THE USE OF METALLIC IMPLANTS TO STUDY THE EFFECTS OF
INDUCED RAPID MAXILLARY EXPANSION IN THE MACACA
MULATTA MONKEY BY MEANS OF LATERAL CEPHALOGRAMS

A Thesis

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By

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INTRODUCTION

Induced rapid maxillary expansion uses orthopedic forces to open the midpalatal suture in patients who exhibit severe maxillary constriction. This is accomplished by placing orthodontic bands on two or more teeth in each of the maxillary posterior segments and attaching a jack screw to their lingual surfaces. The jack screw is turned at regular intervals, creating heavy forces which result in the separation of the maxillae at the midpalatal suture. When the desired amount of expansion has been accomplished, the appliance is fixed so that it can neither open nor close. The appliance maintains the separation until the defect created is filled in by new bone formation. The period of active appliance manipulation is approximately 10-12 days, followed by three months of retention. At the end of this period the increase in the maxillary denture base width becomes stable, and conventional orthodontic procedures can be started.

The changes in the midpalatal suture resulting from rapid maxillary expansion have been well documented in the orthodontic literature. However, the accompanying changes in the contiguous regions of the maxillae have not been clearly determined. When the two maxillae are separated at their suture and moved apart, the orthodontist should be aware of changes produced
other than those apparent in the occlusal relations. A review of the literature on this subject indicates that the orthodontist is not always aware of such changes.

The purpose of this study was to attempt to develop a technique by which any changes which occur in the cranio-facial complex of bones, related to induced rapid maxillary expansion, can be documented by cephalometric radiographs. Metallic implants, placed in the bones adjacent to the cranio-facial stutures of Macaca Mulatta monkeys were studied by lateral cephalometric radiographs in order to detect any movement in their position due to separation of the maxillae. I believe that the technique developed in this study could aid in determining what, if any, changes occur.
LITERATURE REVIEW

From the time this technique was first reported by E. H. Angell in 1860 there has been serious concern about the changes produced in the facial skeleton by separating the maxillae. Angell’s conclusion that increases in maxillary width could be accomplished by separation of the maxillae caused immediate concern. The question was raised as to the relative value of correcting irregularities in the dentition by this method when you may be causing serious disturbances in the bones surrounding the maxillae.

Goddard (1893), Ottolingui (1904), and Willis (1911) among others reported cases treated with a maxillary expansion appliance. The primary emphasis in these reports was on indications for treatment and the degree of clinical success attained. Not until Debbane conducted his study on cats did we begin to acquire some radiographic and histologic evidence of the results of this procedure. Debbane showed that the maxillae did actually separate under these heavy forces. Haas in a similar investigation, using pigs, showed that while some of the expansion noted in the dental arch was due to tipping of the teeth in a buccal direction, most of it was the result of separation of the maxillary bones at the midpalatal suture. Haas also produced histologic evidence of bone repair of the palatal defect created by rapid maxillary expansion.
Cleall, in a study using Macaca Rhesus monkeys which were subjected to rapid palatal expansion, confirmed the results of Debbane and Haas and went one step further in studying the suture during the post-retention period. Histologic and radiographic examinations revealed the suture demonstrated no evidence of breakdown and resembled a normal suture area.

Starnbach, noting that the bones of the cranio-facial complex are united at sutures, reasoned that change in the position of bones at one area would involve sutural adjustment of bones in the adjacent areas. Using Macaca Rhesus monkeys as experimental subjects, he examined histologically the fronto-nasal, maxillo-zygomatic, and zygomatico-temporal sutures for bone changes resulting from splitting the midpalatal suture. The increased cellular activity found in these areas indicated that changes were occurring in these bony sutures.

Haas, in a clinical study of 45 patients who underwent rapid palatal expansion, found that cephalometric point A always moved forward and in many cases moved downward as well. This finding, together with the increase in the angle of convexity and SNA angle, led Haas to surmise that while the maxillae moved laterally, marked activity and adjustment must be occurring at the sutures of the cranial and facial bones with which the maxillae articulate. As the sutures open and the bones slide, the maxillae is displaced forward and sometimes downward. Davis and Kronman, in a cephalometric study of 26 children who had undergone rapid maxillary expansion, found a similar response in point A.
Both Issacson\textsuperscript{10} and Krebs\textsuperscript{12} made use of metallic implants in the maxillary alveolar bone and in the zygomatic process of the maxilla to evaluate the type and amount of bone separation at the midpalatal suture. They concluded, from a comparison of pre- and post-expansion cephalograms, that the maxillae not only moved laterally but rotated, with the lateral aspect moving upward.

