Postnatal Growth Of The Upper Face: Some Experimental Considerations

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INTRODUCTION

Normal development of the body is dependent upon the synchronous coordination of the activities of the growth centers of the skeleton and related structures. Although significant reports in regard to the problem of growth of bones appeared in the literature two hundred years ago, many questions are still left unanswered. What are some of the problems which we are attempting to study? What are the inherent difficulties? Essentially any study of growth of bones concerns itself with one or more of the following questions: What are the sites? What is the amount? What is the rate? Does it vary? When? What is the direction? What are the changes in proportion? By means of both clinical and experimental studies information has been obtained on the role played by these various sites.[1-6]

Any interference which will affect the growth centers of bones will alter the orderly progression of development and will result in some type of deformity. An understanding of the normal growth of bones forms the basis for early recognition and proper treatment of such deformities. However, it is less well appreciated that, conversely, the findings in the abnormal may be employed to test and extend our knowledge of the normal.

The purpose of this report is to summarize and review information obtained over the past several years as a result of certain animal experimentation. The following aspects will be considered:

I. Methods of assessing growth of bones.

II. Growth at several facial sutures in the monkey.

III. Growth at the frontonasal suture in the rabbit.

IV. Growth at the frontonasal suture area after extirpation of the frontonasal suture in the rabbit.

V. Palatal and facial growth after extirpation of the median and transverse palatine sutures in the monkey.

VI. Growth of the rabbit snout after extirpation of the septovomeral region.

VII. Facial and neurocranial growth after resection of the mandibular condyle in the monkey.

A brief description of some of our knowledge of growth of the upper face (defined for this purpose as the face other than the mandible) would be appropriate at this time.

GROWTH OF THE UPPER FACE

The facial skeleton increases in size in all three planes, height, width and depth. But it grows in these three dimensions of space differentially, at different times and at different rates. There are four ways in which growth of the bony upper face occurs, namely, (1) replacement of cartilage by bone in the base of the skull at the spheno-

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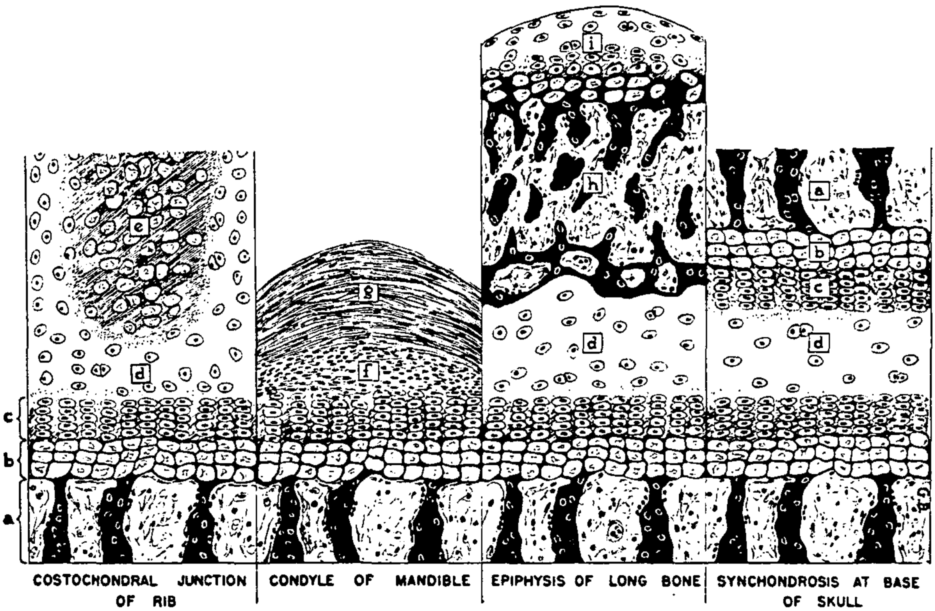

Figure 1. Diagrammatic representation of the variation in tissue arrangement adjacent to endochondral bone formation at the costochondral junction of the rib, condyle of the mandible, epiphysis of the long bone, and synchondrosis at the base of the skull. Note that zones of endochondral bone formation are the same: a, bone: b, zone of hypertrophic cartilage; c, zone of proliferating cartilage. Also note the variation in the tissue arrangement adjacent to the four separate areas of endochondral bone formation: d, zone of resting cartilage; e, mature cartilage with a calcified core; f, transitional zone of cartilage; g, fibrous connective tissue; h, bone and marrow of epiphysis; and, i, articular cartilage.

occipital and sphenoethmoidal junctions which contribute to the forward growth of the face (Figure 1), (2) appositional growth (as well as modeling resorption) on the surfaces of bones contributing to growth in all directions, (3) growth of the nasal cartilaginous septum which contributes to downward and forward growth of the face and palate, and (4) sutural growth. The marked activity of these processes in the young are in contrast to the inactivity in the adult. Thus in the adult although bone, the tissue, is in a state of continuous change as a result of an interplay of formation and destruction, growth of bones as organs has ceased.

Sites of growth for the maxillary complex are three sutures on each side: the frontomaxillary suture between the frontal bone and the frontal process of the maxilla; the zygomaticomaxillary suture between the maxilla and the zygomatic bone (and, secondarily, the zygomaticotemporal suture in the zygomatic arch); and the pterygomaxillary suture between the pterygoid process of the sphenoid bone and the maxillary tuberosity.[5] It is significant that these three sutures are parallel to each other and all are directed from above and anteriorly, downward and posteriorly. Thus growth in these sutures will have the effect of shifting the maxillary complex downward and forward. Transverse growth at the median palatine suture which is affected by the downward and divergent growth of the pterygoid processes is both simultaneous and correlated with the widening of the downward-shifting maxillary complex. There is also anteroposterior growth along the maxillary side of the transverse palatine suture between the horizontal plate of the maxilla and the palatine bone, and along the posterior margin of the palatine bone.

The downward, forward and lateral growth of the subnasal part of the maxillary body is accompanied by the eruption of the teeth and apposition of bone at the free borders of the alveolar process. Thus the apposition in this area contributes to the increase in height and width of the upper facial skeleton. At the same time the downward growth of the alveolar process accounts for the transition from the flatly curved palate of the infant to the highly arched one of the adult. The downward shift of the hard palate by resorption on its nasal and apposition on its oral surface tends, however, to obscure the downward growth of the alveolar process. Growth of the upper facial skeleton is closely correlated to that of the mandible.

Methods of Assessing Growth of Bones

A number of different approaches have been employed to study both normal and abnormal growth of bones (Table I).[6] Each, however, has its limitations. One method may yield information about the sites of growth, another about the rate, while still another about direction. A combination of methods, however, will yield more information, and in certain instances more accurately, than one method alone.

The analysis of many skeletal deformities can be aided greatly by the application of the methods referred to for the study of the growth of bones. Although some of these methods lend themselves primarily to experimental work on animals, they nevertheless will contribute to our fundamental knowledge of the subject and thereby supply information which can be of clinical importance. This will of necessity lead to both a better understanding and more intelligent treatment of the clinical problem.

Osteometry. The earliest studies of human form can be traced to the beginnings of anthropometry in ancient Egypt and Greece. Studies of skeletal remains (skull, pelvis, long bones) and those of human growth received special impetus in the nineteenth century. Camper, Morton, Broca, Topinard are just a few of the outstanding early contributors to this science.[9] Osteometry can be performed on either the living subject or the dried specimen.

When performed on the living (human or lower animals), the measuring instruments must be placed on the soft tissues overlying the bony landmarks thereby precluding minute accuracy of measurements. It does, however, show trends of the rates, total amounts and relative directions of growth in the same individual. This longitudinal approach is dynamic in the sense that serial measurements can be made on the same growing individual and the actual amount of growth can thus be evaluated.

Osteometry of the dried specimen brings with it the disadvantages of the static cross-sectional type of study. Here, measurements are made on a large number of bones of varying ages. By comparison of measurements of progressively older samples growth information is deduced. Posthumous distortions add to the inaccuracy of this static method.

