ROENTGENOGRAPHIC ANALYSIS OF THE PALATAL PLANE IN THE
MACACA MULATTA MONKEY WITH RAPID PALATAL EXPANSION

A Thesis

Presented in Partial Fulfillment of the Requirements
for the Degree of Master of Science

by

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INTRODUCTION

Rapid palatal expansion is a dentofacial orthopedic procedure for expanding the midpalatal suture of the maxilla. The technique has been used to correct maxillary deficiencies, maxillary arch length discrepancies, class III malocclusions, cleft palate conditions, and nasal stenosis. It has been met by varying degrees of acceptance since its introduction in 1859. Lack of knowledge of the effects the forces have on the total craniofacial complex and fear of the unknown dangers involved, delayed widespread use of the procedure.

To produce palatal expansion, a heavy intermittent force generated by a jackscrew mechanism is used. The jackscrew transmits the force across the palate, via a split acrylic palate piece, directly to bands cemented to posterior teeth; .5 mm of expansion per day over a period of two to three weeks with forces of sixteen to thirty-four pounds is employed.

The primary orthodontic objective in separating the maxillary mid-palatal suture is to coordinate the maxillary denture base to the mandibular, and in so doing improve the facial profile. As related in the literature, this is accomplished by increasing the arch length of the
maxilla as well as changing the position of the maxilla relative to the other craniofacial bones.

The radiographic and histological changes that occur in the midpalatal suture are well documented in the literature. However, the varied movements of the individual craniofacial bones are not precisely understood at this time. Since the bones of the craniofacial complex approximate each other at sutures, changes in the orientation of bones in one area may elicit positional changes of bones in another region.

The purpose of this study is to attempt to evaluate the positional change of the palatal plane and any changes between the premaxilla and maxilla in the Macaca mulatta monkey as a result of rapid palatal expansion. The study design incorporated the use of metallic implants and lateral cephalograms.
REVIEW OF LITERATURE

Rapid palatal expansion was first reported in the literature in 1859 by Wescott.\textsuperscript{43} He used a form of removable appliance to "spread the jaw" over a long period of time. Due to this longer period of activation, he may have produced only tipping of the teeth or bending of the alveolar process rather than an actual separating of the midpalatal suture of the maxilla.

Angell\textsuperscript{1} in 1860 used a jackscrew that crossed the palate and connected with gold bands cemented to bicuspids teeth. His results were more conclusive in proving that he actually separated the suture, for he stated: "The jaw was so much widened as to leave a space between the front incisors." Much controversy accompanied these early reports. In the same issue as Angell's report, McQuillen\textsuperscript{33} in an editorial wrote:

\ldots but (we) must beg leave to differ with the writer in the conclusion arrived at, that by the use of the apparatus described he succeeded in separating the superior maxilla from each other. With no disposition to assert that such a thing is utterly impossible, yet, when taking into consideration the anatomical relations existing between the right and left superior maxilla and the other bones of the face with which they articulate, such a result appears exceedingly doubtful. Even admitting the impression of the writer to be correct, it would be a strong argument against the use of such an apparatus: for surely the irregularity of the teeth is a trifling affair compared
with the separation of the maxilla, which could not take place without serious disturbance in the hard and soft parts.

Controversy over these early reports centered around the lack of knowledge of the effects the forces of palatal expansion had on the complete craniofacial skeleton and the dangers involved. This was complicated by the fact that at this date radiography was not available to confirm or disprove their reports. Also, the majority of the early investigators were more concerned with widening the nasal airway than with the orthodontic results.

Haas in a recent article listed the early opponents to rapid palatal expansion as: McGuillan (1860), Farrar (1888), Cryer (1913), Fiederspeil (1914), Kemple (1914), and Stanton (1914). The early advocates of the procedure from the United States were listed as: Goddard (1893), G. V. Black (1893), Monson (1898), G. V. I. Brown (1904), Ottolingui (1904), N. M. Black (1909), Landsberger (1910), Willis (1912), Wright (1912), Barnes (1912), Hawley (1912), and Pullen (1912). European orthodontists that continued to use the procedure were listed as: Babcock (1911), Schroeder-Bensler (1911), Huet (1926), Mesnard (1929), Derichsweiler (1952), Korkhaus (1953), Krebs (1958), Thorne (1960), and others.

Haas states that the functional concept of bone development brought disfavor to the use of the rapid palatal expansion appliance during the period from 1910 to 1938.
Well-known orthodontists during these years—Angle, Case, Dewey, and Ketcham—endorsed this concept. This theory involved expansion of the teeth to a point where the alveolar bone would follow by growth. The staff at the Department of Orthodontics, University of Illinois, discounted this concept with information from a study in 1938. This paved the way for the reintroduction of the procedure in the United States by Korkhaus, Brodie, and Haas.