Issacson,\textsuperscript{9} in a study of midpalatal expansion on cleft palate patients, suggested that the major resistance to forces applied to separate the maxillae is not the midpalatal suture but the remainder of the maxillary bone articulations. He concluded that "the maxillae can be laterally positioned, but the manner by which this occurs and the response of the facial skeleton deserves considerably more investigation." Davis suggested the use of metallic implants as a method for analyzing the changes in the facial skeleton resulting from induced rapid maxillary expansion.
METHODS AND MATERIALS

The technique used in this study consisted of an evaluation of lateral cephalograms taken immediately preceding and following induced rapid maxillary expansion of two female Rhesus monkeys (Macaca Mulatta). Metallic implants were surgically placed on either side of each of the selected facial sutures to be examined. The reason for the use of implants was that any movement in the suture would result in movement of the implants which could be recorded by superimposition of the oriented cephalograms.

Rhesus monkeys were chosen because of their close anatomic relationship to man. However, there is a significant difference in the facial anatomy. The monkey has a separate premaxilla which articulates with the maxillary bones distal to the lateral incisors. The maxillary midpalatal suture is continuous with the premaxillary-maxillary suture and does not continue through the premaxilla. These differences would have to be considered in any attempts to apply experimental conclusions to clinical orthodontics.

These animals were obtained through The Ohio State University Animal Research Laboratories. Monkey number one was not born in captivity and thus its age of five years had to be estimated through dental eruption tables for this species. This animal exhibited a complete permanent dentition, with all teeth in occlusion.
except for the unerupted third molars. Monkey number two was born at the laboratory on August 10, 1967, and thus its age was accurately determined. This animal had a complete deciduous dentition, with the permanent first molars also in occlusion.

A dried skull of the Macaca Mulatta was used to locate the positions of the facial sutures to be studied and to predetermine the positions of the metallic implants (Fig. 1). The sutures chosen to be studied by this technique were the right and left fronto-maxillary, fronto-zygomatic, zygomatico-maxillary and left zygomatico-temporal. The pins were positioned so that the right and left sides of the facial skeleton could be distinguished on lateral cephalograms. Fourteen implants were determined to be necessary for this study. (Table 1, Fig. 2).

The implants used were .031 threaded stainless steel pins which were screwed into a hole made in the bone with an .027 spiral drill using a conventional dental headpiece. The handling of the pins during placement was simplified by the use of a wrench specifically designed for this purpose. These pins, drills, and wrench are supplied in a kit by Whaledent Manufacturing Company. The primary use of this pin kit is in restorative dentistry procedures, but it proved to be ideal for our needs. Using Sernalyn, a CNS depressant specific for use with primates was used and nitrous oxide general anesthesia, the monkey was immobilized. Under sterile surgical procedures, an incision was made in the skin and periosteum over the desired area in order to expose the predetermined areas of the cranio-facial skeleton. A hole was then made in the
bone with the spiral drill and a pin was screwed into place and cut flush with the bone, using orthodontic pin cutters. The wound was irrigated and closed with interrupted silk suture material. The post-operative recovery for both animals was uneventful. Post-operative medication consisted of 600,000 units of bicillin every other day for prophylaxis against infection, and 5 mgm. of elixir of phenobarbital three times a day for five days to decrease the activity of the monkeys during the healing period in order to minimize the irritation of the surgical areas.

Each monkey was again immobilized and positioned in a Broad-bent-Bolton cephalometer, and a baseline lateral radiograph of the pin positions was made. The positions of the ear rods and nosepiece and the midsaggital-to-film distance were recorded for each animal. Baseline occlusal radiographs were also taken at this time.

The cephalometer had to be modified to accommodate these eight- and twelve-pound monkeys. This involved construction of narrower and longer tips for the ear rods in order to fit them in the external auditory canals of the monkey and to adjust them to the inter-meatal width of these small animals. These were constructed of clear acrylic resin and fitted to the existing ear rods and checked for the proper length and alignment.