Implant Markers. Implants used as reference markers have been utilized in the study of growth of bones for more than two hundred years. Hunter[1] inserted two pellets along the length of the shaft of the tibia of a young pig and measured the distance between them. When the tibia was fully grown, it was found that the distance between

TABLE I

Information obtained from various methods used to study growth of bones

Methods	Site of Growth	Amount of Growth	Rate of Growth	Direction of Growth	Type of Study	Limitations
Direct Measurements						
Osteometry a. Skeletal Remains	0	+	+	+	Cross-sectional	Material of unknown history, posthumous distortion
b. Living	0	+	+	+	Longitudinal*	Soft tissues restrict accurate measurement
Implant Markers	++	+++	+	+	Longitudinal*	Local reaction, requires re-operation
Vital Staining[6]	+++	+++	++	+	Longitudinal*	Toxicity, method requires refinement
Histologic and Histochemical Methods	++++	0	0	0	Cross-sectional	Sections show conditions at time of sacrifice only
Indirect Measurements						
Impressions and Casts	0	++	++	++	Longitudinal*	Soft tissues restrict accuracy of measurements
Photographs	0	+	+	+	Longitudinal*	Two dimensional study
Roentgenographs	0	+++	++	++	Longitudinal*	Must obtain stable base, three dimensional information not entirely accurate
Measurements in Combination and Separately						
Roentgenography and Implantation	+++	+++	+++	+++	Longitudinal*	Local reaction to implants, three dimensional information not entirely accurate
Roentgenography and Metaphyseal Bands[7]	+++	+++	+++	+++	Longitudinal*	Record of a toxic process, rate of growth not normal
Radioautographs[8]	+++	0	0	0	Cross-sectional	At present primarily of qualitative value

++++ Microscopically acurate.
+++ Grossly accurate.
++ Relatively accurate.
+ Shows trends.
0 Gives no information.
* The cross-sectional method of study can be applied to longitudinal studies.

the pellets had remained exactly the same. This experiment proved that there was no interstitial growth of bone. Humphry,[3] by placing wire loops around the ramus of the pig mandible, demonstrated that there was resorption on the anterior border and deposition of bone on the posterior border of the ramus. This direct method of study, however, will not yield serial data without re-operation or sacrifice of the animal.

Serial Cephalometric Roentgenogra-

phy. Serial roentgenography permits a longitudinal study of the same individual throughout the growth period. A stable anatomical base, however, must be selected for superimposing the roentgenographic tracings. If there is any shift in the anatomical landmark, the findings will be distorted. This method reveals the rate, the amount, and relative direction of bone growth. It does not, however, reveal the sites or the mode of growth of bones.

In 1931 Broadbent[10] and Hofrath[11] simultaneously, but independently, described a technique of cephalometric roentgenography. The accuracy of this method depends on the standardization of technique. The film target distance is constant. The subject is repositioned at given time intervals to the Broadbent-Bolton cephalometer, instead of adjusting the machine to the subject. Broadbent[10] believed the outline of sella turcica was a stable base and used this for superpositioning roentgenographic tracings of the human skull. Thus, the relative positions of various portions of the skull are recorded on composite tracings and measurements taken therefrom. In 1937 findings gained from cross-sectional studies of large groups of growing children were reported.[12] Brodie[4] in 1941 was the first to apply Broadbent's method to a longitudinal growth study of the skulls of human males from the third month to the eighth year of life.

Serial Roentgenography and Implantation. Use of a combination of serial roentgenography and metallic implantation is a more accurate and reliable method for studying the growth of bone. This method was used in the growth study of the dog palate[13] and mandible,[14] monkey facial sutures,[15] the rabbit snout,[16-18] the pig[19] and the human[20] mandible. The serial roentgenographs demonstrate the increase in size and the change in proportion. The increase in distance between implants on either side of a suture can be measured. In the mandible a stable base for superpositioning the serial roentgenographic tracings is obtained by inserting two or more radiopaque implants. Thus, the ensuing growth can be accurately determined and measured by superpositioning roentgenographic tracings over the images of the metallic implants.

The changes that occurred from one period to another can be determined without sacrifice or re-operation of the animal. There is also no interference with the normal diet of the animals, such as occurs in madder-fed pigs.

Growth at Several Facial Sutures in the Monkey

The purposes of this experimental study in the Macaca rhesus monkey were: (1) to compare the relative amounts of sutural growth in selected areas of the face by means of metallic implants (Figure 2); (2) to compare the roentgenographic with the direct method of measuring growth by means of metallic implants; (3) to study the direction of growth of certain components of the facial skeleton by superpositioning tracings of serially-taken roentgenographs.[15]

The Macaca rhesus monkey was selected because it was the only readily available animal closely related to man. Since all animals were born in freedom, it was necessary to rely on the dentition to ascertain their approximate ages. These animals were divided into three groups. The youngest group had a complete deciduous dentition and was estimated to be approximately eight months of age. The intermediate group had the four permanent first molars and was estimated to be eighteen months of age, while the oldest group was believed to be approximately twenty-four months of age because of the presence of the permanent central

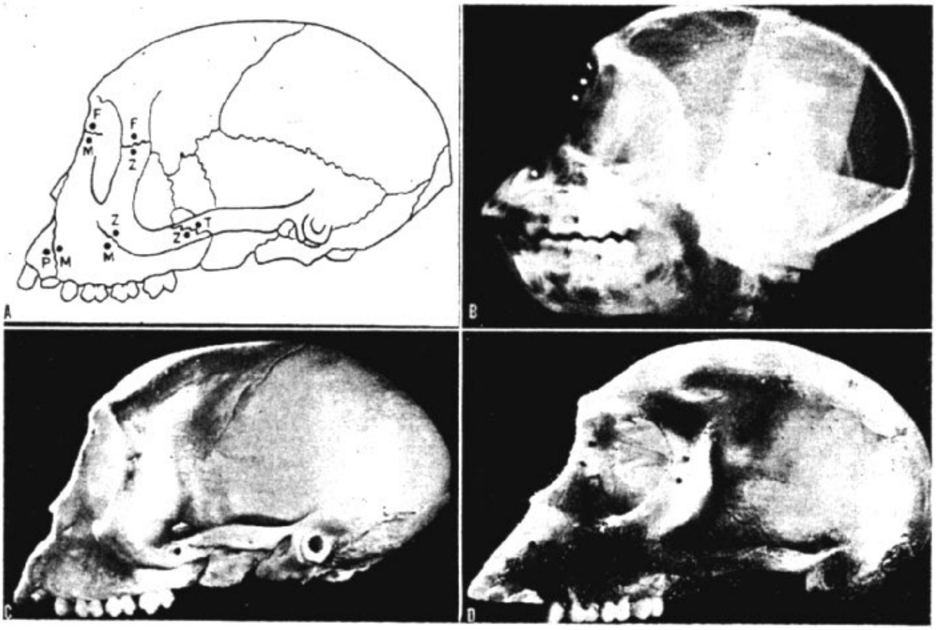

Figure 2. Lateral views of monkey skulls with amalgam implants on each side of facial sutures studied. A, diagrammatic representation. F, frontal bone; M, maxilla; Z, zygoma; T, temporal bone; P, premaxilla. B, lateral cephalometric roentgenograph. Note visibility of all implants. Compare with A, C and D. C, bleached skull. Note visibility of implant in the temporal process of the zygomatic bone. Other implants are not as readily visible. D, cleared skull. Compare increased visibility of the implants with those in C. Implant on the temporal side of the zygomaticotemporal suture is now visible because it had been covered by a thick layer of bone which is now cleared.

and lateral incisors as well as the permanent first molars. The experimental period ranged from seven to ten months.

The zygomaticotemporal and frontozygomatic sutures were exposed by overlying, horizontal, extraoral incisions. The frontomaxillary suture was exposed by a midline, vertical, extraoral incision. The zygomaticomaxillary and premaxillomaxillary sutures were exposed intraorally by incisions which followed the planes of these sutures. A number 35 inverted cone dental bur, mounted in a dental handpiece, was used to prepare cavities in bones adjacent to the selected suture lines. Amalgam was packed into the prepared cavities because of its radiopacity, pliability, and tolerance by tissues. An indentation was made in the center of each implant with the point of a caliper and the distance between each pair of implants recorded. The soft tissue was then replaced and sutured.

Findings

Examination of the prepared skulls postoperatively revealed that the amalgam implants placed on the lateral surface of the frontal bone could no longer be seen from the lateral view (Figure 2). They were now visible only on the medial surface of the frontal bone which formed the lateral wall of the orbit. Pegs placed at the zygomaticotemporal suture on the lateral surface of the zygomatic process of the temporal bone were similarly visible only from the medial surface of the zygomatic arch. Measurements of the increase in distance between sutural implants taken on the skulls revealed that separation of implants at the zygomaticotemporal suture exceeded all other areas studied. Next in amount of separation were the implants in the area of the zygomaticomaxillary suture. Separation of paired implants at the frontozygomatic, frontomaxillary, and premaxillomaxillary sutures was considerably less. Variations in the increased distance between paired implants of the same suture in different animals were noted. In several animals the separation of implants at the frontomaxillary suture exceeded that of the premaxillomaxillary suture. In others the reverse was true. This lack of consistency, as well as the small amount of increase in the separation of paired sutural implants at the frontomaxillary, frontozygomatic, and premaxillomaxillary sutures, made it difficult to place these areas in a definite order. In the two older groups of animals the implants were separated to a lesser degree than was observed in the younger group, the only exception being the implants at the premaxillomaxillary suture.