The more recent investigations have placed more emphasis on the orthodontic results rather than on the correction of nasal stenosis. Questions that they have tried to answer are: What are the effects of the forces on the complete craniofacial complex; and what is the actual path of movement of the maxilla during the procedure?

Dembene in 1958 studied the histologic and cephalometric effects of rapid palatal expansion on cats. With the aid of cephalometrics, he found the premaxilla repositioned in a downward direction, except in cases where disarticulation at the sutures did not take place. In these cases the position was changed to a vertical displacement. Histologically, he found increased activity at all facial sutures. The new suture that was formed filled in with bone and was reestablished to normal.

Cheall (1965), using Macaca monkeys, found that with expansion the midpalatal suture was split and the bony defect quickly filled with new bone.
Starnbach\textsuperscript{41} (1966), in another study with the Macaca monkey, found that the zygomatic bones moved laterally with the maxilla. The maxilla split and seemed to rotate around the midpalatal suture with a flattening effect to the palate. Histologically, among the facial sutures, he showed the greatest activity was at the nasal suture with the least amount of activity at the zygomatico-temporal.

Igleburger\textsuperscript{24} (1970) used metallic implants and frontal radiographs to study two Macaca monkeys. He found that the zygomatic bones moved laterally as a result of palatal expansion. Movement of the maxilla and zygomatic bones occurred as a rotation around an anterior-posterior axis near the zygomatico-frontal suture. Lindenfelder,\textsuperscript{31} using lateral cephalograms on the same monkeys, found that the lateral portions of the maxilla moved upward and forward while the frontal processes moved in a downward direction.

Gardner and Kromer\textsuperscript{16} (1971), using six Macaca monkeys, found that the maxilla moved downward and forward with expansion. Activity at the sphenoccipital suture was also noted. They thought that this activity may have been partially responsible for the forward and downward movement of the maxilla.

Many cephalometric studies have been done on humans undergoing rapid palatal expansion. Krebs (1959)\textsuperscript{28} reported that the maxilla rotated in the transverse and
frontal plane during the separation. He also found that
the lateral portions of the maxilla moved upward, with the
vomer being attached to either one of the maxillary bones
or on occasion remaining stationary. Wertz \(^{42}\) (1970) showed
that the maxilla also rotated in the frontal plane. This
was verified by Haas (1961,1965).\(^{18,19}\) who showed that
the maxilla separated along the midsagittal suture in the
form of a triangle with the apex at the superior aspect.

From lateral cephalograms, Haas\(^{18}\) showed point A
moved in a forward direction and, in approximately fifty
per cent of the cases, also in a downward direction. Davis
and Kronman,\(^{12}\) Biederman,\(^{3}\) and Issacson and Murphy\(^{25}\) also
showed that point A moved in a forward direction. Haas
theorized that the downward and forward movement was
carried by the relationship of the facial sutures (hafting
zone) and the adjustments in these sutures that takes place
as the midpalatal suture opens. Biederman theorized that
the forward movement of point A was due to the rotation
of the maxilla in a horizontal plane around the maxillo-
palatine suture. The resulting wider opening of the
suture in the anterior would move these parts laterally
and forward as the maxilla disarticulated and was in
essence pushed forward at the posterior. Biederman also
found that if the maxilla disarticulated with the adjacent
bones, point A would drop downward. However, if no disar-
ticulation occurred, point A moved in an upward direction.
This follows Debbane's findings with the cat. Issacson and Murphy\textsuperscript{25} (1964) researched the affect of rapid palatal expansion on cleft lip and palate patients. These subjects provided a chance to evaluate the buttressing of the sutures with negligible effect from the mid-sagittal suture. The results showed that from the lateral view, the maxilla moved in a superior and anterior direction. This result may have been due to the absence of resistance from the midpalatal suture. One 22-year-old subject's palate did not split with the procedure. This they attributed to the large amount of resistance exhibited by the buttressing action of adjacent bones. Krebs\textsuperscript{29} (1964) agreed with this conclusion, for he stated that the buttressing action of the adjacent bones to the maxilla was greater than the opening of the suture. Zimring and Isaacson\textsuperscript{46} studied the forces present during the retentive phase of palatal expansion and concluded that the forces were so high that they could not attribute them solely to the midpalatal suture but also had to include the articulating sutures.