Other modifications included an acrylic plate 1/8 inch thick which was attached to the adjustable nonepiece of the cephalostat and positioned for each animal beneath the mandible to help support the head in a set position. A seat constructed of 1/4 inch plywood was attached to a standard dental chair, the back of which was in a
completely prone position. The position of the dental chair was marked on the floor, and the height of the chair was recorded for each animal when positioned in the cephalostat.

As a further aid in orienting the head position on subsequent radiographic examinations, each monkey was tattooed on the skin over the frontal eminence and the right and left infra-orbital areas. Plastic rods, sharpened to a point, were placed in contact with each of the three tattoos and fixed in that position to the nosepiece of the cephalometer. This tripoding effect allowed repeatable accurate location of the head. These accommodations were deemed necessary to assure, as accurately as possible, the repositioning of the monkey’s head following palatal expansion, (Fig. 3).

Prior to the construction of the palatal separating appliance, separation of the teeth for banding was obtained by stripping the interproximal areas of the teeth with vulcarbo discs in a dental hand-piece. At this time a silicone impression was made of the separated teeth. This impression was sent to T.P. Laboratories, La Porte, Indiana, for the indirect fabrication of orthodontic bands on the second premolar and first and second permanent molars of monkey number one and on the first and second deciduous molars and the first permanent molar of monkey number two (Fig. 4). These bands were fitted to the monkey’s teeth and a silicone impression was made. The bands were removed and waxed to place in the impression, and a working model was poured in dental stone.
A Haas 6 type split acrylic palate expansion appliance was constructed (Fig. 5). A .036 base wire was soldered to the lingual surfaces of the orthodontic bands. A central expansion screw was waxed to place, centering it on the midpalatal raphe, and cold-cure acrylic was adapted over the lingual wire and the lateral aspects of the expansion screw on each side. The finished appliance was seated to place in the monkey's mouth with orthodontic cement for retention.

Activation of the appliance consisted of two consecutive 0.25 mm. turns of the screw per day. Continued for twelve days, this produced a maximum opening of approximately 6 mm. for the screws used in these appliances.

At the end of the period of activation the monkey was repositioned in the cephalostat, the baseline settings were duplicated, and a lateral cephalogram was made. The appliance was then fixed in position with a wire ligature and cold-cure acrylic so that the amount of expansion could be maintained for further studies involving histologic examination of the suture areas.

Tracings, which included the pin positions, were made of the pre- and post-separation head plates. The three pins in the frontal bone, one in each fronto-zygomatic process and one in the glabella, were assumed to be stable through the procedure because of their position in a cranial bone which should not be affected by the separation of the maxillae. These three pins, hereafter called reference implants were therefore chosen as the registration point
for superimposing the two tracings. The most anterior-superior position of each pin was used as the point of measurement of change in position of the pins. (Figure 6.)
RESULTS AND DISCUSSION

After six days of appliance activation in monkey number one, frontal and occlusal radiographs were taken. These views failed to reveal any sign of palatal separation. Clinical examination revealed an increase in the intercanine width, but exact measurements were not made at this time. There was no sign of a diastema between the maxillary central incisors which would indicate that the premaxilla had separated. Cleall had pointed out that even though there was an increase in cellular activity in the bone between the central incisors of the monkeys following rapid palatal expansion, a diastema did not necessarily appear. Thus the maxillae could be separated without producing a midline diastema. This could be explained by the presence of anatomically separate premaxilla found in the Rhesus monkey.

On the eleventh day of appliance activation in monkey number one, it was found that she had removed the appliance from her mouth. Up to this time there was no evidence that maxillary separation had occurred in this animal. Sacrifice of the monkey and dissection of the palate proved this to be the case. It is surmised that this monkey, the older of the two subjects, had reached a level of development where ossification of the maxillary sutures was advanced enough to prevent separation. Histologic examination may indicate those
sutures in which ossification was advanced or complete in this animal. It must be concluded that this animal's age was too far advanced for successful rapid palatal expansion to occur.