Cephalometric roentgenographs were taken on the Broadbent-Bolton cephalometer at monthly intervals. Individual tracings were made of the serial roentgenographs for each animal. Tracings of the original and final roentgenographs were superposed on the outlines of sella turcica and the most superior portion of the anterior cranial fossa defined by the roofs of the orbits (Figure 3). This revealed a downward and forward movement of all implants except those on the temporal side of the zygomaticotemporal suture which moved downward and posteriorly. The findings in the oldest group of animals were similar with the exception of the implants in the zygomatic process of the temporal bone. These appeared to be stationary throughout the study. Outlines of the occlusal plane and floor of the nose descended in a plane parallel to each other. In the youngest group the bony profile of the face was shifted anteriorly, maintaining the original outline, while in the intermediate and older groups there was a trend toward snouting. The oldest group also exhibited the beginning of formation of the supraorbital ridge.

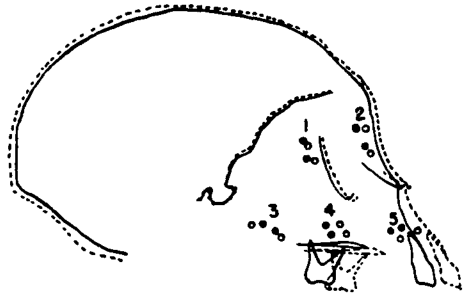

Figure 3. Superposed tracings of serial cephalometric roentgenographs demonstrating movement of implants with total growth of the face in the monkey. 1, frontozygomatic suture; 2, frontomaxillary suture; 3, zygomaticotemporal suture; 4, zygomaticomaxillary suture; 5, premaxillomaxillary suture. Tracing of original roentgenograph at approximately 8 months of age, continuous line; tracing of final roentgenograph at approximately 15 months of age, dotted line. Position of implant at the beginning of the study, ● ; position of implant at the completion of the study, O. Note downward and forward movement of all implants with the exception of the one placed on the temporal side of the zygomaticotemporal suture which moved downward and posteriorly. Also note stability of the facial pattern.

Variation in the distance of the implants from the film and the variation in angulation of paired implants to the central ray of the x-ray tube were at least two factors responsible for some distortion. A minimum of distortion occurred with implants lying in a plane perpendicular to the central ray of the x-ray tube. Implants placed in the frontomaxillary, frontozygomatic, and zygomaticotemporal sutures fell into this category. However, implants placed in the area of the zygomaticomaxillary and premaxillomaxillary sutures were in a plane oblique to the central ray of the tube and consequently showed distortion. This error was avoided in measurements taken directly on the skulls.

Measurements taken between implant images on the roentgenographs followed closely those taken on the specimens. Implants at the zygomaticotemporal suture showed the greatest amount of separation. Implants at the zygomaticomaxillary suture were next. The small amount of separation of implants in the other three areas precluded their placement in a definite order. In all three age groups studied, the rate of separation of implants in the zygomaticotemporal suture exceeded all other areas. In the youngest group of animals the rate of separation of implants in the zygomaticotemporal and zygomaticomaxillary sutures exceeded that of the other two groups. In the middle group the rate of separation at the frontomaxillary and frontozygomatic sutures exceeded that of the other two groups, while in the oldest group the rate of separation of the implants in the premaxillomaxillary sutures exceeded that of the other two groups.

Comment

The greatest amount of separation of paired implants occurred in the areas of the zygomaticotemporal and zygomaticomaxillary sutures. These areas contribute primarily to the anteroinferior growth of the face. That the tuberosity of the maxilla exhibits prolific growth against a rather stable base (pterygoid process) has been well established.[4] The zygomaticotemporal suture lying, as it does, in the general plane of junction between the viscero and neurocranium reflects the growth of this area. The zygomaticomaxillary suture, lying anteriorly but in a plane parallel to that of the craniofacial hafting zone, contributes to the downward and forward movement of the middle face. The two sutures observed in this study which contributed most to the downward growth of the face were the frontomaxillary and frontozygomatic. Although growth was evident in these areas, it did not account for the entire vertical growth of the face. The floor of the nose was found to have descended to a lower level than could be accounted for by growth of the frontomaxillary and frontozygomatic sutures. The same was true of the occlusal plane of the teeth. Although no two animals exhibited identical quantitative growth, the general pattern of growth was similar. This study suggested that sutural growth of the face varied in different age periods as follows: (1) the anteroposterior growth was most active in the age group from approximately 8 to 15 months; (2) vertical growth was most active in the age group from approximately 18 to 34 months.

Comparison Between the Roentgenographic and Direct Methods of Measuring Growth. Harmonious growth of the craniofacial complex takes place in three planes of space. There is a vertical, lateral and an anteroposterior component. Whether growth is measured either on the skull or on serial roentgenographs, the true direction of this development is extremely difficult to observe, not only because the various sutures grow at different rates but also because of their position in space. It is likely that with growth the positions of the sutural planes to each other are changed. Growth of the face, therefore, does not follow straight lines, but with the rotation of the sutural planes, the bones of the face follow various curves. Measurements of this growth, taken either on the skull or on the roentgenographs, show only the linear enlargement. Although this study concerns itself with the growth of the face, it is

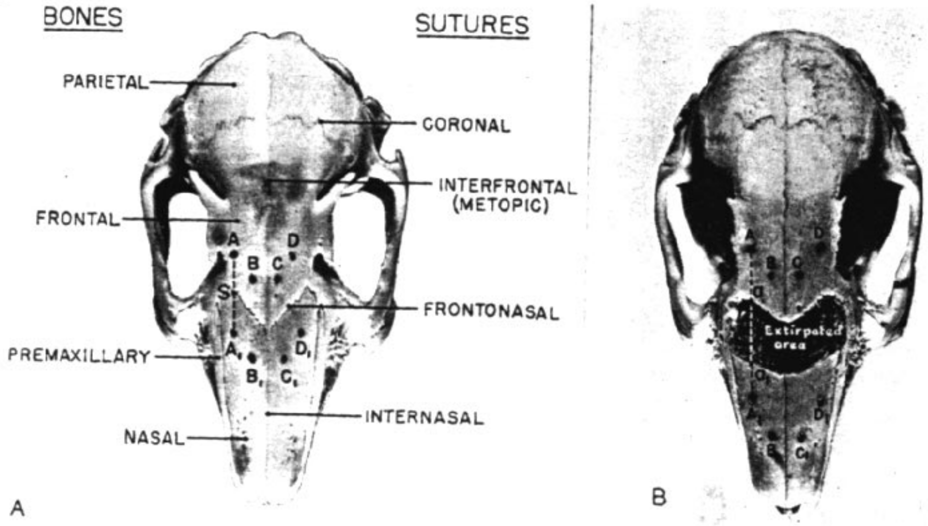

Figure 4. Dorsal view of rabbit skulls showing sites of implantation of silver amalgam in the nasal and frontal bones. A, normal animal with frontonasal suture intact. S, point on frontonasal suture where straight line crosses between AA_1, etc. B, animal in which the frontonasal suture was extirpated seven days before death. a, a_1, points on either side of extirpation site where a straight line crosses between AA_1, etc.

fully realized that an inseparable coordination exists in the growth of the face and the skull as a whole. The advantage of the direct method of measuring growth is that it gives accurate information about total growth, while the advantage of the roentgenographic method is that it permits the study of the rate and relative direction of growth. Because they complement each other, the two methods of studying bone growth were combined.

Growth at the Frontonasal Suture in the Rabbit

The combination of gross and serial cephalometric roentgenographic methods with metallic implants was utilized in this study to determine the contribution of the frontonasal suture to the growth of the rabbit snout.[17] Growing female New Zealand albino rabbits were used. Their ages ranged from 42 to 84 days at the beginning of the experiment. These animals were selected primarily because of their rapid growth and large snout which lends itself to ready implantation and accurate serial roentgenography. A disadvantage, however, was the size and complexity of the pinna which made difficult the insertion of earposts for serial roentgenography. Into the prepared undercut cavities in the cortical plate of each frontal and nasal bone dental amalgam was packed (Figure 4A). An indentation was made in the center of each implant with the point of a caliper, and the distance between the centers of each pair of implants recorded to the nearest 0.1 mm. The postoperative survival ranged from 7 to 84 days. After sacrifice of the animals, the distances between the same groups of implants were again determined as at the beginning of the experiment.

