Functional Cranial Analysis of the Human Maxillary Bone: I, Basal Bone

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INTRODUCTION

Available techniques for the study of cranial growth in living man exceed those applicable to skeletal material. The use of metallic implants in man, as well as in experimental animals, permits accurate superimposition of tracings obtained from serial x-rays. In this way *absolute* dimensional and *relative* spatial growth changes within a given bone, or between adjacent bones, are easily determined.[1,2] In essence, such implants provide biologically valid *stable* points and planes of registration. No craniometric technique can provide such valid registration sites in human skulls. The introduction of roentgenographic methods to craniology did not materially aid this situation in the past, since it was coupled with the use of a variety of cephalometric techniques, derived from orthodontics, which were equally incapable of expressing the biological processes underlying the observed growth changes in either cross-sectional or longitudinal data. Recent conceptual advances, however, have now begun to alter this situation. There is now general agreement that students of human skull growth should discard the array of both "natural" and "artificial" points and planes (i.e., nasion, Frankfort Horizontal) and substitute in their places a series of biologically meaningful planes, surfaces and contours. For example, we know that the growth of the anterior cerebral lobes is completed in the first few years of life. Accordingly, the contour of the endocranial (cerebral) surface of the anterior cerebral fossa may be used with a high degree of certainty as a fixed plane (or contour) of registration in both skeletal as well as living material.[3,4,5,6,7,8] In this manner, it is easy to show the relative spatial and dimensional growth changes of the splanchocranial bones with reference to the base of the neurocranium.[9] In the living, the additional use of implants in the several facial bones also permits the determination of absolute spatial and dimensional changes between and within these bones.[6] Studies of facial bone growth using skeletal material have been denied an analog of this method until now. The application of the newer method of Functional Cranial Analysis is beginning to overcome this problem.[10,11] With regard to maxillary bone growth, this paper presents data that support the hypothesis that the plane of the infraorbital canal is a fixed, and biologically valid, plane of registration, and that the infraorbital foramen is an equally valid point of registration on that plane. This plane and point are as useful with cross-sectional craniological data as the implant method is for the living. The use of this spatially stable contour permits the determination of *absolute* dimen-

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sional and directional growth changes *within* the maxillary bone. When combined with other data (mensurational, histological) it permits a more meaningful statement about maxillary bone growth.

MATERIALS AND METHODS

The present paper reports on a cross-sectional series of forty-seven Eskimo skulls in the collections of the National Museum in Washington, D.C. These are but a portion of a substantially larger series, studied simultaneously, of various other ethnic groups.

The skulls were classified by dentition as: a) *deciduous* — no permanent teeth erupted ($n = 10$), b) *mixed* — both permanent and deciduous teeth present, without regard to the nature of the mixture ($n = 15$) and c) *adult* — no deciduous teeth present, two or three molars erupted ($n = 22$). The following landmarks were used:

1) the most medial point of the external rim of the infraorbital foramen.
2) midpoint of the posterior end of the infraorbital canal (groove).
3) most medial point of the ectocranial rim of the foramen rotundum.

These same points were marked with a radiopaque barium sulfate paste and films taken in norma lateralis and norma verticalis. Additional films were taken with a wire-based pipe cleaner inserted in the infraorbital canal. The following measurements were made:

a) projective length of the infraorbital canal (1-2). This was measured bilaterally with vernier calipers and the average used.
b) minimal projective distance between infraorbital foramina (1-1) with calipers.
c) minimal distance between foramina rotunda (3-3). This was measured from films in norma verticalis and with calipers.
d) minimal projective distance between midpoints on posterior ends of infraorbital canals (2-2) with calipers.
e) minimal projective distance between infraorbital foramen and foramen rotundum using films in norma verticalis (1-3).
f) by subtracting distance (a) from distance (e) the minimal projective distance between the foramen rotundum and the posterior end of the infraorbital canal is determined, being effectively the anteroposterior length of the base of the pterygopalatine fossa (2-3).

In taking the films we used the following factors: no screen film, 60 K.V., 10 M.A., 4 sec. Acetate tracings were made of significant maxillary and cranial base structures.

Finally, the position of the dentition relative to the infraorbital foramen was noted in each skull. Here we considered a vertical line to extend from the lower border of the foramen, in norma lateralis, to the dentition and recorded the position of its point of intersection.