To prevent monkey number two from removing the separating appliance before completion of the activation and record-taking, a chair specifically constructed to control the activity of the monkey was used. This chair was constructed of adjustable plexiglass parts, its primary feature being a partition which was fitted to the monkey's neck and which prevented her from reaching her mouth with her hands. This chair proved to be successful for the purpose for which we used it, and future investigators should consider its use in similar experiments.

Following appliance activation, frontal and occlusal radiographs revealed maxillary and premaxillary separation had occurred in monkey number two. This was verified clinically by the presence of a 1.5 mm. diastema between the maxillary central incisors, Fig. 7). The occlusal radiographs demonstrated a separation of premaxilla from the maxilla by a widening of the premaxillary-maxillary suture (Fig. 8).

Examination of the superimposed tracings of the lateral cephalograms revealed that the reference implants were stable and did serve the purpose of registration points for superimposition of the head plates. Implants 4 and 5 located in the frontal process of the right and left maxillae bones had moved downward approximately 1 mm. A possible explanation of this movement can be found in Haas's
description of the widening of the maxilla in a triangular configuration with the apex at the fronto-maxillary suture. As the maxillae separate, the base of the triangle increases; and since the length of the legs of the triangle remain constant, the apex must move downward. Lawrence’s finding of tension in the area of the fronto-maxillary suture during rapid maxillary expansion also indicates this type of movement.

Implants 6 and 7 located in the right zygomatic bone showed no movement on the lateral cephalograms studied. This does not necessarily mean that they did not move. Igleburger in a concurrent study of frontal radiographs showed that these implants did move but movement was in a lateral direction only. Implants 9 and 11 located in the right maxillae also showed no movement on the lateral radiographic examination. A similar explanation as seen in #6 and #7 would apply to these results.

Implant number 13, which was in the zygomatic process of the temporal bone, moved the same amount and direction as number 14 which was in the temporal process of the left zygomatic bone. It was anticipated that this implant would not move at all, since it was placed in a bone of the cranium which would not be affected by movement of the maxilla. This assumption proved incorrect in this study. Any explanation for this movement would be conjecture. One possibility may be that the zygomatico-temporal suture was ossified to the extent that movement of the zygoma resulted in movement of the temporal bone. Whether this explanation is correct or not, the
possibility of its occurrence would warrant the placement of implants in more of the bones of the cranium in future studies of this type.

Implants 10 and 12, both in the left maxilla, moved equally upward and forward approximately 0.5 mm. This concurs with Haas's finding that when the maxillae moved apart they also moved forward, as indicated by the movement of cephalometric point A.

Various explanations may be offered for the difference in reaction to this procedure of the right and left side of the monkey's face. Among these are: (1) Assymmetrical construction of the appliance results in unequal forces exerted; (2) lack of facial symmetry; (3) differences in sutural aging.

The author realizes that any results and observations made in this paper are necessarily restricted by the monkey used. Some of the proposed explanations of the results obtained go beyond the scope of this paper. However, these are offered as possible areas of exploration for future studies on larger numbers and age ranges of experimental subjects.
SUMMARY AND CONCLUSIONS

A study was conducted to evaluate the effectiveness of a technique using lateral cephalograms to follow the movement of metallic implants located in the maxilla and contiguous bones of a Macaca Mulatta monkey with induced rapid maxillary expansion. Radiographs taken at pre- and post-appliance activation indicated that the implants in the frontal bone could be used for registration points to superimpose the cephalograms. They also revealed that implants in the left maxillae, left zygoma, and left temporal bone moved as a result of rapid maxillary expansion.

The technique proposed in this paper was shown effective in studying the adjustment of the craniofacial complex of bones in Macaca Mulatta monkeys which are subjected to induced rapid maxillary expansion.
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<td>Left zygomatic process of frontal bone</td>
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<td>4</td>
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<tr>
<td>5</td>
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<tr>
<td>13</td>
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Figure 1. Dried skull illustrating position of implants.
Figure 2. Tracing of baseline lateral radiograph showing position of implants.
Figure 3. Monkey positioned in modified Broadbent-Bolton cephalometer.

Figure 4. Impression, model, and orthodontic bands on working model.
Figure 5. Palate separating appliance.
Figure 6. Superimposed tracings of pre- and post- expansion lateral radiographs.
Figure 7. Midline diastema present following palatal expansion.

Figure 8. Post-expansion occlusal radiograph.
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