In order to measure distances between the radiopaque implants, a cephalometric roentgenograph of a ventrodorsal view of the frontonasal region

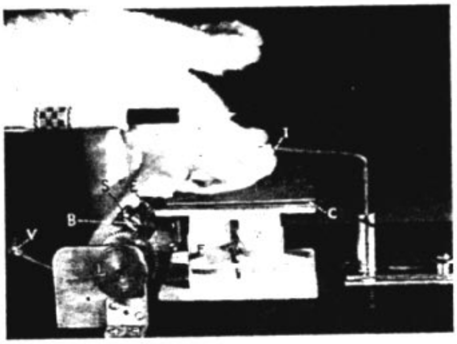

Figure 5. Lateral view of headholder with rabbit. Head in position on cassette with earpost going into external ear. B, earpost bearing block; C, film cassette; E, earpost; F, film elevator; I, incisal pin; L, horizontal block moving gear; S, earpost set screws; V, vertical rotating gear.

with the plane porion-interdentale oriented to the horizontal was desired (Figure 5). This view had proved advantageous in the study of animal snouts, and a special headholder had been designed and constructed to obtain strictly comparable serial cephalometric roentgenographs.[16] Immediately on completion of the surgical procedure a cephalometric roentgenograph was taken. This was repeated at 14-day intervals and at death. The distances were measured between the estimated centers of the radiopaque images of the metallic implants on the roentgenographs. It had been demonstrated that measurements between implant images (in frontal and nasal bones) on the roentgenographs are strictly comparable with measurements made directly on the skulls.[16]

Findings

The increased distance between paired implants on either side of the frontonasal suture was determined directly on the skulls by subtracting the initial from the final measurement. This difference varied with the age of the animal at the time of implantation, the duration of the experiment, and the individual animal. Thus, in 42-day-old rabbits the increased amount of separation of the implants after 7 days ranged from 0.3 to 1.3 mm. In another group of rabbits the increased separation of the implants during an 84-day period (42 to 126 days of age) ranged from 10.6 to 11.9 mm. In addition to the total separation of the paired implants, the individual contributions of the frontal and nasal bones' side of the suture to the increased separation of the paired implants was determined. Measurements were taken between each implant (in nasal and frontal bones)

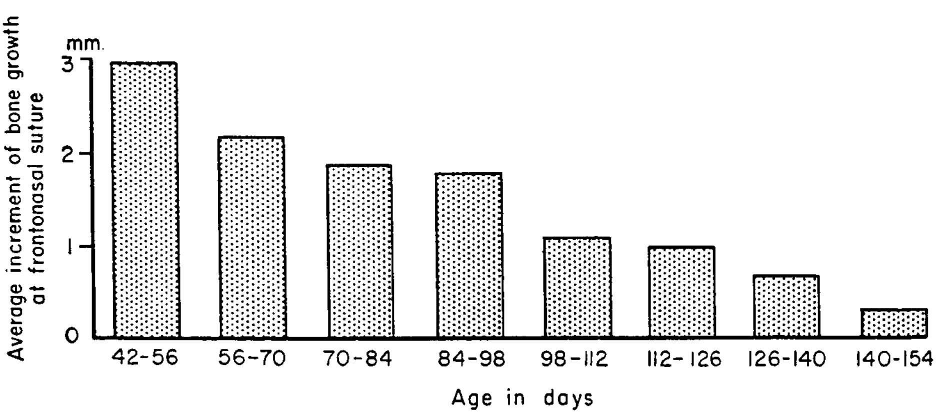

Figure 6. Mean increment of growth of bone at frontonasal suture at 2-week intervals as determined from implant images on serial cephalometric roentgenographs.

and a point on the frontonasal suture at the beginning and the end of the experiment. These values indicated that the mean frontal contribution was approximately one-half to three-fourths that of the mean nasal contribution.

Examination of the serial cephalometric roentgenographs revealed that there was an increase in separation of the pegs on either side of the frontonasal suture for each 14-day period from 42 to 154 days of age, when the experiments were terminated. The measurements indicated that the animals were in a phase of declining bone growth (Figure 6). For example, the mean increment of growth from 42 to 56 days of age was approximately 3.0 mm, whereas from 140 to 154 days it was only 0.3 mm.

Growth at the Frontonasal Suture Area After Extirpation of the Frontonasal Suture in the Rabbit

The purpose of this experiment was to study the effects of trauma upon the frontonasal suture.[18] The maximal injury was imposed, that of extirpation of the suture. Growing female New Zealand albino rabbits were used. Their ages ranged from 42 to 84 days at the time of the surgical operation. Rabbits were selected primarily because of the rapid growth in the region of the frontonasal suture. Thus, one would expect conditions affecting growth at this suture to be reflected in altered growth of the snout. A dental bur, mounted in a handpiece, was used to extirpate the frontonasal suture either unilaterally or bilaterally (Figure 4B). The extirpation channel was cut equally out of the frontal and nasal bones, and was approximately 1.0 cm wide. In unilateral extirpations, which were always on the right side, the bur cut extended slightly beyond the midline. In most cases the adjacent premaxillary tip was also cut. Dental amalgam was packed into prepared cavities 0.5 to 1.0 cm from the channel edge. An indentation was made in the center of each amalgam implant with the point of a caliper and for each pair of implants the distance between these centers (AA_1, BB_1, etc.) was recorded to the nearest 0.1 mm.

In the experimental animals the distance between each implant and its adjacent channel border, and the width of the extirpated area were also measured on a line between the corresponding frontal and nasal bone implant. Immediately upon completion of the surgical procedure a cephalometric roentgenograph was taken. This was repeated at 14-day intervals and at death (Figure 7). The postoperative survival ranged from 14 to 84 days. The heads were immediately severed and the soft tissue dissected. The distances between the same groups of implants and extirpation borders were again determined as at the beginning of the experiment.

Comments

The gross appearance of the snout in terms of size and shape, in the animals in which the frontonasal suture had been bilaterally or unilaterally extirpated, was similar to that of the control animals. No lateral deviation of the snout was observed in the animals with a unilateral extirpation. It was found in each animal that total longitudinal growth was essentially the same regardless of whether or not the suture had been extirpated, either bilaterally or unilaterally. The nasal part of the frontonasal suture contributed approximately one-half, the extirpation site one-fourth and the frontal part one-fourth to the increased separation of the implants. The channel width itself did not become less. Rather it increased as longitudinal growth proceeded. Thus a wedging or expansive force between frontal and nasal bones by the fronto-

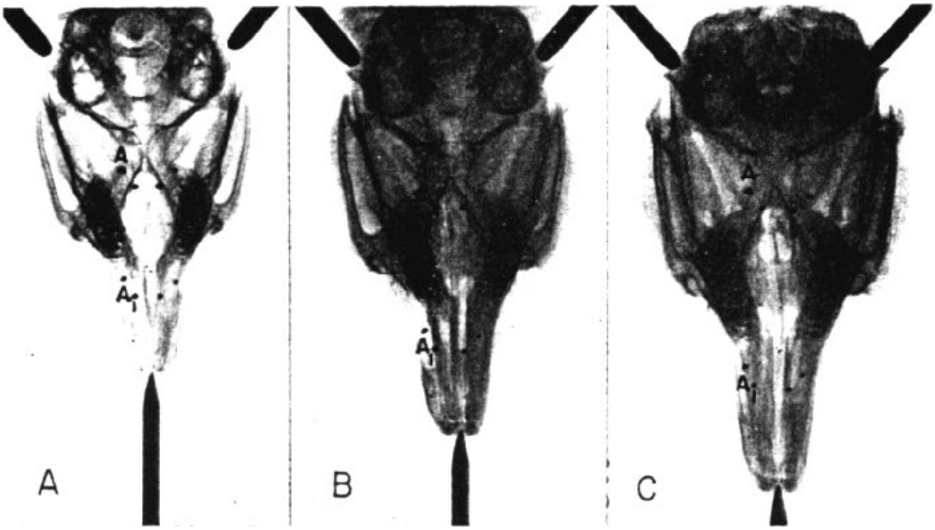

Figure 7. Ventrodorsal cephalometric roentgenographs of rabbit No. 29. The right frontonasal suture was extirpated and implants (A, A_1, etc.) inserted into the nasal and frontal bones at 42 days of age. A, 42 days of age; B, 70 days of age; C, 112 days of age. Note that there is no change in symmetry of the snout 70 days after extirpation of the right frontonasal suture. Also note the symmetrical increase in size and change in form of the skull and the increased longitudinal and lateral separation of the implants on either side of the frontonasal, internasal and interfrontal sutures. The distances between the implants in the nasal bones and the anterior margin of these bones has also increased with age. The distance between implants in the nasal or frontal bones, however, remained constant. The tips of the earposts are in the external auditory canals. The incisal pin is in position.

nasal suture apparently was not necessary for growth in that area. Separation of the nasal and frontal bones continued at all times in an amount not significantly different from normal in the absence of the normal suture.

Palatal and Facial Growth After Extirpation of the Median and Transverse Palatine Sutures in the Monkey

The purpose of this experiment was to determine grossly the effects of reduced vascularity upon the hard palate and the effects of trauma by removal of the sutural growth sites of the hard palate upon palatal and facial growth in the normal rhesus monkey.[21] The following was done to accomplish this: 1) complete unilateral removal of the palatal mucoperiosteum and severance of the descending palatine artery and 2) extirpation of the median and transverse palatine sutures. It should be pointed out that this experiment was not meant to be comparable with that of the problem of the cleft lip and palate patient with an underdeveloped maxilla. It was felt, however, that this approach would offer an important and basic contribution to the general subject of the effect of decreased circulation and trauma upon growth and to the specific subject of the effect of palatal trauma on palatal and facial growth.

Because the growth activity of the face is greatest during early life, the youngest Macaca rhesus monkeys obtainable were used. Their age at the beginning of the experiment was estimated, according to the primary dentition, to be approximately 8 months. They weighed from 4.5 to 6 pounds.