These data were used to make two constructions. The first used the craniometric data and is presented as if it were projected in norma verticalis (Fig. 1). The roentgenographic data were treated as follows: The tracings of each of the three groups were studied separately. In each of the three groups the acetate tracings were overlaid and variously oriented as discussed below. Composite tracings of the three dental age groups were made by visual inspection. A final comparative tracing was made from the three composites (Figs. 2, 3). Since we wish to demonstrate a *process* primarily, the obvious factors of sex and age, and individual variation do not significantly disturb our method.

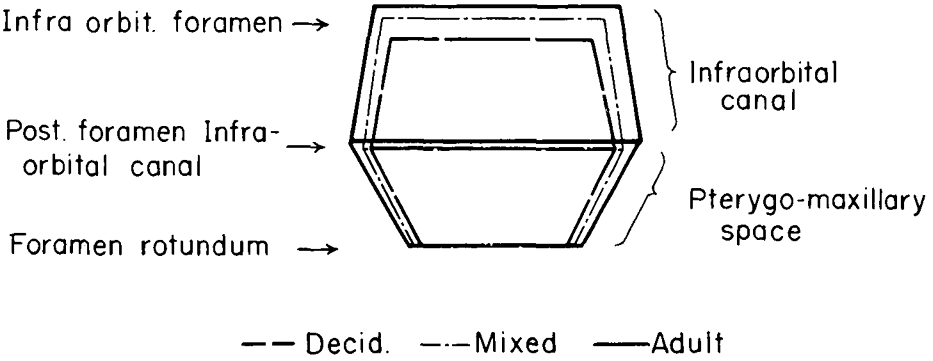


Fig. 1 Schematic presentation of the mean values for horizontal and antero-posterior dimensions of the three age groups of Eskimo material presently studied. This figure, seen in norma verticalis, is registered on the foramen rotundum and shows the mean growth changes of the posterior end of the infraorbital canal as well as of the foramen rotundum.

RESULTS

Linear growth: The craniometric data are shown in Table I. It is observed that the absolute increase in width between the three points measuring the horizontal distance between the two maxillary nerve trunks shows an increasing gradient as we pass postero-anteriorly.

These data also show that in our Eskimo sample the mean length of the deciduous infraorbital canal is 82% of the adult mean, while this mean length in the mixed dentition skulls is 94% of the adult mean value. Mean minimal infraorbital widths (1-1) are 82% of the adult values in the deciduous series, while the mixed dentition values are 91% of the adult. The values of mean minimal distances between posterior ends of the infraorbital canal (2-2) are 86% and 89% of the adult values respectively. Obviously all increases in width between the bilateral maxillary nerve trunks are relatively constant, and nearly identical with the percentage length increases of the infraorbital canal. Put in other words, the basal maxillary skeletal unit maintains a constant *shape* while increasing in *size.*

Inspection of Table I also demonstrates that while infraorbital canal length increases an average of 4.7 mm from the deciduous to adult dentition stages, the mean horizontal increase in pterygopalatine fossa length is only 1.3 mm. As we shall discuss below, these data point toward the conclusion that

Table I

Mean Millimetric Measurements

	Width between infraorbital foramina (1-1)	Width between posterior ends of infraorbital canals (2-2)	Width between foramina rotunda (3-3)	Length of infraorbital canal (1-2)	Length infraorbital foramen to f. rotunda (1-3)	Length pterygo-palatine fossa (3-2)
Deciduous	38.8	47.8	27.5	21.4	39.0	17.6
Mixed	43.0	49.5	31.2	24.5	42.9	18.4
Adult	47.5	55.8	33.3	26.1	45.0	18.9

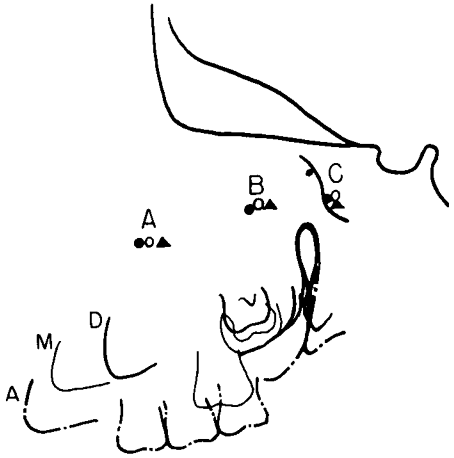


Fig. 2 The mean tracings of the three Eskimo age groups are shown registered on the cranial base. This figure depicts the growth of the maxilla, in norma lateralis, relative to the cranial base. Note the differential motion of the three points indicating the position of the infraorbital neurovascular triad, with the foramen rotundum displaced least. The constancy of the outline of the pterygopalatine fossa is a feature of such registrations.

