Facial Changes in the Macaca Mulatta Monkey by Orthopedic Opening of the Midpalatal Suture

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INTRODUCTION

Numerous studies have shown that strong orthopedic forces are capable of opening the midpalatal suture in children and youths. On the horizontal plane this opening may be parallel but is usually wider anteriorly and hence triangular in shape. Because the separated maxillae evidently rotate outward on an axis located in or near the frontal process, the vertical aperature is also triangular.

The initial separation of the maxillary central incisors is the most striking effect of lateral movement. This movement also increases the width of the maxillary arch and hence alters the alignment and occlusion of the teeth; an expansion of the maxillary apical base accompanies these changes.

Within the oral cavity the palatal vault is widened, lowered, and hence flattened; at the same time there is a widening and lowering of the nasal floor and an expansion of nasal width. This often permits straightening of a deviated nasal septum. Remodeling of the nasal passageways increases intranasal space and thus nasal permeability. Other compensatory changes such as lateral expansion of the mandibular arch follow maxillary separation.[13,17,25,31]

Surprisingly little experimental attention has been given to the effect of maxillary separation on the anatomy and configuration of the face. In man there is convincing evidence for a consistent downward and forward movement of the expanded maxillae.[4,10,13,31,34,73] Among the consequences of these changes are a downward and backward movement of the mandible[10,13,25,33,34,73,76] with an opening of the bite and an increase in anterior facial height with an accentuated convexity of the midface. This work deserves further exploration. Evidence for growth, remodeling and other changes involving virtually all the facial and cranial sutures including the spheno-occipital synchrondrosis further suggests that facial changes should be examined.[26] Only when the pervasive effects of midpalatal expansion on the face are known and anticipated can the impact of clinical intervention be successfully predicted and assessed.

The purpose of this study, therefore, was to confirm the midpalatal separation of the maxillae under orthopedic stress and to explore the resultant changes which occur in the bony configuration of the midface.

MATERIALS AND METHODS

The *Macaca mulatta* monkey was selected as the experimental subject. It was felt that its suitable order characteristics outweighed species differences limiting the direct transference of findings to man. These differences included a premaxilla that does not divide in the median plane and a normal buccal occlusion which requires forcing animals into occlusal dysfunction.

Four males and one female, estimated at twenty-two to twenty-six months of age by the method of Hurme,[38] were maintained on Purina

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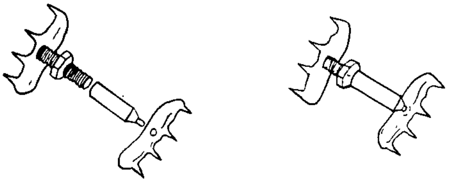

Fig. 1 Maxillary expansion device.

monkey chow pellets fortified with isoniazid for the prophylaxis of tuberculosis. They were also given milk on alternate days to assure optimal dietary calcium. All the animals made comparable weight gains during the experimental period.

To facilitate handling, the animals were tranquilized with a solution of 1-(1-phenylcyclohexyl) piperidine hydrochloride (20 mg/ml) administered intramuscularly. One-fourth milliliter sufficed for a 30 minute interval. One-half milliliter was required for a 90 minute to two hour session.

For purposes of the investigation the animals were randomly distributed into experimental and control groups. Two males and the female were thus selected for experiment with the remaining two males retained as controls.

Appliance

When a banded appliance for effecting movement was repeatedly dislodged by monkey digital interference, a new device was designed and developed. This consisted of a jackscrew and two chrome-cobalt castings with pin-like projections to engage the lingual embrasures of the premolars and first molar on each side of the arch (Fig. 1). Preparation and placement of the device required surgical reduction of the gingival mucosa in these areas.

A measurement of arch width was taken with the appliance initially in position. Then the device was activated until positive pressure was felt. After a 15 minute interval to allow for expansion, the activation was repeated. The appliance was activated a third time after another rest interval. Each of the three activations spread the maxillae approximately 2 mm so a final separation of 6 mm was achieved by the appliance.

Activation of the appliances was neither difficult nor apparently painful. The only response of the animals was a blink of the eyes during the application of positive pressure. At the same moment, transient blanching of the palatal tissues occurred over the area corresponding to the midpalatal suture. The premaxillary areas retained their normal color.