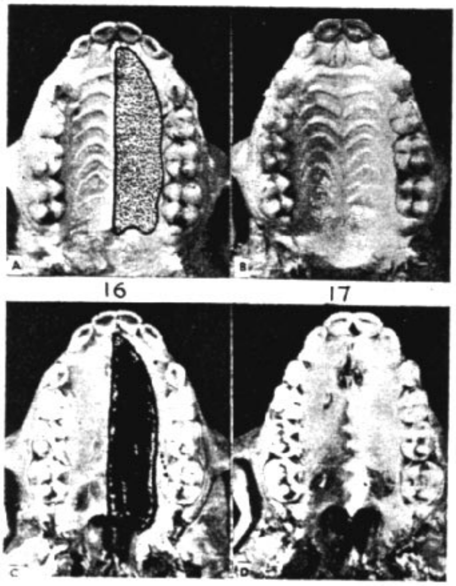

Figure 8. Postmortem photographs of oral palatal area of unoperated control monkeys. A, stippled area indicates extent of unilateral removal of mucoperiosteum in experimental animal numbers 9 and 10 (see Figure 9). B, note regularity and distribution of rugae. C and D, mucoperiosteum has been removed. C, black area indicates extent of unilateral removal of hard palate including median palatine suture, left transverse palatine suture including major palatine foramen. D, note form and contour of hard palate, position and direction of median palatine suture, presence and position of major palatine foramen, and transverse palatine suture just behind the junction of the two posterior molars.

A total of 14 monkeys were included in this report: 7 unoperated controls and 7 operated animals. In two animals the mucoperiosteum was incised on the left half of the hard palate along the posterior border, then anteriorly close to the midline on the right side and along the lingual border of the alveolar process (Figure 8A). The descending palatine artery at its exit from the major palatine foramen was isolated, ligated, cut and permitted to retract. The foramen was plugged with dental amalgam. The remaining mucoperiosteum was then elevated and removed completely. The palatal aponeurosis was dissected from the posterior part of the hard palate on the left side only. In addition, in five animals the exposed left bony palate was resected with a dental tapered fissure bur. This included the median and left transverse palatine sutures, the major palatine foramen and nasal mucoperiosteum. Care was taken not to disturb either the alveolar process or the teeth (Figure 8C). Thus communication was established between the oral and nasal cavities. The postoperative survival period ranged from one to thirty-four months.

Upon the death of the animal the head was severed and fixed immediately in a ten per cent solution of formalin. After removal of the mandible and the tongue, a photograph was taken of the oral palatal surface (Figure 9, upper row). The skull was then dissected and additional photographs were taken of the denuded hard palate (Figure 9, lower row). In addition the soft tissues of the unoperated and operated sides of the oral hard palate in three animals were prepared for microscopic study. Some of these findings have been reported elsewhere.[22]

Healing After Palatal Surgery. It was difficult to correlate the palatal findings with either the type of surgical procedure or postoperative survival. Regardless of the type of unilateral surgical operation there was no asymmetry in maxillary dental arch size or form.

In two animals (Figure 9, numbers 9 and 10), although only the mucoperiosteum was removed, extensive clefts of the bony palate were found at the time of death (8 and 14 months postoperatively). The palate at one month postoperatively, however, appeared to be intact in these two animals. The loss of bone in the hard palate could possibly have been a result of the surgical trauma, the reduced vascularity incident to removal of the oral mucoperiosteum

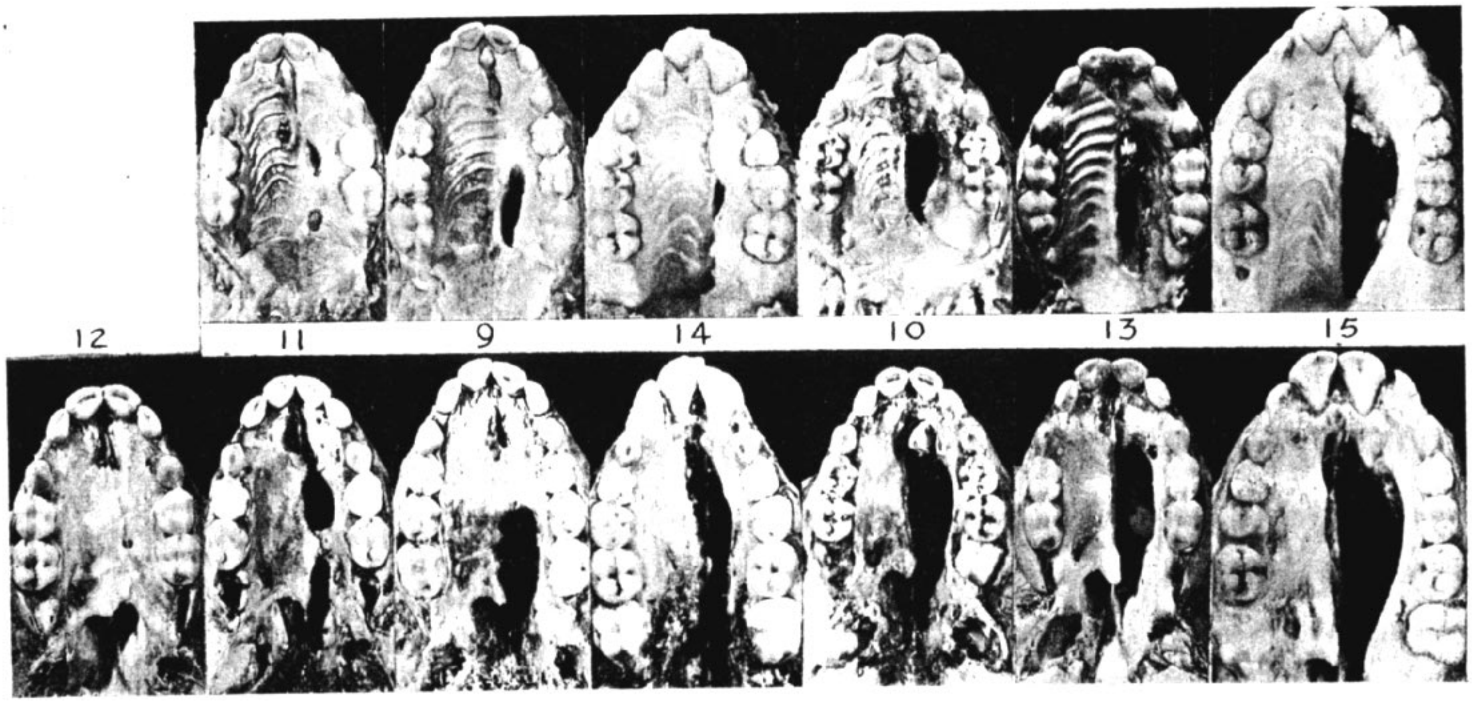

Figure 9. Postmortem photographs of oral palatal area of operated monkeys arranged in approximate order of increasing defect in bony palate. Animal numbers 9 and 10 had only the mucoperiosteum removed from the left half of the palate and ligation and cutting of the descending palatine artery at its exit from the major palatine foramen (see Figure 8A). The remaining animals had the left hard palatal area resected (see Figure 8C). The upper row of photographs was taken prior to the removal of the soft tissues. The lower row of photographs is of the corresponding animals after removal of the soft tissues. Note how the soft tissues mask the underlying bony defect. The rugal pattern is absent in the epithelial surface of the healed operated side. Note in the lower row, animal numbers 12, 11 and 9, that there has been partial bony healing ofthe palatal defect and that the suture line is eccentric, toward the operated side. The major palatine foramen is not evident on the operated (animal's left, reader's right) side. In animal number 14 the upper left permanent central incisor is malposted because of the absence of the adjacent permanent lateral incisor. There is no gross asymmetry of the maxillary arch.

and ligation of the descending palatine artery or subsequent infection. The bony palate on the operated side was thinner and more fragile than on the unoperated side.

The findings in the above animals could not be distinguished from those in whom not only the mucoperiosteum was removed but also the sutures of the left half of the bony palate. The findings in the latter group ranged from complete persistence of the cleft (animal number 15) to nearly complete closure (animal number 12). Interestingly enough, the animal with complete closure had a postoperative survival of four months whereas the animal with the wide open cleft had a postoperative survival of thirty-four months. It was not ascertained in this experiment whether or not part of the tongue was ever lodged in the cleft so as to retard or prevent its closure. In those animals where there was a regrowth of bone and the palatal shelves had rejoined forming a new suture, it was not in the midline but eccentric on the operated side (Figure 9; animal numbers 9, 11 and 12). Apparently bone had grown faster from the intact palatal process than the alveolar margin. In every animal the soft tissue contribution to the closure of the cleft was greater than that of bone. The fact that the mucoperiosteum and alveolar bone were intact anteriorly and the soft palate was intact posteriorly no doubt played a role in the healing of these clefts. It would be of interest to determine the extent of healing were these clefts to extend completely through the alveolar process and the hard and soft palates.