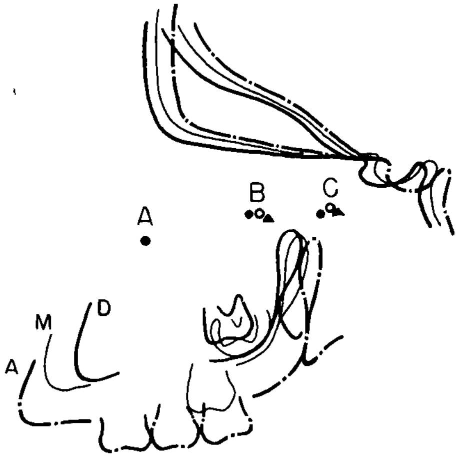


Fig. 3. The same three tracings are now redrawn registered on the infraorbital foramen and the plane of the infraorbital canal. This figure more accurately indicates the intramaxillary growth changes which occur in the lateral plane while the downward and forward relative motion shown in Figure 2 above is taking place. The backward growth of the tuberosity, for example, is well shown, as are the changes at anterior incisal region.

the distance between the ectocranial (pharyngeal) surface of the foramen rotundum and the posterior end of the infraorbital canal remains essentially constant for the time period presently studied (approximately 5-21 years).

Relative Maxillary Movements: A graphic representation of this is shown in Figure 1, viewed in norma verticalis. The registration point in this figure is the ectocranial surface of the foramen rotundum. Just as Figure 1 illustrates the movement of the maxillary basal skeletal unit relative to the *cranial base* in norma verticalis, so Figure 2 illustrates this movement in norma lateralis. Here the biologically correct depiction of mean total maxillary movement relative to the cranial base is shown, with the registration plane at the *endocranial* surface of the anterior cranial base including the sella turcica. That these two figures show downward, forward and lateral growth of the maxillary basal skeletal unit relative to the cranial base is neither new nor surprising.

The virtual constancy of the external orifice of the foramen rotundum in Figure 2 is noted. These same tracings, when registered on that foramen, show virtually identical relative growth changes of the maxilla. The angular constancy of the mean vertical position of the two infraorbital canal points (1, 2) is easily seen. Hence we really observe that the projective vertical position of the maxillary neurovascular triad is constant relative to the anterior cranial base, while the other portions of the maxillary bone are being spatially relocated relative to the cranial base.

Maxillary Bone Growth: The topographic constancy of the infraorbital canal noted above provides us with a registration (or reference) plane with which to study the absolute growth of the other portions of the human maxilla during the developmental period ex-

Table II

Developmental Position of Dentition Relative to the Infraorbital Foramen in an Eskimo population

	C-P^1	P^1	P^1-P^2	P^2	P^2-M^1
	IV	IV	IV-V	V	V
Deciduous	5	1	2	1	
Mixed		7	8		
Adult		2	4	16	

tending from the complete deciduous to the complete adult dentition. A graphic representation of the mean growth is shown in Figure 3. Here the lateral maxillary outlines are registered on the plane of the infraorbital canal and the infraorbital foramen. The vertical and anteroposterior alterations of palatal, alveolar and dental structures are illustrated. It is understood, and explicitly stated, that no such figure can depict *where* osteogenesis or osseous resorption occur. This will be discussed below. What is shown are the dimensional and spatial changes that are the resultant of *all* of the growth processes involved.

Another point of interest is shown in Table II. Here we note the resultant of mesial migration *within* the maxilla of the maxillary dentition, relative to a fixed infraorbital foramen. These data are completely in concordance with previously published studies of mandibular dental mesial migration relative to the mental foramen.[12,13,14]

DISCUSSION

Functional Cranial Analysis: Experimental studies on rat cranial growth, together with a series of analyses of normal and pathological human cranial growth,[15,16,17,18,19,20,21,22] led us to postulate an analytical method which permits biologically meaningful statements to be drawn from craniological data.[10,11] The theoretical basis for this method rests upon the work of van der Klaauw[23] whose original conceptualizations we have been able to experimentally verify and to extend.

