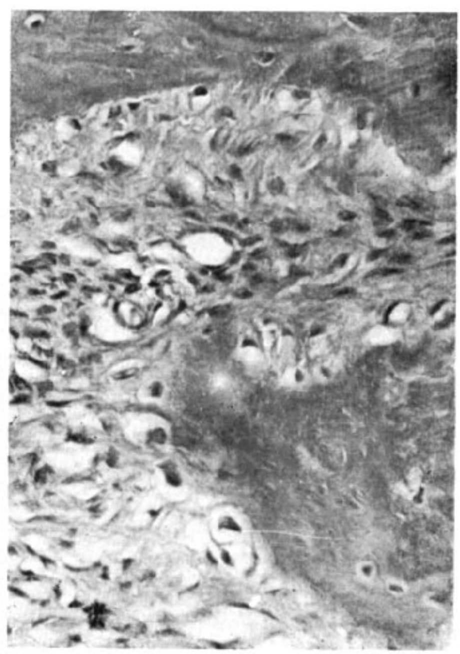

Fig. 10B Higher power (x400) shows abnormal cellular activity.

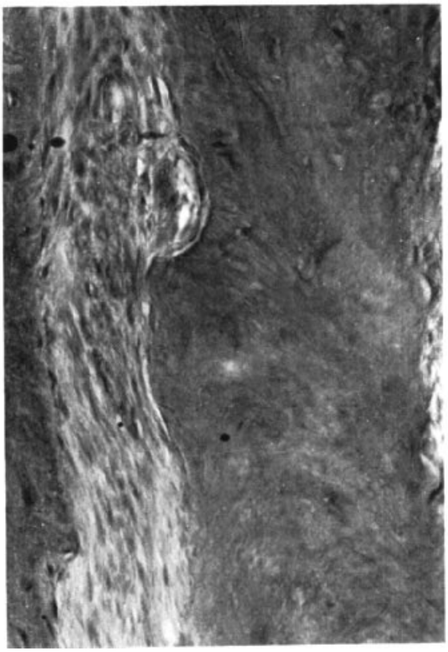

Fig. 11 Photomicrograph (x400) showing return to normal sutural morphology.

and showed evidence of marked resorption at other regions. The reaction observed in the maxillary-zygomatic suture was similar but the activity appeared to be less intense. The histologic picture for the zygomaticotemporal suture, although indicating some adjustment, showed the least amount of activity.

The animal sacrificed after three months of retention and the one sacrificed after retention and a postretention period showed progressive repair in the sutural regions and a reduction in the level of sutural activity. The third experimental animal, which was sacrificed after three months of retention, showed evidence of considerable sutural remodelling, with the sutural bony processes being largely composed of new bone. The differential of most activity to least activity from the nasal, to the maxillary-zygomatic, to the zygomaticotemporal region noted in the second experimental animal was also observed in the animal sacrificed after retention. The final monkey, sacrificed after a three-months postretention period, showed a return to normal sutural morphology in all three sutural regions. The sutural bony processes, however, still largely consisted of recently layed-down cellular bone (Figure 11).

In summary, the histologic examination of the three aforementioned sutural regions of the face revealed that changes took place in these sutures as a result of the forces which disrupted and separated the midpalatal suture. It was further observed that these changes were most obvious in the nasal region and least in the zygomaticotemporal suture region. The disturbed sutures seemed to return to the normal morphologic appearance following retention.

Discussion

As previously mentioned, it has been determined that strong expansion forces can split the midpalatal suture of the monkey. The resulting widened sutural area is rapidly filled in with new bone. After a period of time the maxillary midpalatal suture has been shown, histologically, to reform to a near-normal sutural morphology. Since the two maxillae can be forcibly moved away from each other, the question arises as to the effect of this procedure on the surrounding structures of the face. If orthodontists have and will be using appliances to rapidly separate the two maxillae, then it is important to ascertain the reactions to this procedure in the more remote areas of the upper face. To date, detailed information relative to the effect of this procedure on the adjacent facial skeleton has not been presented.