Implants

To facilitate detection and measurement of sutural movement from the radiographs, two stainless steel pins, .020 inch in diameter by 2 mm in length, were implanted on either side of the midpalatal suture in all five animals. For this purpose a trephine needle fitted with a .020 plunger was used to penetrate the soft tissues and to hold the pins firmly against the bone. Short, quick taps upon the plunger with a surgical mallet then embedded the implant in the bone.

Radiographs

Intraoral occlusal radiographs were taken at right angles to the palate before the appliances were placed, after each succeeding activation, and at the end of treatment.

Study Casts

Full upper and lower study casts were made at the beginning and again at the end of treatment from alginate impressions. The casts permitted the measurement of changes in arch form and size during treatment as well as the study of differences between the experimental and control animals.

Vital Stain

To disclose the sites and amount of bone apposition and remodeling, the animals were given 8 ml of a 2% fil-

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tered solution of alizarine red "S" injected intraperitoneally every fourteen days.[62] All seven injections provoked a slight toxic reaction on the day following administration. Noticeable urinary excretion of the dye occurred the first day after injection.

Intact Skulls

The animals were sacrificed with intravenous nembutal eleven weeks after the appliances were first activated. The heads were removed, macerated and left in a colony of dermestid beetles three weeks for final cleaning. This avoided boiling or chemical cleaning of the skulls which might have removed the vital stain. The gross skulls were then photographed and measured.

Sectioned Skulls

In preparation for embedding the skulls were degreased in several changes of acetone and dehydrated in xylol. To prevent the embedding plastic from clearing the fragile bones, the skulls were quickly immersed in an aqueous solution of sodium carboxy methyl cellulose and then allowed to dry in an oven for two hours at 120° F.

For the purpose of embedding the skulls were individually placed in a simple form consisting of a cellophane base and formica sides sealed with heavy duty scotch tape. The sizes were adjusted to give at least 1 cm clearance to the skulls in each dimension.

Plastic embedding was accomplished by the method of Lutz[53] using a polyester resin, styrene monomer, dual promoters and a catalyst. To minimize the heat of polymerization the polyester was poured in seven successive layers at 24 hour intervals. For the final pour a solution of 10% scale wax in toluene was added to the polyester in the amount of 15 drops per ounce to produce a tack free surface.

The cured blocks were squared on a wet sanding wheel and then sectioned with a 1/16 inch thick carborundum disc. Eight frontal sections, 3/16 or 1/4 inch thick, were cut serially from each embedded skull. The cuts began with the incisor teeth and left intact with the cranium posterior to the pterygoid plates. Individual sections were sealed by reimbedding them in four layers of resin. Each completed section was approximately one centimeter thick.

Measurements

Statistical analysis of the small sample was not feasible. Analysis was therefore limited to the detection of gross differences in measurement and to visual inspection of obvious tinctorial and configurational changes.

The distances between the paired implants on either side of the midpalatal suture were measured on the occlusal radiographs. Measurements of maxillary width, palatal depth, maxillary length, and mandibular width were taken with a Korkhaus calipers on the plaster casts. Maxillary width was defined as the distance between the central fossae of the upper first permanent molars. Palatal depth was recorded from the central fossae of the upper first permanent molars but the broad central pin of the caliper made it difficult to obtain accurate readings of this dimension. The length of the maxillae was measured anteroposteriorly from the central fossae of the upper first permanent molars to the anterior surface of the upper central incisors. The mandibular width was established as the distance between the central fossae of the lower first permanent molars.

On the sectioned skulls, measurements were made with the calipers of the width of the floor of the nose, of the middle of the nares, and of the nasal sinus complex. Measurements were also taken of the height of the nasal sinus complex, the shortest distance from the orbit to palate, and the thickness of the palate in the narrowest area.