Functional cranial analysis begins with a simple statement. The head is a composite structure, operationally consisting of a number of relatively independent functions: olfaction, respiration, vision, digestion, speech, audition, equilibration and neural integration. Each function is carried out by a group of soft tissues which are supported and/or protected by related skeletal elements. Taken together, the soft tissues and skeletal elements related to a single function are termed a *functional cranial component*. The totality of all of the skeletal elements associated with a single function is termed a *skeletal unit*. The totality of the soft tissues associated with a single function is termed the *functional matrix*. It may further be demonstrated that the origin, growth and maintenance of the skeletal unit depend almost exclusively upon its related functional matrix. (see Moss[11] for a more detailed discussion using an older nomenclature).

The form (size and shape) of any given skeletal unit is related entirely to the form of its functional matrix. For example, the endocranial surfaces of the frontal, parietal, temporal, occipital, ethmoid and sphenoid bones form a single, large, skeletal unit subserving one common function: the protection and support of the enclosed neural mass. The ectocranial surfaces, however, are composed of several skeletal units and so they may and do respond to a number of other, independent matrices and their independent demands (temporalis muscles, occipital muscles, etc.). At the other end of the scale, we find that a single bone, in the classical sense, is often made up of several, relatively independent, skeletal units. In this case we must fractionate the bone in order to appreciate the biological significance of its total size and shape. Such an analysis of the mandible has been published[22].

This situation is true for the maxilla also. The classical anatomical descriptions of this bone vary little from one textbook to another. While such statements are by no means incorrect, *per se,* they fail totally to give any understanding of how the maxilla participates in the several relatively independent functions with which it is associated. Indeed, we quickly realize that from the functional point of view there is no such entity as the maxilla. Rather, we have a bone composed of several, relatively independent, functional skeletal units that are associated with many functions among which are: vision, respiration, digestion, speech and the protection of neurovascular structures (Figs. 4, 5).

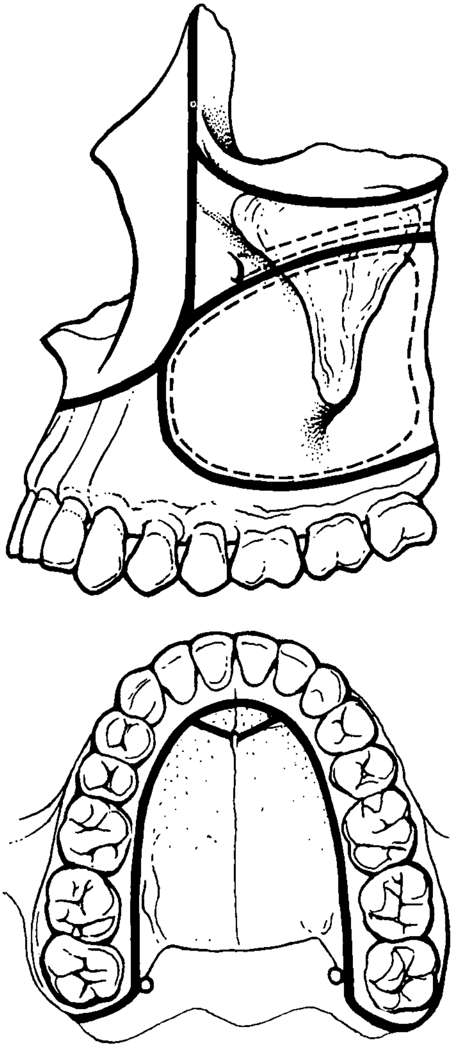


Fig. 4-5. A functional analysis of the maxilla is depicted in a lateral and palatal view. The rough separations of nasal, orbital, pneumatic, alveolar, palatal, premaxillary and basal skeletal units are shown. This is to be understood as a didactic approximation without consideration of mutual interactions and modifications between adjacent skeletal units.

Within this conceptual framework we initiated a functional cranial analysis of the form and growth of the postnatal human maxilla. The present paper, the first of a series on the maxilla, concerns the skeletal unit termed "basal bone". This phrase, originally derived from dental usage, designates here that maxillary skeletal unit which serves to protect and support the infraorbital neurovascular triad. Or, put another way, it is that portion of the maxilla "left over", as it were, when all other maxillary skeletal units have been subtracted. A brief review of the functional analysis of the mandible will make this clear. The mandible has alveolar bone (related to teeth), a coronoid process (related to the temporalis muscle), an angle (related to masseter and medial pterygoid muscle) and a condyloid process (related to lateral pterygoid muscle and the secondary cartilage mass of this process).[21,22] What is left, with some minor exceptions (chin, mylohyoid line, etc.) serves only to protect and support the mandibular (inferior alveolar) neurovascular triad.