Tracings of the palate and the long axes of the teeth which were obtained from the undecalcified sections indicated that there was some increase in the width of the nasal cavity. A change in the floor of the nose or the roof of the mouth was also noted. As the separation of the maxillae progressed, it can be hypothesized that they were moved in an outward and possibly upward direction. The midpalatal edges of the maxillary palate moved in an outward direction as well. This combination of events not only resulted in a widening of the nasal cavity, but also a flattening of the roof of the oral cavity. On a lateral headplate this might extend an impression of a dropping or lowering of the nasal floor as illustrated by Haas.[4] In actuality, it may possibly be a tilting of the nasal floor as the maxillae are moved in a lateral direction. This combination of reactions to the orthopedic procedure could conceivably result in a flattening of the palatal vault.

It has been expressed by Haas that patients clinically subjected to this procedure feel pressure in the vault of the palate, in the region of the alveolar processes, and in the frontonasal region. Some patients indicate a sensation of some pressure in the region of the cheeks and a spot slightly posterior to this area. Interestingly enough, this clinical reaction could be somewhat corroborated by the histologic reactions of the various remote sutures studied. The sutures in the nasal area showed the greatest reaction to the maxillary expansion procedure. As the maxillae are separated at the level of the palate, the more superior aspects of these bones are changing in relation to adjacent bones. This explains the pressure that has been noted, clinically, at the bridge of the nose. The sutures in the area of the nasal complex were obviously disrupted. The second most active suture was found to be the zygomatic-maxillary suture and some adjustment was noted in as remote an area as the zygomaticotemporal suture. It could be hypothesized that the zygomatic bone was being moved as well as the maxillary bone. One could assume that the maxillary bones could move or slide along the maxillary-zygomatic suture permitting the development of a greater width to the maxillary palate. However, the fact that adjustment was noted in the zygomaticotemporal suture, even though it was minimal in nature, would tend to indicate that the zygomatic bone is being moved as well.

It is difficult to determine where the fulcrum of rotation for the maxillary bones would be located. In all probability the cranial base level at the area of junction with the nasal bones would be the superior adjustment area. Some area more posteriorly located, close to the zygomaticotemporal suture area, would be the probable posterior area of adjustment. No matter where the fulcral areas are located, the findings in this study indicate that this orthopedic procedure should not be initiated without careful thought and consideration. Unquestionably, bones of the maxillary facial complex are reoriented and changed in their relationships to adjacent bones. Adjacent sutures are affected, necessitating adjustment to newly achieved positions of the maxillary bones. Since bones are repositioned it would behoove the orthodontist to be secure about the desirability of undertaking such a procedure. He should also be careful in evaluating the end result of such bony repositioning.

Summary and Conclusions

Previously it has been shown that the midpalatal suture can be expanded and that new bone is rapidly formed in the area of the bony defect. A histological investigation of the maxillary teeth was done on rhesus monkeys subjected to rapid maxillary expansion.

Results showed that, in the control animal, the periodontal membrane and alveolar bone appeared normal. The fibers of the periodontal membrane were well oriented. The vascular bed and cellular elements were also within normal limits. In the animal that was expanded for three months the periodontal fibers were disorganized with a wider periodontal membrane on the palatal side. The alveolar bone showed resorption on the pressure surface. The reactions seen in the animal that was retained for four months, and the animal that was retained for four months and then placed in postretention for four months, showed progressively less reaction. The evidence indicates that tooth movement was predominantly bodily rather than tipping.

The facial sutures were the nasal suture, the maxillary-zygomatic suture, and the zygomaticotemporal suture. Normally growing sutures were seen in the control animal. In the monkeys subjected to palatal expansion, all three sutures showed evidence of great cellular activity, the nasal suture showing the most. The reactions appeared less the longer the animals were retained after expansion. In conclusion this study indicates that, as a result of rapid expansion of the midpalatal suture of the monkey, concomitant changes occur in the surrounding structures.

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