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TABLE I

MEASUREMENTS OF PLASTER CASTS
(in mm)

	Treated I		*Treated II*		*Treated III*		*Control I*		*Control II*	
	Begin	*End*	*Begin*	*End*	*Begin*	*End*	*Begin*	*End*	*Begin*	*End*
Maxillary width	24.0	30.5	25.5	34.0	23.0	32.0	24.5	25.5	26.5	27.0
Palatal depth	6.2	5.5	7.5	7.5	6.5	6.0	7.0	7.5	10.0	10.0
Maxillary length	29.0	28.0	31.0	30.5	28.0	27.0	30.0	30.5	30.5	32.0
Mandibular width	20.5	22.0	21.5	24.0	20.0	22.0	21.0	21.0	23.0	23.0

TABLE II

MEASUREMENTS OF GROSS SKULLS
(in mm)

	Treated I	*Treated II*	*Treated III*	*Control I*	*Control II*
Arch width	30.0	33.5	31.5	24.5	26.5
Palatal depth	6.0	8.5	7.0	8.0	9.5
Arch length	26.0	29.5	26.0	28.0	29.0
Width of Incisive foramen	7.2	9.5	8.0	4.5	6.0
Anterior nares Width	11.0	13.0	10.9	11.6	10.5
Vertical	12.9	14.2	11.6	14.0	17.0
Interpalatine foraminal distance	12.5	14.5	15.1	10.6	11.2
Nasion to Prosthion	32.0	34.2	34.2	36.7	43.5
Prosthion to external occipital protuberance	91.5	98.0	91.5	98.2	102.0
Length of nasal bone	9.1	10.5	10.5	12.0	20.0
Right orbit Width	21.5	21.5	21.5	21.5	24.1
Height	18.0	19.0	19.5	20.1	21.0
Bizygomatic width	36.0	40.0	37.0	31.1	35.1
Orbital to alveolus	14.5	18.7	15.7	19.0	22.5

Before sectioning, the dry intact skulls were examined and described with a total of fourteen measurements. The location and intensity of vital staining with alizarin red "S" was determined by visual inspection.

Findings

From the radiographic record it is clear that the midpalatal sutures were opened from 3.5 to 5.0 mm on the treated animals while the sutures on the control animals remained undisturbed.

The increase in width of the maxillary arch upon opening of the suture was demonstrable from measurements made on the plaster casts (Table I) and from a comparison of maxillary arch width in treated and control skulls (Table II, Fig. 2). The increased bizygomatic width in the treated animals also reflects lateral separation of the maxillae (Table II). These changes were accompanied by dysfunction of the upper and lower buccal teeth and subsidiary expansion of the mandibular arch (Table I).

Inspection of the sectioned skulls revealed that the palatal vault was

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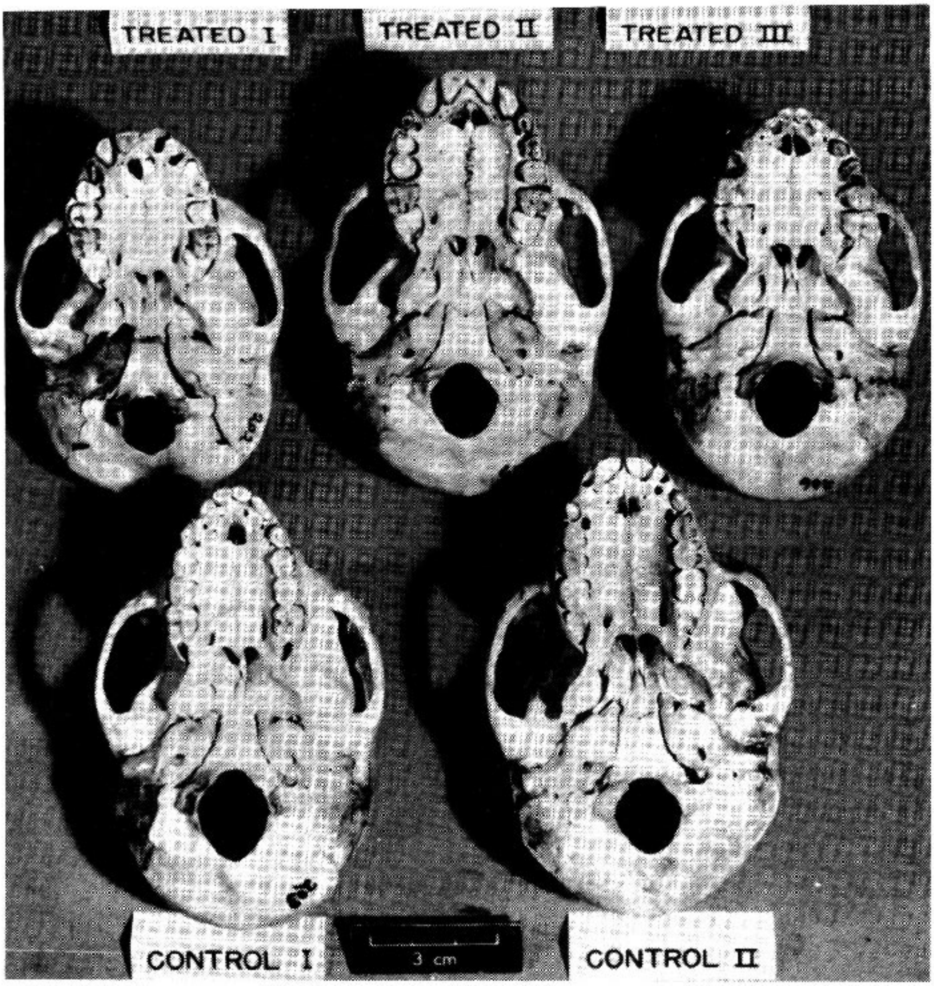