A review of literature on this subject indicates a variance of opinion concerning the repositioning of the craniofacial bones due to rapid palatal expansion. This may be attributable to biologic variance or possibly sample size and type.
A brief review of some of the movements made by the maxilla that are pertinent to this study are: The pre-maxilla moved down in the studies by Haas and Reid. It moved upwards in studies by Issacson & Murphy and in a few samples in Biederman's study. The palate dropped according to Biederman, N. H. Black, Byrum, Haas, McCurdy, and Wertz. Davis and Kronman found that the palate remained in the same vertical relationship during the expansion. The rotation of the maxilla along an anterior-posterior axis around the zygomaticomaxillary suture seems to be the consensus of most of the researchers. The non-standardization of variables in these findings results in the variance of conclusions.
METHODS AND MATERIALS

The Macaca mulatta monkey was used as the sample in this study. The resultant movement of bones from rapid palatal expansion were recorded by superimposing tracings of lateral cephalograms. Employment of metallic implants helped pinpoint the movements and superimpositions.

Animals

The Macaca mulatta monkey was chosen for use in this study because of its similarity in anatomy and histology to that of humans. The monkeys have the same number and types of both deciduous and permanent teeth. The dental eruption pattern is also similar to humans. The human and monkey skull are essentially the same except that the human premaxillae is an integral part of the maxilla, while the monkey premaxillae remain as separate bones articulating with the maxillae at the maxillo-premaxillary suture. This suture closes at approximately eighteen months of age. The premaxillae articulate with each other on the medial aspect at the interpremaxillary suture, with the maxilla on its posterior border and with the vomer on its superior medial border forming the vomer-premaxillary suture.
Ten *Macaca mulatta* monkeys were obtained through the Ohio State University Laboratory Animal Center Procurement Service. They were quarantined for sixty days at the Ohio State University Laboratory Animal Center Quarantine Station to reduce the high risk of introducing monkey pox, tuberculosis, and other common infectious diseases. Following the sixty day quarantine, the monkeys were housed at the Department of Animal Laboratories, located at Wiseman Hall on the Ohio State University campus.

The initial weights of the monkeys ranged from 4-1/2 to 6-1/2 pounds. The estimated age ranged from twelve to twenty-four months, based on the findings of Haigh and Scott\(^{20}\) (1965) and Herm\(^{23}\) (1963). Each animal had a full complement of deciduous teeth, and the older monkeys had their permanent first molars.

**Study Design**

The ten monkeys used in the study had twenty-one metallic implants placed at specific positions near craniofacial sutures. Two of the monkeys were randomly selected as controls. The other eight monkeys had the rapid palatal expansion appliance placed on the maxillary teeth. These eight monkeys were assigned treatment times based on the length of treatment and amount of activation. Lateral, frontal, and basilar headplates were taken prior to the placement and activation of the appliances. The experimental
## TABLE I
STARTING DATA

<table>
<thead>
<tr>
<th>Monkey Number</th>
<th>Grouping</th>
<th>Sex</th>
<th>Starting Dental Formula</th>
<th>Starting Weight (Pounds)</th>
<th>Estimated Age* (Months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control</td>
<td>Male</td>
<td>edcba abcde6 edcba abcde6</td>
<td>5 3/4</td>
<td>18-21</td>
</tr>
<tr>
<td>8</td>
<td>Control</td>
<td>Male</td>
<td>edcba abcde6 edcba abcde6</td>
<td>5 1/2</td>
<td>18-21</td>
</tr>
<tr>
<td>2</td>
<td>Treated</td>
<td>Female</td>
<td>edcba abcde6 edcba abcde6</td>
<td>6</td>
<td>18-21</td>
</tr>
<tr>
<td>3</td>
<td>Treated</td>
<td>Male</td>
<td>edcba abcde6 edcba abcde6</td>
<td>4 1/2</td>
<td>12-15</td>
</tr>
<tr>
<td>4</td>
<td>Treated</td>
<td>Male</td>
<td>edcba abcde6 edcba abcde6</td>
<td>4 1/2</td>
<td>12-15</td>
</tr>
<tr>
<td>5</td>
<td>Treated</td>
<td>Male</td>
<td>edcba abcde6 edcba abcde6</td>
<td>6 1/2</td>
<td>21-24</td>
</tr>
<tr>
<td>6</td>
<td>Treated</td>
<td>Male</td>
<td>edcba abcde6 edcba abcde6</td>
<td>4 1/2</td>
<td>12-15</td>
</tr>
<tr>
<td>7</td>
<td>Treated</td>
<td>Male</td>
<td>edcba abcde6 edcba abcde6</td>
<td>6 1/4</td>
<td>21-24</td>
</tr>
<tr>
<td>9</td>
<td>Treated</td>
<td>Male</td>
<td>edcba abcde6 edcba abcde6</td>
<td>5 3/4</td>
<td>18-21</td>
</tr>
<tr>
<td>10</td>
<td>Treated</td>
<td>Male</td>
<td>edcba abcde6 edcba abcde6</td>
<td>5 3/4</td>
<td>18-21</td>
</tr>
</tbody>
</table>

*Age estimated by dental formula and weight according to:
1. Hurme, (1960)
2. Haigh and Scott, (1965)
animals were to be radiographed and sacrificed at three-
day intervals (72 hours). One control was sacrificed at
72 hours for histological purposes but no radiographs were
taken. Following fourteen days of activation, maximum
appliance expansion was attained (6 mm) and the three-day
interval expansion system was disrupted, but the fifth
animal sacrifice time interval of fifteen days was main-
tained. The last three experimental animals were radi-
ographed and sacrificed at sixteen days, thirty-two days,
and sixty-one days after final expansion. Table II lists
the time sequences.