Palatal and Facial Growth after Palatal Surgery. Extirpation of the median and transverse palatine sutures in the experimental animals did not influence maxillary arch size or form. Thus it might be assumed that these sutures either do not make an important contribution to maxillary growth or that other growth sites adjusted to the altered conditions. In this regard it should be remembered that in these animals the jaws were in occlusion at the beginning of the experiment and that the mandible may have guided maxillary growth. Of course, in a congenital midline cleft of the hard palate there is no median palatine suture and in the complete unilateral cleft the bony fragments are separated so that this site of growth is not present.

Comment

A comparison of the skulls of the operated and unoperated sides with each other and of the operated animals with approximately comparable unoperated controls revealed no significant gross difference in growth and development of the hard palate, maxillary arch, mandibular arch, maxillomandibular relationship (arch size and form, occlusion and tooth relationships) or total face. Thus within the limits of this experiment it is concluded that unilateral traumatic surgery in the form of (1) elevation and removal of the mucoperiosteum and severance of the descending palatine artery, and (2) resection of the hard palate and adjacent sutures did not produce in either the palate or the face a growth arrest which was grossly apparent.

Growth of the Rabbit Snout After Extirpation of the Septovomeral Region

The septovomeral region is considered an important growth center of the nose and adjacent facial structures. The purpose of this experiment was to study the effects of injury to the septovomeral region upon the growth of the rabbit snout.[23] Growing rabbits ranging from 29 to 48 days of age were used. Different degrees of injury were imposed by extirpating varying amounts

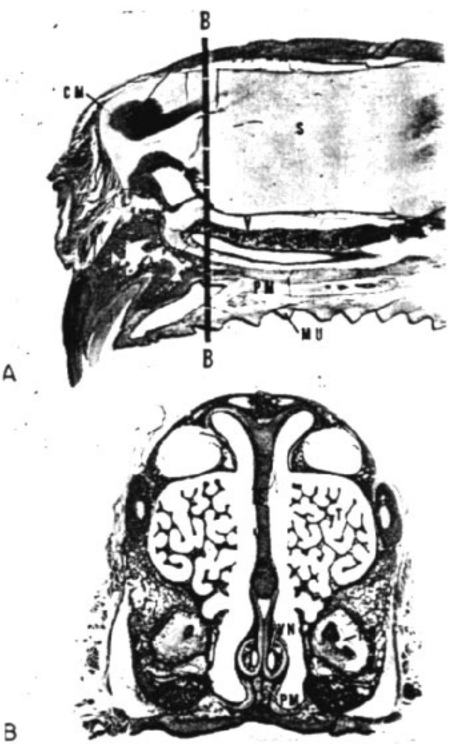

Figure 10. Photomicrographs of sagittal and transverse sections of snouts of 28-day-old normal rabbits demonstrating the septovomeral region. A, sagittal section; B, transverse section, taken at approximately line BB. CM, caudal margin of septum; I, labial incisor; i, lingual incisor; IB, basal end of incisor; MU, palatal mucosa; PM, palatine process of premaxilla; S, septum; T, maxilloturbinate; V, vomer, VN, vomeronasal organ.

of the septovomeral joint, caudal portion of the cartilaginous nasal septum, vomer, and maxillary process of the premaxilla (Figure 10). A sublabial approach was used. The postoperative survival ranged from 7 to 118 days.

Findings

In general, the gross findings in the snouts of the operated animals ranged from moderate to extreme. The degree of change varied directly depending upon either the amount of injury or removal of the septovomeral region and the length of postoperative survival.

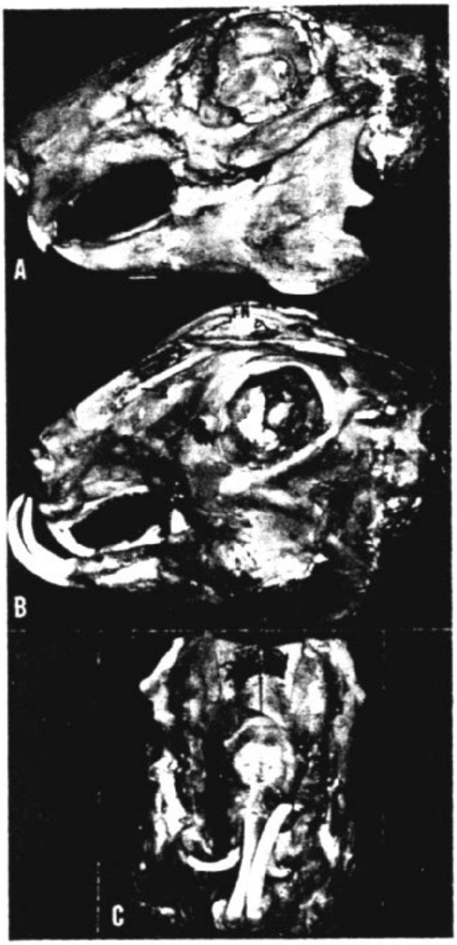

Figure 11. Photographs of lateral view of A, unoperated on control rabbit No. 23, and lateral, B, and frontal view, C, of operated litter mate rabbit No. 21. A portion of the septum and vomer was removed at 28 days of age. Postoperative survival was 118 days. Both animals were killed at 146 days of age. In B, note shorter snout, acute angulation and peaking at region of frontonasal suture, FN, and sharp downward direction of nasal bones; R, ridge. Contrast this with the longer snout and smoothly curved dorsum of control rabbit. Also note malalignment and overgrowth of all incisors in B and C.

The snout, when viewed from the side, appeared shorter and relatively thicker than the unoperated control (Figure 11). There was a definite downward anterior deflection of the snout beginning at the region of the frontonasal suture. This was in contrast to the smoothly curved dorsum of the unoperated animal. From above, the nasal bones appeared to be shorter. The ridge produced by the junction of the frontal process of the premaxilla and the nasal bone was more prominent. From below, the incisive foramen appeared shorter and relatively wider. From in front, the snout appeared relatively broader. In addition to the anteroposterior slanting of the snout, the nasal bones slanted acutely downward from the midline to their lateral borders.

After the skulls were sectioned parasagittally, additional findings were noted. The area of surgical extirpation was in the caudal portion of the septum (Figure 12). This represented approximately thirty to forty per cent of the total area of the septum. The upper border of resection extended to the ventral surface of the nasal bones superiorly, to the floor of the nose inferiorly, and extended posteriorly to and including a portion of the perpendicular plate of the ethmoid bone. The entire caudal border of the septal cartilage was absent. The palatine process of the premaxilla was shorter and higher. The slope and direction of the snout was even more striking than in the other views.

The incisors were completely out of occlusion, were elongated and grew laterally. There was no consistent pattern in the different animals. The lingual incisors were also deformed but to a lesser degree (Figure 11).

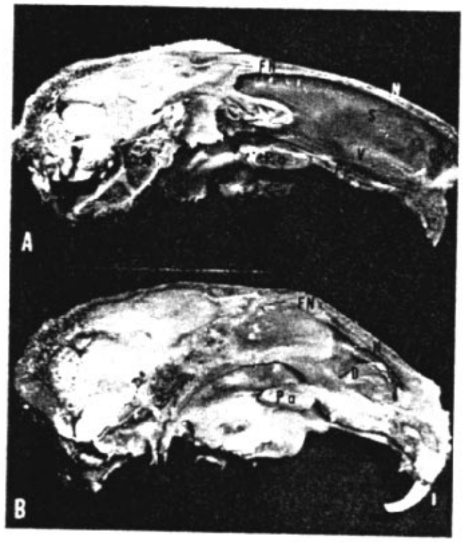

Figure 12. Photographs of parasagittally sectioned crania of A, unoperated control rabbit No. 23, and B, operated litter mate No. 21. CM, caudal margin of septum; I, incisors; Pr, premaxilla; S, septum; V, vomer; Pa, palate; FN, area of frontonasal suture; N, nasal bone. Note in B the defect, D, present in the septum 118 days after surgical intervention. Also note in the operated animal, B, that the snout is shorter and deflected more acutely downward than in the unoperated animal, A. In B, the incisors, I, are overerupted and are directed more lingually.

Comment

Site of injury. The youngest rabbits available were used so that the injury would be imposed during a period of rapid growth. It was of interest to note that such severe deformities involving many facial structures could be produced by removing portions of midline structures, namely, the cartilage of the nasal septum, the vomer, and premaxilla. It would be of further interest to observe the changes occurring after a more radical extirpation of the septovomeral area.

In a few animals which expired at the time of, or shortly after surgery, postmortem examination revealed that approximately sixty to seventy-five per cent of the cartilaginous portion of the septum was removed. Consequently, it was surprising to find that in the animals with 118 days postoperative survival, the surgical defect represented only approximately thirty to forty per cent of the septum. This can be explained, probably, on the basis that the rest of the nasal septum continued to grow and, although the defect may have remained the same in actual size, proportionately, it became smaller. Histologic investigation of the border of the septal defect may provide interesting information regarding the regenerative activity at this site.