Fig. 2 The rounded shape of the upper arch in the three treated skulls contrasts sharply with the more oblong and narrow upper arches of the control skulls. The midpalatal suture is virtually reclosed with new bone on the treated animals.

widened and flattened in the treated animals. Measurements on the plaster casts and particularly on the intact skulls indicate that the palate was also slightly lowered.

Measurements on both the intact skulls and the skull sections likewise confirmed the expansion of the nasal floor and lateral nasal walls (Tables II, III; Fig. 3). In compensation for the palatal separation, new bone was deposited in the midpalatal suture. At the time the animals were sacrificed, the suture was virtually reclosed in all three experimental animals. In other findings there was an expansion of the incisive foramen and an increase in the interpalatine foraminal distance in the experimental animals.

The definite thinning of the palate at the narrowest area is indicative of a remodeling of palatal architecture. An increase in both the height and breadth of the nasal sinus complex suggests considerable structural remodeling in this area as well. Not surprisingly, the

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TABLE III

MEASUREMENTS OF THE SECTIONED SKULLS
(in mm)

	Treated I	*Treated II*	*Treated III*	*Control I*	*Control II*
Floor of nose Width	9.0	10.0	9.5	5.5	7.0
Middle of Nares Width	12.5	13.5	11.5	10.5	11.0
Nasal sinus Complex Width	23.0 (5)	25.5 (5)	27.0 (4)	21.5 (5)	21.0 (5)
Height	27.0 (5)	19.0 (5)	25.0 (4)	22.0 (5)	20.0 (5)
Orbit to Palate Shortest Distance	14.0 (5)	14.0 (5)	12.5 (5)	14.0 (5)	18.0 (5)
Thickness of Palate	2.0 (4)	2.0 (5)	1.5 (4)	3.0 (5)	4.0 (5)

Fig. 3 Frontal skull sections from experimental and control animals show the relative widths and thicknesses of the palate, the shape of the nasal sinus complex, the orbit to palate, and orbit to alveolus distance, as well as the bite relationship.

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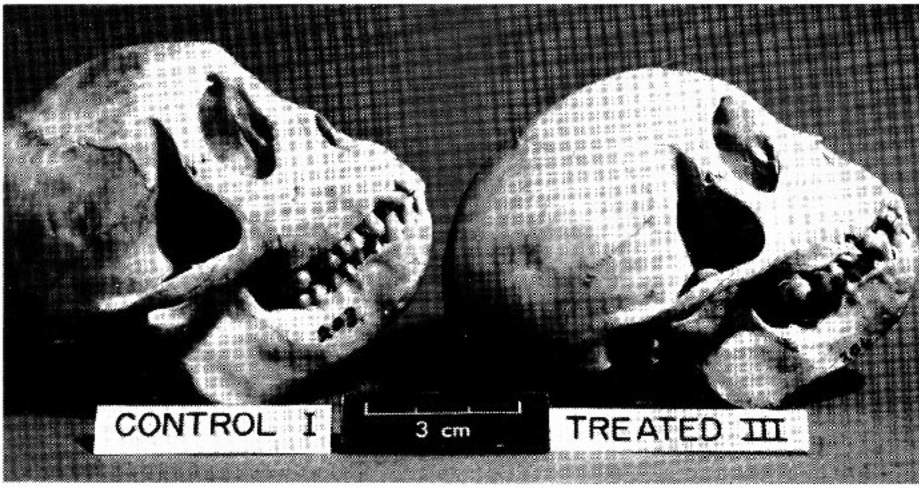