Implants

Metallic implants were placed across selected cranial
and facial sutures prior to expansion of the appliance.
The locations of the implants were planned on a dried
Macaca skull. The sites were selected so that any change
across a suture might be evaluated. Twenty-one implants
were used in the experimental and control monkeys. (See
Figure 1).

"Sernylan," a skeletal muscle paralytic agent, was
used to immobilize the monkeys. After locating the sutures
by inspection and palpation, the implants (small pins of
hard tantalum), Figure 9, were placed in the bone with a
pencil-shaped instrument developed by Bjork. The pins were
placed using a non-surgical technique. The dates of im-
plantation are listed on Table II-A.
### TABLE II
EXPERIMENTAL DESIGN

<table>
<thead>
<tr>
<th>Monkey Number</th>
<th>Control Animals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>72 hours sacrifice for histological uses. No radiographs.</td>
</tr>
<tr>
<td>8</td>
<td>29 day sacrifice with radiographs.</td>
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</table>

### Experimental Animals

<table>
<thead>
<tr>
<th>Monkey Number</th>
<th>Activation Period in Days</th>
<th>Number of Activations by 1/4 Turns</th>
<th>Activation in Millimeters</th>
<th>Time of Sacrifice After Last Activation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td>6</td>
<td>1.3</td>
<td>24 hrs.</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>12</td>
<td>2.6</td>
<td>24 hrs.</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>18</td>
<td>3.9</td>
<td>24 hrs.</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>24</td>
<td>5.2</td>
<td>24 hrs.</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>28</td>
<td>6.0</td>
<td>48 hrs.</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>28</td>
<td>6.0</td>
<td>16 days</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>28</td>
<td>6.0</td>
<td>32 days</td>
</tr>
<tr>
<td>10</td>
<td>14</td>
<td>28</td>
<td>6.0</td>
<td>61 days</td>
</tr>
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</table>
# TABLE II-A

## CLINICAL PROCEDURES

<table>
<thead>
<tr>
<th>Monkey Number</th>
<th>Implants</th>
<th>Dates</th>
<th>Impressions</th>
<th>Appliance Cmentation</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>8/3</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>8/3</td>
<td>8/1</td>
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</tr>
<tr>
<td>8</td>
<td>8/3</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>9</td>
<td>8/3</td>
<td>8/1</td>
<td>8/1</td>
<td>8/7</td>
</tr>
<tr>
<td>10</td>
<td>7/20</td>
<td>7/20</td>
<td>7/20</td>
<td>8/7</td>
</tr>
</tbody>
</table>
Appliance

The rapid palatal expansion appliance was a fixed maxillary device consisting of two acrylic halves with an expansion jack screw placed between the halves. Bands were attached to the lateral aspect of the acrylic (Figure 10).

Sernykan was introduced as slice preparations were made with a small carborundum disk to open the contact areas of the maxillary posterior teeth. Irreversible hydrocolloid impressions were made in custom fitted trays. The impressions were then poured up in orthodontic stone.

Bands were pinched on the stone casts for the first and second deciduous molars and, when present, the permanent first molar. Connecting bars consisting of .040 stainless steel wire were soldered to the buccal and lingual surfaces of each orthodontic band. The lingual wire was extended palatally at the mesial and distal ends.

A small palatal expansion screw (Ortho International Services Inc. number 601-112) was centered at right angles to the midpalatal raphe and parallel to the occlusal plane. A piece of baseplate wax was used to position the screw and keep the two halves separated. Quick cure acrylic was applied to the cast by a dust-on method and built up to cover the expansion screw and the palatal extensions of the lingual bars. After the acrylic had set up, the appliance was separated from the cast and trimmed to make
sure that all portions contacting palatal mucosa were smooth. The wax was then removed, separating the two halves. The appliance was polished with pumice and whiting stone. One to one and a half millimeters of acrylic was trimmed from the midpalatal tissue surface of the appliance to prevent contact with the soft tissue in the midline area of the palate.