The basal portion of the maxillary bone is but one of a series of relatively independent skeletal units which in their totality comprise the maxillary bone. The other skeletal units include those osseous tissues related to the teeth, the orbit, the nasal cavity, the oral cavity, maxillary sinus, etc.

The Functional Matrix: The origin of each skeletal unit is undoubtedly determined by intrinsic (genetic) factors. However, all further dimensional growth, spatial relocation, size and shape and, indeed, the very presence of each skeletal unit depends upon extrinsic (environmental) factors forming the functional matrix.

We have shown previously that the growth of both neurocranial bones and of the mandible is a secondary, compensatory and mechanically obligatory response of the skeletal units to the primary growth of the several functional matrices.[10,11] This is, of course, true for the maxilla as well. All of the observed skeletal changes currently observed must be understood as secondary *responses* to primary matrix growth changes. The craniologist is all too apt to forget that the hard tissue he studies reflects the resultant of prior soft-tissue alterations, and so he comes to believe that the dimensional and spatial changes in the growing maxillary bone, for example, are due primarily to the growth of these same skeletal tissues. With this precaution, we now note that the functional matrix of the maxillary basal skeletal unit consists solely of the infraorbital neurovascular triad. Of the three components of this triad, it seems to us that it is the maxillary division of the trigeminal nerve that plays the major role in maintaining the spatial constancy of the infraorbital canal to the anterior cranial base, and thus indirectly producing a similar constancy of the spatial position of the basal maxillary skeletal unit relative to this same base.

Anatomy and Growth of the Infraorbital Canal and Groove: The area of the infraorbital foramen is the site of the first ossification of the human maxillary bone (the premaxilla being a separate entity)[24] with bone formation beginning at about the end of the sixth week in the form of a series of radiating trabeculae which soon transform themselves into a smooth border platelike bone.[25] An infraorbital groove is noted in a 30 mm C.R. fetus[26] and at 38 mm[27] which gradually is converted to a canal by the growth of bone from both sides of the groove to meet in the midline leaving a horizontal infraorbital suture. The fetal stage at which the closure begins is not known to us. This closure is incomplete proceeding in an anteroposterior direction. The canal that is formed occupies a variable length of the orbital floor. In an examination of several hundred additional skulls of various origins and ages, we never observed complete closure of the groove, although in one case as much as seven eighths of the area was occupied by the canal. Bilateral asymmetry was the rule with about two thirds of the length of the orbital floor existing as a canal. At the margin of the lower orbital rim, this groove continues to run to the upper rim of the infraorbital foramen as a vertical infraorbital suture.[28] In our extended series we found some variation in this regard, with disappearance of this vertical suture most marked in a series of adult Australian aboriginal skulls.

The topography of the canal and groove is somewhat variable. In most skulls with deciduous dentitions the canal and groove form a relatively smooth and even plane, while in many skulls with mixed and adult dentitions often there is a declivity to the anterior portion. Usually the plane of the canal and groove form two distinct limbs, like a very shallow inverted V, with the apex approximately above the mesiobuccal root of the first molar tooth. However, we must emphasize the range of normal variation with respect to this feature. We did not observe multiple infraorbital foramen (cf: Riesenfeld[29], for this data, as well as further literature references).

At all ages studied, the horizontal position of the curved infraorbital canal/groove, as visualized in norma verticalis, is lateral to the maxillary dentition with only minor exceptions of a molar root or two. In this plane we consistently observe an externally directed convexity, arcing fairly evenly along its whole length.

A few remarks about the growth of the orbital mass (functional matrix) are appropriate here. Weiss[30] reported that at three years the orbital volume was constant and remained so until puberty when a slight further increase occurred. Whitnall[31] reports cross-sectional data on orbital dimensions noting that by seven years they approximate those of the adult. Essentially similar data are noted for the eyeball by Scammon and Armstrong.[32] In essence, by the end of the first decade, the orbital matrices have virtually ceased their volumetric growth (if not their spatial relocation.). It is of interest to note that the definitive height of the nasal cavity is attained at the same time[33] as is growth of the several diameters of the sphenoidal sinus.[34] In summary, all of the functional matrices that might affect the position of the maxillary basal skeletal unit have come to rest at this time and do not participate in further growth of the maxillary complex as a whole. While other, nonbasal, maxillary matrices related to oral and dental functions do continue their growth after this time, the earlier cessation of basal matrix growth aids in producing the observed stability of this unit alone. With these data in mind, we may now profitably consider the processes of bone growth.