The Snout. One of the more striking findings was the marked foreshortening of the entire snout which was probably related to the marked downward angulation of the nasal bones. All of the bony structures involved in the make-up of the snout were affected by the surgical trauma imposed on the area of the septovomeral joint. A possible explanation for the foreshortening and the downward deflection of the portion of the snout that includes the nasal bones may be on the basis that surgical removal of that portion of the septum in the septovomeral region lessened the amount of growth. Posterior to this region, however, growth continued, so that the dorsum of the skull in the region of the frontonasal suture was higher than the anterior portion of the snout. As in the structures dorsal to the area of resection of the septum, those ventral to it, namely, the premaxillary portion of the palate, appeared to be similarly affected by a lessened amount of downward and forward growth. There was an apparent lessening in the height of the snout in the operated animal as compared with the unoperated animal measuring from the posterior border of the premaxillary portion of the palate to the dorsum. It would be of interest to compare both the rate and amount of separation of amalgam implants at the frontonasal suture in these and control animals.

This experiment demonstrated that trauma to the septovomeral area of the rabbit produced definite gross changes in the structures of the snout, including nasal bones, maxilla, premaxilla, palate, and teeth, ranging from minimal to severe, depending upon the particular growth period of the animal and the extent of the trauma or amount of tissue removed.

Facial and Neurocranial Growth After Resection of the Mandibular Condyle in the Monkey

The purpose of this report was to demonstrate that removal of the condylar endochondral growth site of the mandible will markedly influence not only the growth of the mandible but also that of the face and neurocranium.[24] Because the growth activity of the mandibular condyle is greatest during early life, the youngest monkeys obtainable were ordered. Their age when received was estimated according to the dentition to be approximately eight months. The monkeys in this experiment included unoperated controls, animals in which the right mandibular condyle was resected, and animals in which both mandibular condyles were resected either partly or completely. The postoperative survival period ranged from 25 to 35 months.

Findings and Comments

Anterior Aspect of the Skull. A marked asymmetry was noted in those animals in which one condylar growth center had been removed. (Figures 1 and 13). On the operated side total facial height and width were less. This was because of lesser growth of all the bony components but, particularly, the maxillary and mandibular ones. The face on the operated side had a rounder appearance than the unoperated side, which appeared longer and flatter. The maxilla was shorter and narrower, and the plane of occlusion of the teeth was higher than on the unoperated side. Thus, the plane of occlusion was considerably closer to the level of the zygomatic arch and the external auditory

Figure 13. Anterior view of skulls of three growing monkeys with jaws in occlusion. A, control animal number G-2. Note symmetry of face. B, animal number 6. The right condyle was resected 14 months before death resulting in asymmetry of the face. Note shift of the mandible toward the right side, as evidenced by relationship of the upper to the lower incisors. Also, note that downward growth of the left side of face is greater than the right side. C, animal number 13. The right condyle was resected 29 months before death. Note on the operated right side the lesser amount of total facial height, the relatively lower level of the zygomatic arch, the lesser height of the ramus, and length and height of the body. These differences are more accentuated than those in B, which had a postoperative survival of 14 months (See Figures 14 and 15B).

canal on the operated than the unoperated side.

The growth of the mandible at the condylar cartilage is indispensable for the normal vertical growth of the upper face. Upward and backward growth at the condyle, which rests against the articular fossa of the temporal bone at the cranial base, results in movement of the entire mandible downward and forward, so that the upper and lower teeth and alveolar processes become more distant from each other. Since the teeth maintain occlusion by continued vertical eruption, the alveolar processes grow at their free borders. Disorders of mandibular growth, therefore, lead secondarily to changes in the upper face. They generally involve only the subnasal part of the maxilla. This experiment demonstrated that with inhibition of increase in ramus height, increase in maxillary and mandibular body height were concomitantly inhibited. Because of the smaller maxilla on the operated side the maxillary sinuses were examined to determine whether or not they also varied in size. No definite conclusions could be made, however, because of the small size of the sinuses. The mandible appeared to be swung toward the operated side. On the unoperated side, ramus and mandibular body height and mandibular body length were greater than on the operated side.

Lateral Aspect of Skull. Comparison of the lateral view of skulls of growing monkeys, in which the mandibular condyle had been excised, with the opposite unoperated side or control animals revealed striking differences (Figure 14). Facial height and length were less on the operated side. Whereas, on the side with the intact condyle, the zygomatic arch and external auditory canal were in the region of the middle of the skull, well above the inferior border of the maxilla, on the operated side they were in the region of approximately the junction of the middle and lower thirds of the skull at about the level of the inferior border of the maxilla or even the occlusal plane of the teeth. The coronoid process was also directed more posteriorly and above the zygomatic arch on the side from which the condyle had been removed.

Basal Aspect of Skull. Examination was made of the ventral surface of the base of the skulls of growing monkeys in which one mandibular condyle had been resected, with the mandibles articulated and in occlusion. This revealed that, on the side from which the condyle was removed, the upper posterior border of the ramus was markedly anterior and in the region of the temporosphenoidal suture. There was a space of about 3-5 mm between the operated surface of the mandible and the skull. This was filled with fibrous tissue at the time of dissection. The unoperated side of the mandible appeared longer and the chin was markedly directed to the operated side.

Examination of the basal aspect from the ventral surface of skulls of these monkeys disclosed that the anterior and posterior parts deviated toward the

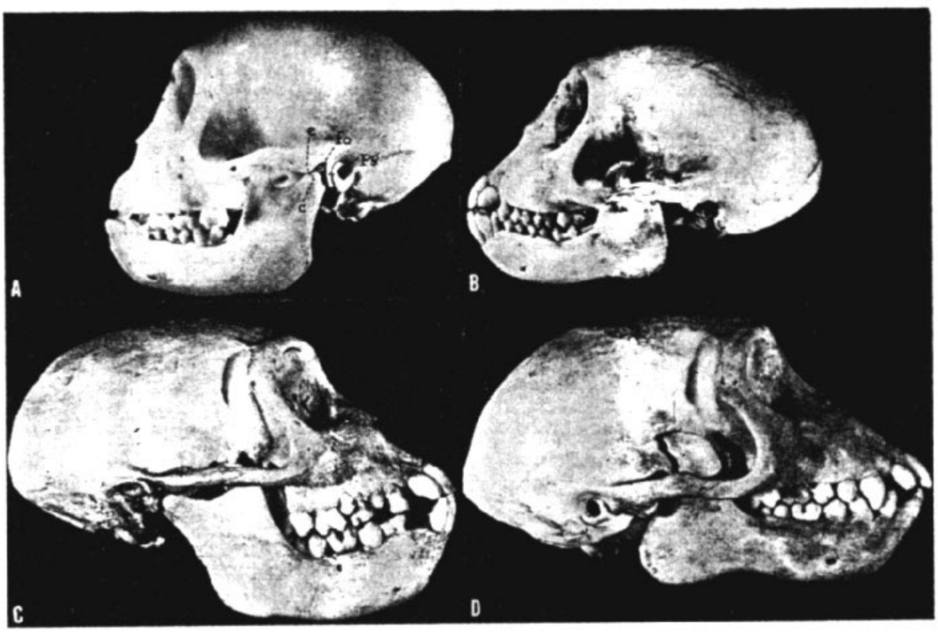

Figure 14. Lateral view of skulls of four growing monkeys with jaws in occlusion. A, unoperated animal number G-1. Note the condyle, c; its position in the articular fossa, o; the articular eminence, e; the postglenoid process, pg; height of ramus, relation of posterior border of ramus to fossa and the mandibular angle. The coronoid process does not extend above the zygomatic arch. B, animal number 12, approximately the same age as animal number G-1. Both condyles were resected 17 months before death. Note the lesser total facial height; no true condyle, fossa or articular eminence visible; the considerably wider and heavier coronoid directed more posteriorly and above the zygomatic arch; the shorter, wide, anteriorly positioned ramus (and coronoid); the relation of posterior border of ramus (region of sphenotemporal suture) to where the true fossa should be; the mandibular angle which appears to be 90 degrees or less; the accentuation of the antegonial notch and the lesser height of the mandibular body. Compare with A and D. C and D, animals of comparable age with permanent dentition, but older than animals in A and B. C, unoperated animal number 2. D, animal number 13. The right condyle was resected 29 months before death. Compare with C and B (animal of only 17 months' postoperative survival). Also, see Figures 13B and C.

operated side (Figure 15). On the operated side the following findings were noted: the maxillary teeth were less well-erupted and the palate appeared to be somewhat higher; the palatine foramen was more anterior and appeared to be larger; the horizontal plate of the palatine bone was more anterior; the great wing of the sphenoid was smaller; the zygomatic arch was shorter, more curved, did not extend as far posteriorly and appeared heavier; the temporal bone was shorter and not as wide; the articular eminence, the fossa and the postglenoid process of the temporomandibular joint were either less well developed or absent and in a more anterior and medial position; the external auditory canal was in a more anterior position; the carotid canal and the stylomastoid foramen were also in a more anterior position, as was the posterior part of the temporal bone. Examination of the dorsal aspect of the base of the skull, after removing the top of the skull, revealed no significant