The animals were again tranquilized with "sernylan" when the appliances were cemented in the mouths with ordinary orthodontic cement. The procedure used was similar to that used with a human orthodontic patient. The appliance was activated by fitting a small key into the expansion screw. Each activation consisted of a quarter turn (90 degrees) of the screw which resulted in approximately .21 mm of expansion. Two activations per day (180 degrees = .43 mm expansion) were instituted. Three persons were required to accomplish the procedure. Anaesthesia was not used for the activations. The expansion was continued on each monkey (Table II) until a maximum of fourteen days or six mm was reached. The two appliances that were kept in the mouth after fourteen days were fixed by a small brass wire that was fitted through the slot in the expansion screw and secured with a small amount of acrylic.

**Radiographic Technique**

A modified Wehmer cephalometer was used to take the frontal, lateral and basilar radiographs. The standard
headholder was altered because of the small size of the monkeys' heads. Smaller diameter and longer length ear rods were constructed for the adjustable ear posts. To support the monkey's head, a plastic extension was constructed to fit the adjustable nose piece of the headholder.

A custom acrylic seat was constructed to support the monkeys under the headholder. The seat was attached to a standard dental chair which could be raised and lowered. The animal was secured to the chair with tape. (Figures 13 and 14.)

To help insure a reproducible position of the monkey in the headholder, tattoos were placed on the skin of each monkey. Three tattoos were used in repositioning for lateral and frontal headplates—one on the right and left side of the frontal bone in the supraorbital area and one on the left or right infraorbital area. The exact locations of the tattoos were dependent upon where the tips of three sharpened plastic rods contacted the skin. The plastic rods fit into a special portion of the nose piece adaptor. At each subsequent radiographic procedure, the monkey's head was repositioned so that each pointer rested on its respective tattoo mark. Masking tape was used to help immobilize the monkey's head in the headholder.

"Sernylan" was again employed during the taking of the baseline or initial x-rays. Lateral, frontal and basilar radiographs were taken, but the basilar headplates were not
used in this study.

Midline film distance for the lateral radiographs was standardized at thirteen centimeters. Portion-axis film distance was standardized at fourteen centimeters. Several settings were used to achieve the greatest clarity in the films. It was found that the best settings for the lateral films were: 74kVp, 20mA, and 0.5 second. For the frontals, exposure was set at 78kVp, 20mA, and 0.5 second. A General Electric Stationary grid was used when taking all radiographs. The cassettes used in the study were manufactured by the Keleket X-Ray Corporation and contained Radelin T-2 screens.

Thirty-nine radiographs were taken; sixteen were used in this study, and the remaining were discarded because of poor film exposure or lack of a reproducible head position.

Table III is a listing of all films taken. The day of initiation the activation is shown as "0," and the number of days before and after activation are indicated by a "-" or a "+." Typical lateral and frontal radiographs with and without the palatal expansion appliance are shown in Figures 3A, 3B, 3C, and 3D in the Appendix.

Tracings

Tracings were made of the radiographs on "Unitek" acetate film using a fine 4H pencil. The inner and outer cortical plates of the calvarium and all of the metallic
pins were traced from each film used.

Seven cranial implants were used as registration points for superimposing the tracings. The positions of these implants are: one in the glabellar portion of the frontal bone, three in the area of the junction of the coronal and midsagittal sutures, and three in the area of the junction of the occipitomastoid and parietotemporal sutures.

Before a film was considered acceptable for use, these seven pins had to superimpose on one another in order to negate any chance of head movement by the monkey or error in machine angulation. Since there was no measurable growth the pins studied could be accurately measured.

Two tracings were made from the headplates taken on four of the monkeys (#2, #4, #9, #10) before and after activation. On #6 and #7, only two tracings were made, both after activation had started; Monkeys #9 and #10 had an additional headplate traced to check for changes after fixation of the appliance.

The metallic implants chosen for study were the two pins implanted on the premaxilla located on opposite sides of the midsagittal suture, (Figure I, pins #4 & 5) and two pins located on the palatal process of the maxilla, also located opposite each other across the suture. Only one pair of pins (one palatal, one premaxillary) per monkey were used: either pins #4 and #20 or #5 and #21 (Figure I, pins #20 and #21). Although two palatal pins were
implanted in each monkey, only one pin could be positively
identified on the lateral x-rays in some cases. Where two
palatal pins were identified, one side of the monkey was
chosen for study by random selection. Frontal radiographs
were used to insure that the palatal and premaxillary pins
were located on the same side of the midsaggital suture.
To further confirm the identity of the pins, the frontal
radiographs were orientated with the laterals on the Bol-
ton Orientator.

An angular and linear method was used to study the
positions of the pins on superimposed tracings. A base
line was made using two of the stationary cranial pins.
The anterior pin was located in the glabellar portion of
the frontal bone, (Figure I, pin #9). The posterior pin
was located in the area of the junction of the occipito-
mastoid and parietotemporal suture (Figure I, pin #17).
Both the linear and angular measurements were made to the
line connecting these two pins.

The angular method of study was used to arrive at the
direction of change by measuring the angle of convergence
of the palatal plane, one side either pins #4 and #20 or
pins #5 and #21, to the cranial base line.