Maxillary Bone Growth: A recent series of publications have provided useful data on this subject. Björk[6] reported on a longitudinal series of patients with intraosseous metallic implants, while Enlow and Bang[35] and Enlow[36] utilized histological criteria of osseous structure in a cross-sectional study of skeletal material to establish the localized sites of bony apposition and resorption and then applied these concepts to tracings of x-rays of a longitudinally-studied series of patients. The reader is referred to these papers for complete descriptions of these growth processes.

The essence of their work is to call attention to the fact that, while the maxilla, as a whole moves downward, forward and laterally, relative to the cranial base (when studied with roentgenographic techniques which register the tracings on the cranial base), the actual growth processes of the maxillary bone itself do not necessarily proceed in these directions alone. Indeed, to the biologically unsophisticated, their data may appear contradictory at first, showing as they do actual background growth of many areas which are associated with apparent forward motion. This confusion is removed by integrating their data with the concepts of functional cranial analysis. Just as the neurocranial bones are enclosed within a neurocranial capsule, so the facial bones are enclosed within an orofacial or splanchnocranial capsule. Just as the calvarial bones are *passively* carried outwards by the expansion of their enclosing capsule in direct response to the growth of neurocranial matrices (the neural mass) so the facial bones are passively carried outward (i.e., downward, forward, and laterally) by the primary expansion of the enclosed splanchnocranial matrices (orbital, nasal, oral matrices). Finally, just as the actual growth of calvarial bones is secondary, compensatory and mechanically obligatory, as responses to the primary passive expansion of the matrices, so in a homologous manner is the growth of the facial bones in general, and of the maxilla in the present instance.

For example, in the calvaria the passive motions of cranial vault bones would tend to cause an increased sutural area widening if the secondary, compensatory bone growth at the sutural areas were not so well correlated with this motion as to maintain constancy of sutural area widths. In the maxilla, as the several related splanchnocranial matrices expand, the maxilla would tend to be carried away from adjacent bones. The actual growth observed, as in the orbital floor for example, is secondary and compensatory for such vertical lowering so that the orbital cavity is not unduly enlarged in this passive manner. That the orbital matrix itself is actually increasing in volume during this time (roughly up to the age of eight years) is another matter and is associated with other *secondary* bony alterations detailed below. In the anteroposterior plane, this forward, passive motion of the maxilla is constantly being compensated for by accretions posterior to the maxillary tuberosity, and to the palatal processes of both the maxillary and palatine bone.[37]

Actually, then, there are three types of bone growth change to be observed in the maxilla. First, there are those associated with compensation for the passive motions of the bone brought about by the primary expansion of the orofacial capsule. These changes tend to maintain anatomical and functional continuity between the maxillary and adjacent bones. Secondly, there are changes in bone morphology associated with alterations in the absolute volume, size, shape or spatial position of any (or all) of the several relatively independent maxillary functional matrices, such as the orbital mass. Finally, there are bone changes associated with the maintenance of the form of the bone itself. The posterior repositioning of the zygomatic arch which accompanies relative forward movement of this arch is a case in point.[35,36] Such processes tend to retain relative constancy of proportions of the maxilla in the face of disproportionate increases in the several maxillary areas. It must be remembered, finally, that these three processes do not occur necessarily simultaneously. This concept of differential or sequential expression of differing growth phases has been expressed by several workers. A recent exposition of this viewpoint is given by Walker.[38]

Infraorbital Registration: We will restrict our attention now to the region of the infraorbital canal. The site of the infraorbital foramen apparently is a stable point anteroposteriorly. This is noted by Enlow and Bang[35] where they indicate that the foramen is situated between an area of ectofacial appositional growth above and an area of ectofacial resorption below.

The position of the infraorbital foramen is also stable vertically while the orbits are expanding in the horizontal plane. That is, while the orbits are expanding laterally with growth, as noted in Figure 1 and Table I, the orbital floors are also changing their spatial position, tilting downward and laterally as it were. Enlow[35] clearly shows this. The point to be noted here is that the intersection of the changing outlines of the lower orbital borders occurs at the site of the infraorbital foramen.