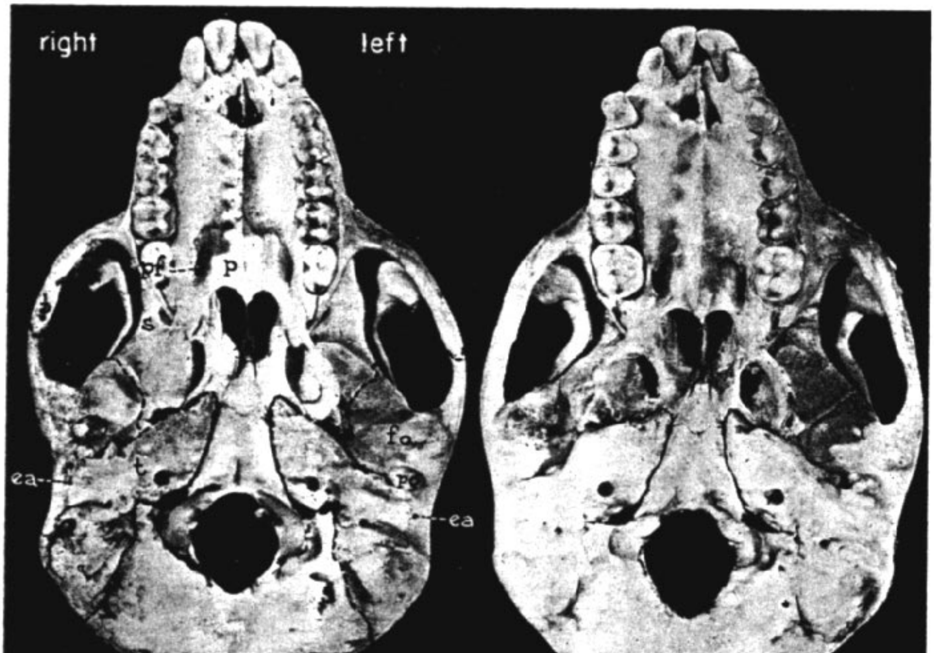

Figure 15. Ventral view of skulls of two growing monkeys whose right mandibular condyles were resected in A, animal number 4, 25 months before death; and in B, animal number 13, 29 months before death. p, horizontal plate of palatine bone; pf, palatine foramen; s, great wing of sphenoid bone; z, zygomatic arch; fo, articular fossa, pg, postglenoid process; t, temporal bone indicated by broken line; ea, opening of external auditory canal. Note that the right border appears to be shorter than the left and the anterior and posterior parts of the skull tend to veer toward the right side. The maxillary teeth on the left side have erupted more than on the right side and are inclined lingually. The palate on the left side appears to be slightly lower, and the horizontal plate of the left palatine bone is more posterior than the right. The left zygomatic arch extends more posteriorly, and is longer, thinner and straighter than the one on the right. There is no semblance of an articular fossa in the right temporal bone and the remaining right postglenoid process is not as far posterior as the left one. The external auditory canal is more posterior on the unoperated left side.

differences between the left and right sides.

Summary and Conclusions

A series of animal experiments on postnatal growth of the upper face are briefly reviewed. The methods employed were gross studies with or without the use of metallic implants and serial roentgenography. The increased separation of implants on either side of a suture was taken as an indication of sutural bone growth. Several different facial sutures were studied. A variation in the amount and rate of growth was found depending upon the particular suture studied and the age of the animal.

In an attempt to produce a growth arrest, the frontonasal and the median and transverse palatine sutures were resected. A comparison of the skulls of the operated and unoperated sides with each other and of the operated animals with approximately comparable unoperated controls revealed no significant gross differences. Resection of the septovomeral region and the mandibular condyle, however, had profound effects upon facial growth.

Thus, from these experiments, it seems that areas of cartilaginous growth (septovomeral region, mandibular condyle) are primary and important growth sites, while areas of sutural growth are secondary or accommodating growth sites.

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References

1. Cited from Keith, A.: The Foundation of our Knowledge of Bone Growth by Duhamel and Hunter, Chap. XIV, p. 221. *Menders of the Maimed.* London: Henry Frowde and Hodder & Stoughton, 1919.
2. Brash, J. C.: Some Problems in the Growth and Development Mechanics of Bone. *Edinburgh Med. J.* 41: 305-319, 363-387, 1934.
3. Brash, J. C.: *The Growth of the Jaws and Palate.* London: Dental Board of the United Kingdom, 1924.
4. Brodie, A. G.: On the Growth Pattern of the Human Head from the Third Month to the Eighth Year of Life. *Am. J. Anat.* 68: 209-262, 1941.
5. Weinmann, J. P. and Sicher, H.: *Bone and Bones.* St. Louis: The C. V. Mosby Co., 2nd ed., 1955. Lacroix, P.: *The Organization of Bones.* Phila.: The Blakiston Co. 1951.
6. Sarnat, B. G. and Gans, B. J.: Growth of bones: Methods of Assessing and Clinical Importance. *Plast. and Reconstr. Surg.* 9: 140-160, February, 1952.
7. Adams, C. O. and Sarnat, B. G.: Effects of Yellow Phosphorus and Arsenic Trioxide on Growing Bones and Growing Teeth. *Arch. Path.* 30: 1192-1202, December 1940.
8. Dixon, A. D.: Studies on the Growth of the Upper Facial Skeleton Using Radioactive Calcium 40: 204-216, 1961. Dixon, A. D. and Hoyte, D. A. N.: A Comparison of Autoradiographic and Alizarine Techniques in the Study of Bone Growth. *Anat. Rec.*, 145: 101-113, 1963.
9. Hrdlicka, A.: *Practical Anthropometry.* Phila.: The Wistar Institute of Anatomy and Biology, 1939.
10. Broadbent, B. H.: A New X-Ray Technique and its Application to Orthodontia. *Angle Ortho.*, 1: 45-66, 1931.
11. Hofrath, H.: Bedeutung der Roentgenfern and Abstandsaufnahme fur die Diagnostic der Kieferanomalien. *Fortschr. der Orthod.*, 1: 232-242, 1931.
12. Broadbent, B. H.: The Face of the Normal Child. *Angle Ortho.*, 7: 209-233, 1937.
13. Black, W. H.: A Method of Roentgenographic Cephalometric Study of the Growth Changes in the Facial Bones of a Dog. Northwestern University M. S. Thesis, 1948.
14. Hulen, G. R.: A Method of Roentgenographic Cephalometry as Combined with the Use of Metallic Implants in Studying the Growth of the Mandible in the Experimental Animal: The Dog. Northwestern University M. S. Thesis, 1948.
15. Gans, B. J. and Sarnat, B. G.: Sutural Facial Growth of the Macaca Rhesus Monkey: A Gross and Serial Roentgenographic Study by Means of Metallic Implants. *Am. J. Ortho.*, 37: 827-841, 1951.
16. Selman, A. J., and Sarnat, B.G.: A

Headholder for Serial Roentgenography of the Rabbit Skull. *Anat. Rec.*, 115: 627-634, 1953.

17. Selman, A. J., and Sarnat, B. G.: Sutural Growth of the Rabbit Snout: A Gross and Serial Roentgenographic Study by Means of Metallic Implants. *Am. J. Anat.*, 97: 395-408, 1955.
18. Selman, A. J., and Sarnat, B. G.: Growth of the Rabbit Snout after Extirpation of the Frontonasal Suture: A Gross and Serial Roentgenographic Study by Means of Metallic Implants. *Am. J. Anat.*, 101 (2): 273-293, September, 1957.
19. Robinson, I. B. and Sarnat, B. G.: Growth Pattern of the Pig Mandible: A Serial Roentgenographic Study using Metallic Implants. *Am. J. Anat.*, 96: 37-64, 1955.
20. Bjork, A.: Facial Growth in Man Studied with the Aid of Metallic Implants. *Acta Odont. Scand.*, 13: 9-34, 1955.
21. Sarnat, B. G.: Palatal and Facial Growth in Macaca Rhesus Monkeys with Surgically Produced Palatal Clefts. *Plast. and Reconstr. Surg.*, 22: 29-41, July, 1958.
22. Weinmann, J. P., Sarnat, B. G., and Sicher, H.: Tissue Reaction in Surgical Defects of the Palate in Macaca Rhesus. *Oral Surg., Oral Med., and Oral Path.*, 11: 20-25, January, 1958.
23. Wexler, M. R., and Sarnat, B. G.: Rabbit Snout Growth. Effect of Injury to Septovomeral Region. *Arch. Otolaryng.*, 74: 305-313, 1961.
24. Sarnat, B. G.: Facial and Neurocranial Growth after Removal of the Mandibular Condyle in the Macaca Rhesus Monkey. *Am. J. Surg.*, 94: 19-30, July, 1957.