The linear measurements were used to measure the
amount of change between pins. Measurements were made to
an accuracy of .25 mm but a final limitation of .5 mm was
used to insure an acceptable degree of accuracy. The
distance between the premaxillary and palatal pin was measured along the line connecting the two pins. This measurement should indicate activity such as expansion between the premaxilla and maxilla. The other linear measurement was made to note the vertical movement of the palatal and premaxillary pins. This was done by constructing lines perpendicular to the cranial base line and intersecting with the respective pin, either premaxillary or palatal chosen for study in that monkey. The lengths of these lines were then measured.
RESULTS

Control

There were no significant irregularities noted in the superimposition of the initial and final radiographs of the control monkey. Any lack of total superimposition was well within the value attributed to tracing error. The thirty-six-day span between the initial and final films, with no movement of the metallic implants, indicates that no measurable growth took place during the study.

Angular Change Between the Palatal Plane and the Cranial Baseline

The cranial baseline in this study of the lateral radiograph is defined as the line connecting two of the cranial pins (Figure II, pins #9 and #17). For convenience sake pins #4 or #5 will be labeled pin A, pins #20 or #21 will be labeled pin B (Figures 2, 3, 4, 5, 6, 7, 8). The palatal plane was drawn by connecting the premaxillary pin (A) to the palatal pin (B) (Figure II).

Table IV shows that the angular change in degrees between the palatal plane and the baseline increased in all monkeys with activation, except monkey #10, where it decreased. During three days of activation, the angle

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### TABLE III

**RADIOGRAPHS**

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**Key**

- $X$ - Film Taken
- $X^*$ - Film Used in This Study
TABLE IV
ANGULAR CHANGE, WITH ACTIVATION, BETWEEN THE PALATAL PLANE AND CRANIAL BASELINE BY DEGREES AND DAYS FOR THE MONKEYS INDICATED

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TABLE V
MEAN ANGULAR CHANGE PER DAY, WITH ACTIVATION, BETWEEN THE PALATAL PLANE AND CRANIAL BASELINE BY DEGREES FOR THE MONKEYS INDICATED

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*Mean change/day 0.34 SE 0.147 p < .07
increased 3 degrees in monkey #2, 0.5 degrees in monkey #4. With six days of activation, an increase of 1.5 degrees in monkey #6 and 2.0 degrees in monkey #7 was noted. An increase of 4.5 degrees was noted in monkey #9 over a 12-day period of activation, as previously stated. There was a decrease of 1.0 degree in monkey #10 over the 12-day period of activation.

The amount of change in degrees per day is listed in Table IV. The mean change per monkey day was 0.34 degree, SE 0.147 and P < .07.

Vertical Movement of the Palatal Pin

The vertical movement of the palatal pin was analyzed by a linear measurement of a straight line extending from the palatal pin (b) perpendicular to the cranial baseline. This measurement was made before and after activation of the appliance (Figure II).

The measurement varied; some pins moved superiorly while others moved in an inferior direction. The amount of movement in millimeters is noted in Table VI, both in total amount of movement and change per day of activation. The palatal pin in monkey #2, with 3 days of activation, showed a superior repositioning of 0.5 mm, resulting in a change per day of activation of 0.166 mm superiorly. The pin in monkey #4 moved inferiorly 0.5 mm with the 3 days of
### TABLE VI

VERTICAL MOVEMENT OF THE PALATAL PIN, MEASURED ON A LINE PERPENDICULAR TO THE CRANIAL BASELINE. (+ INDICATES SUPERIOR MOVEMENT, - INDICATES INFERIOR MOVEMENT). MEASUREMENT IS IN MILLIMETERS

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Mean change/day = .00067 mm  SE .0469 no difference

### TABLE VII

VERTICAL MOVEMENT OF THE PREMAXILLARY PIN, MEASURED ON A LINE PERPENDICULAR TO THE CRANIAL BASELINE. (+ INDICATES SUPERIOR MOVEMENT, - INDICATES INFERIOR MOVEMENT). MEASUREMENTS ARE IN MILLIMETERS

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<th>MONKEY NUMBER</th>
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<td>0.0</td>
<td>12</td>
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Mean change/day = .1867  SE .0522  p < .02
activation, giving a change per day movement of 0.166 inferiorly. During six days of activation, the palatal pin (B) in monkey #6 moved inferiorly 0.5 mm, resulting in a change per day movement of 0.086 mm. Monkey #7 indicated no measurable vertical change in the palatal pin. Monkeys #9 and #10 showed a superior movement of the palatal pin of 0.5 mm over 12 days of activation, resulting in a change per day of activation of 0.041 mm. The mean change per monkey day was 0.00067 mm inferiorly, SE 0.0469 showing no difference.