That appositional growth occurs at the posterior end of the infraorbital canal, associated with absolute growth of the maxillary tuberosity, is beyond question. The maxilla as a whole undergoes a downward, forward and lateral growth *relative to the cranial base.* During these processes, the length of the infraorbital canal is increased posteriorly. The integration of both events produces the constancy of pterygomaxillary fissure outline presently observed in our Eskimo data. This is a general phenomenon. Slavkin et al.[39] noted that "the superior extension of the pterygopalatine canal and fossa was relatively stable, and that the foramen rotundum maintained its position two years following birth." Similar constancy of this anatomic area was reported by Björk.[5]

So far our data, together with that in the literature, have established that the sites of the posterior end of the infraorbital canal and of the maxillary tuberosity are constant after two years of age, *relative* to the anterior cranial base outline and to the foramen rotundum, both vertically and anteroposteriorly. We have also shown that within the maxillary complex, without regard to extramaxillary structures and points, the infraorbital foramen is similarly a fixed point with reference to other maxillary structures.

Indeed our data go further. They show that the topographic position of the entire infraorbital canal is vertically constant *relative to the cranial base.* We wish to discuss now the hypothesis that the canal itself is also a fixed position *relative to other maxillary skeletal units* and, as such, furnishes a useful reference plane for studies of maxillary growth itself without reference to extramaxillary points or planes (see Ashton and Zuckerman[40]).

The entire orbit is engaged in a process of "area relocation." "In the floor of the orbit, the lateral part is lower in its level than the medial region. As the orbit shifts laterally, this medial area continuously comes to occupy regions that formerly were more lateral in their position and were lower in level. The progressive deposition of new bone on the surface of the sloping orbital floor thus serves (1) to shift the entire orbit laterally and (2) to elevate the former lateral areas that have become relocated sequentially into higher-positioned medial regions".[36]

Speaking directly of the floor of the orbit, and by implication of the infraorbital canal also, Enlow and Bang[35] note that the upper ("periosteal") surface is depository, while the lower ("endosteal") surface is resorptive in character. Similar data are reported by Björk.[6] That these processes are adjustive in nature we have discussed above with the clear implication that, when we correlate their data with our own, we seem to arrive at a statement of how dynamic growth processes combine to maintain spatial stability of the infraorbital canal relative to *both* the anterior cranial base as well as to the maxilla considered independently.

When we consider the total picture provided by all these data we suggest that Enlow[36] is incorrect when he states that "there is no stable or fixed reference point that will enable the worker to superimpose precisely tracings of the progressive growth movements themselves." Our data strongly suggest that the infraorbital canal and foramen do furnish precisely such sites. We have demonstrated the constancy of the vertical spatial position of all three foramen associated with the maxillary division of the trigeminal nerve, both within the maxillary bone itself, as well as in their relation to the anterior cranial base. We have further demonstrated that orientation on the infraorbital foramen produces a picture of maxillary bone growth changes entirely consistent with those reported by both Enlow and Björk. These data, together with the valid descriptions of the histological processes involved in these growth changes, allow us to propose the following methods to students of cranial growth.

Growth of the maxilla relative to the cranial base: Longitudinal growth studies of total resultant motion of the entire maxillary bone relative to the cranial base are easily carried out. With lateral films, registration is made on the endocranial contours of the anterior cerebral fossa, i.e., the cerebral surface of the frontal bone, the cribriform plate and the planum sphenoidale. With posteroanterior films, the registration is on the cribriform plate and the lesser wings of the sphenoid. Cross-sectional studies may be carried out with similar techniques. Superimposition of the tracings will demonstrate the movement of the maxillary bone complex in two planes of space relative to a biologically *fixed* anterior cerebral fossa.

Registration techniques for the evaluation of intramaxillary growth: With lateral films the cephalometric tracing should again include the outline of the cerebral surface of the anterior cranial base (sella, planum sphenoidale and cribriform plate of ethmoid) and cerebral surface of frontal bone. An arbitrary line connecting the mean outlines of the planum and cribriform plate surfaces is drawn. To facilitate identifying the cortical rim of the infraorbital foramen the orbital outline may be traced. Directly below the inferior border of the orbit the cortical rim of the infraorbital foramen can be identified. Radiographically this will be seen most frequently as a small area of increased density, or the foramen itself will clearly be seen as an area of radiolucency circumscribed by the increased opacity of the cortical rim. In most x-ray films the infraorbital canal can be traced to its anterior termination at the foramen for further verification of the shadow. The foramen is now traced and a vertical line is projected from the cranial base line (Fig. 6). For superimposing multiple tracings of a given individual the following procedure is recommended. Complete the anatomical tracing of the second film, including anterior cranial base and infraorbital foramen as previously described. The cerebral surfaces of the anterior cranial base outlines are superimposed and the cranial base line of the original tracing duplicated on the second tracing. It is to be noted that there is no necessary relationship of this arbitrary line to the usual sella-nasion construction, since the stability of point nasion, particularly in longitudinal studies of several years duration, is questionable. Any tipping in the S-N plane would be reflected in the vertical plane and distort an accurate visualization of the growth changes.