Fig. 4 The treated animals displayed a distal positioning of cephalometric point A and a loss of procumbency of the midface.

movements and interactions initiated by palatal separation were accompanied by conspicuous vital staining of growth sites not only on the maxillae but also on the mandible and suture lines of the calvarium. Staining of normal growing sutures was also observed in the controls. But the greater staining in the animals subjected to sutural expansion indicates the extensive remodeling which must occur under these circumstances.

The evident reduction in the orbital to alveolar distance in the treated animals compared with the controls (Table II; Fig. 3) indicates an upward movement of the maxillae at the lateral border. This observation contrasts with the slight downward movement of the maxillae at the median plane. It is also interesting to compare the magnitude of the lateral expansion of the maxillae at various vertical levels. Thus at the central fossae it was 6.5 to 9.0 mm, at the palatal suture 3.5 to 5.0 mm, at the bizygomatic level approximately 4.5 mm, in the floor of the nose 3.25 mm, and in the middle of the nares it was approximately 1.75 mm. These observations strongly suggest that midpalatal separation induces a rotation of the maxillae on an axis located somewhere in the frontal process.

Some of the unexpected findings of this study were the slight diminution of maxillary arch length, the decrease in the distance of prosthion to the external occipital protuberance (Tables I, II) and the apparent posterior movement of cephalometric point A. The effect of these movements is to alter the gross appearance of the midface. There is a crowding or "pinched in" effect in the area of orbitale, a fullness in the area of the canine eminence, and an over-all reduction in the procumbency of the face to create a "pug-nosed" effect (Fig. 4).

Discussion

The observations made in this study generally confirm the findings of previous investigations. As other studies have suggested, some of the increased width of the maxillary arch may be attributed to compression of the periodontal membrane and buccal tipping of the posterior teeth as well as to midpalatal separation and lateral movement of the maxillae.

The widespread deposition of vital stain at growth sites throughout the

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face and calvarium, together with the marked changes in the internal architecture of the nasal sinus complex, suggests that a more pervasive remodeling of the face accompanies expansion of the maxillary arch than is usually emphasized.

But the gross changes in facial appearance may be even more significant. The findings of this study conflict with the observation that maxillary expansion is accompanied by downward and forward movement of the maxillae, thus increasing their procumbency.[4,10,13,31,34,73] This difference most likely involves the presence of a distinct premaxillary bone in the monkey. Apparently, premaxillary retrusion accompanies maxillary expansion in the monkey. It underscores the fact that with rapid expansion of the maxillary arch there are concomitant changes in many of the surrounding structures of the maxillary complex. A thorough understanding of the impact this procedure has upon facial morphology is essential to effective orthodontic treatment planning.

Summary and Conclusions

Opening of the midpalatal suture under orthopedic stress in the *Macaca mulatta* monkey induced an outward movement of the maxillae with upward rotation of the lateral borders. Accompanying this movement were such characteristic changes as expansion of the maxillary arch, initial separation of the upper incisor teeth, a widening, lowering and flattening of the palatal vault, and enlargement of the intranasal space. Compensatory changes included bone growth at the midpalatal suture and lateral expansion of the mandibular arch.

Extensive remodeling of the internal architecture of the midface was suggested by the increase in both width and height of the nasal sinus complex. Unlike the human, midpalatal separation of the maxillae in the monkey induced posterior movement of the premaxillary segment with a loss in the procumbency of the face. This change was accentuated by apparent reduction in maxillary height which produced a "pinched in" effect or crowding in the area of orbitale and a fullness around the canine eminence.

These configurational changes of the midface re-emphasize the critical importance of understanding and anticipating the manifold consequences of midpalatal separation before undertaking the clinical use of orthopedic stress.

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