Vertical Movement of the Premaxillary Pin

The vertical movement of the premaxillary pin (A) was analyzed by a linear measurement of a straight line from the pin perpendicular to the cranial baseline. The premaxillary pin moved inferiorly in all animals with activation, except in monkey #10 where no vertical movement was noted. The change in millimeters is listed in Table VII, both in total change and in change per day of activation. Monkeys #2 and #4 showed a downward movement of 1.0 mm over a period of three days of activation, with a change per day of activation inferiorly of 0.333 mm. Monkeys #6 and #7 showed a 1 mm drop of the pin over a six-day period of activation, resulting in a 0.144 mm change per day of activation. During 12 days of activation, monkey #9 indicated a 2 mm movement
<table>
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downward, with a .166 mm change per day of activation. Monkey #10 showed no vertical change during 12 days of activation. The mean change per monkey day was 0.1867, SE .0522 with a P < .02.

Change in Distance Between the Palatal Pin and Premaxillary Pin as Measured Along the Palatal Plane

The distance between the palatal pin (B) and maxillary pin (A), as measured along the palatal plane, changed very little or not at all. The amount of change in millimeters and number of days of activation are noted in Table VIII. The distance decreased 0.5 mm in monkey #2 with 3 days of activation, while it increased 0.5 mm in monkey #9 over 12 days of activation. There were no changes noted in this dimension in monkeys #4 (3 days of activation), #6 and #7 (6 days of activation), and monkey #10 (12 days of activation). Statistically no difference was noted.
DISCUSSION

The results of this study indicate that rapid palatal expansion induces a vertical repositioning of the maxillary complex in the Macaca mulatta monkey. The lateral view studied showed the anterior portion of the complex (the pre-maxilla) moved downward in relation to the cranium a greater degree than did the posterior portion.

Haas, Krebs, and Wertz with humans and Iglesburger and Starnbach, with monkeys reported a rotation of the two halves of the maxillary complex in the frontal plane, the two halves forming a V, with the lateral aspect of the complex moving superiorly while the midsagittal suture area was repositioned inferiorly. This may be one of the explanations for the palatal pin (Table VI) showing no relative change in vertical position. If the pin was placed near the suture, a downward movement would be observed, but with a lateral pin placement an upward movement would be noted. Only a placement of the pin at the axis of rotation would give a true indication of any vertical movement. Another factor involved in measuring the movements of the implants was the small dimensions used in measuring the monkeys' head. Other factors that may have introduced error are: variations in forces and force
vectors exerted by the appliance, and tracing and super-
imposition errors.

The greatest vertical change in the maxilla was noted in the anterior maxillary segment; measurement of the down-
ward movement of the premaxillary pin (Table VII) shows a decisive inferior movement in relation to the cranium.

The angular change between the palatal plane and the cranial baseline showed an increase in all monkeys except #10. This change is due to the positional change between the palatal pin and the premaxillary pin. The palatal im-
plant showed no relative vertical change, whereas the pre-
maxillary implant showed a mean downward movement. This might indicate an intersection of the palatal plane at or near the palatal pin. However, one must consider the incisive suture in the Macaca mulatta monkey, which lies between the palatal pin and premaxillary pin. Butler and others found an indication of histological activity at this suture site. A movement, either rotational or translatory, must be considered at this suture site. A change was noted in the distance between the palatal pin and premaxillary pin (Table VIII). This change was within tracing error, (0.5 mm) but it does maintain the possi-
bility of activity at the incisive suture.
SUMMARY AND CONCLUSIONS

This study was designed to evaluate the positional change of the palatal plane in the maxillary complex of the Macaca mulatta monkey following rapid palatal expansion. Superimposition of lateral radiographic tracings indicated any vertical changes of metallic implants during activation of the appliance. Frontal radiographs were used to verify the identity of the pins.

The rapid palatal expansion appliance was activated in six monkeys, with an additional monkey used as a control. The dentition included a full complement of deciduous teeth with some monkeys having the four permanent molars.

Tracings were made from the lateral radiographs that were taken before and after activation of the appliance. Seven cranial pins were used to accurately superimpose the tracings. A straight line connecting two of the cranial pins was then used as a baseline for measurements. One pin located in the palate and another in the premaxilla designated the palatal plane as used in this study.

The angular measurements between the cranial baseline and the palatal plane increased, indicating a greater vertical drop in the anterior portion of the maxillary complex.
than in the posterior portion. Linear measurements from the palatal pin and premaxillary pin were made on a line perpendicular to the baseline. The premaxillary pin showed a definite inferior repositioning, whereas the palatal pin showed no difference in vertical position. This indicates a rotation of the maxillary complex in an anterior-posterior direction, with the center of rotation at or near the placement of the palatal pin. However, one must consider the incisive suture is the Macaca mulatta monkey, which lies between the palatal pin and premaxillary pin. Butler and others found an indication of histological activity at this suture site. A movement, either rotational or translatory, must be considered at this suture. A change was noted in the distance between the palatal pin and premaxillary pin along the palatal plane as used in this study. This change was within tracing error (0.5 mm), but it does maintain the possibility of activity at the incisive suture.

Improvement in study design would be recommended if this study was to be duplicated. A smaller number of differently shaped implants would enhance pin recognition on the radiographs. Improvement in head stabilization by using bony support versus soft tissue, as used in this study, would improve the reproducibility of the head position.
Future studies should take into consideration that Xerox copies of tracings produced an unequal reproduction resulting in variable measurements. All measurements in this study were made on the original tracings.
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FIGURE 1 IMPLANTS

1. Maxilla-frontal process
2. Maxilla-zygomatic process
3. Maxilla-body
4. Right Premaxilla
5. Left Premaxilla
6. Zygomatic bone-frontal process
7. Zygomatic bone-maxillary process
8. Zygomatic bone-temporal process
9. Frontal bone-nasal process
10. Frontal bone-zygomatic process
11. Frontal bone-anterior to coronal suture
12. Frontal bone-anterior to coronal suture
13. Nasal bone-center
14. Temporal bone-zygomatic process
15. Temporal bone-anterior to junction of occipitomastoid and parieto-temporal sutures
16. Parietal bone-posterior to coronal suture near mid-sagittal suture
17. Parietal bone-anterior to lambdoidal suture, superior to junction of occipitomastoid and parieto-temporal sutures
18. Occipital bone-posterior to junction of occipitomastoid and parieto-temporal sutures
19. Maxilla-body, left side
20. Maxilla-right side of midpalatal suture posterior to maxillopremaxillary suture
21. Maxilla-left side of midpalatal suture posterior to maxillopremaxillary suture
Right Side

Palate

Superior View
Figure 2: **KEY**

(applies to all tracings in the Appendix)

Cranial pins used for superimpositions:

9. **Frontal bone - nasal process. Used for cranial baseline**

12. **Frontal bone - anterior to coronal suture, left of midsagittal suture**

11. **Frontal bone - anterior to coronal suture, right of midsagittal suture**

16. **Parietal bone - posterior to coronal suture near midsagittal suture**

17. **Parietal bone - anterior to lambdoidal suture, superior to junction of occipitomastoid and parietotemporal sutures. Used for cranial baseline**

15. **Temporal bone - anterior to junction of occipitomastoid and parietotemporal sutures**

18. **Occipital bone - posterior to junction of occipitomastoid and parietotemporal sutures**

A represents the premaxillary pins

B represents the palatal pins
Figure 2. Superimposed tracings of first and second lateral radiographs of monkey #8 - Control. First solid; second dotted. Pin A represents the pre-maxillary pin, B represents the palatal pin.
Figure 3. Superimposed tracings of first and second lateral radiographs of monkey #2. First, solid; second dotted. Pin A represents the premaxillary pin, B represents the palatal pin. 3 days of activation.

Figure 4. Superimposed tracings of first and second lateral radiographs of monkey #4. first solid; second dotted. A represents the premaxillary pin, B represents the palatal pin. 3 days of activation.
Figure 5. Superimposed tracings of first and second lateral radiographs of monkey #5. First, solid; second dotted. A represents the premaxillary pin, B represents the palatal pin. 6 days of activation.

Figure 6. Superimposed tracings of first and second lateral radiographs of monkey #7. First, solid; second, dotted. A represents the premaxillary pin, B represents the palatal pin. 6 days of activation.
Figure 7. Superimposed tracings of first and second lateral radiographs of monkey #9. First, solid; second, dotted. A represents the premaxillary pin, B represents the palatal pin. 12 days of activation.

Figure 8. Superimposed tracings of first and second lateral radiographs of monkey #10. First, solid; second, dotted. A represents the premaxillary pin, B represents the palatal pin. 12 days of activation.
Figure 9. Metallic Implants and the Instrument Used to Place Them

Figure 10. The Rapid Palatal Expansion Appliance
Figure 11. Palatal View of the Macaca Mulatta Monkey Skull. Note the Midsagittal Suture and the Incisive Suture which separates the Premaxilla from the Maxilla.

Figure 12. Frontal View of the Macaca Mulatta Monkey indicating the Midsagittal Suture and separate Premaxilla.
Figure 13. Lateral View of the Monkey Positioned in Headholder for the Radiographs.

Figure 14. Frontal View of the Monkey Positioned in the Headholder for the Radiographs.
Figure 15. Lateral Radiograph Without Appliance

Figure 16. Lateral Radiograph With Appliance
Figure 17. Frontal Radiograph, Used for Pin Identification