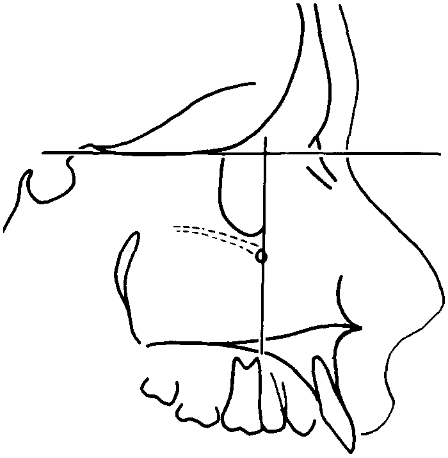
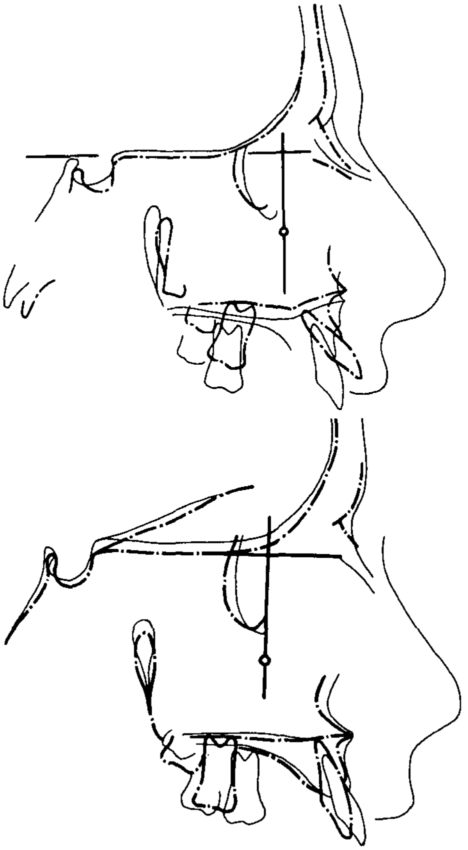


Fig. 6. The technique of infraorbital registration presently proposed is illustrated. The location of the infraorbital foramen and of the arbitrary line representing the mean outline of the anterior cranial base is shown, together with a perpendicular connecting this line and the foramen. Successive tracings can be prepared in this way and then compared by registering these tracings on the common perpendicular line and on the infraorbital foramen. The clinical usefulness of this method in a longitudinal study is shown in Figures 7 and 8. Similar methods may be used equally well in cross-sectional growth studies.



Figs. 7-8. These figures illustrate the method of infraorbital registration in two individuals treated by Dr. S. N. Greenberg who prepared these tracings. The individual differences in maxillary growth are well shown, the marked anteroposterior increase in Figure 7 differing from the virtual lack of change in Figure 8. Note also the differences in growth changes at the region of the anterior nasal spine.

Figure 7. Female, white; Class II, Div. 1; treatment, nonextraction, Pretreatment, 9 yrs. - 9 mo.; Posttreatment, 15 yrs. - 11 mo.

Figure 8. Female, white, arch length deficiency; treatment, extraction of four first premolars, postretention. Pretreatment, 9 yrs. - 3 mo.; Posttreatment, 12 yrs. - 10 mo.

The perpendicular line from the cranial base line to the infraorbital foramen is drawn on the second tracing and both tracings can now be superimposed registering on the vertical line and infraorbital foramen (Figs. 7, 8). The above procedure provides a method for accurately registering succeeding stages of maxillary growth to permit an assessment of the maturational changes taking place. Figures 7 and 8 show before and after treatment tracings of several cases as examples of the varying intramaxillary growth changes to be noted. Cross-sectional study of intramaxillary growth using skeletal material is best carried out with similar roentgenographic techniques.

Finally, we wish to emphasize the fact that these methods are applicable for *all* groups, human as well as primate. Our present use of Eskimo data is a methodological convenience only. While they may indicate something quantitatively unique about Eskimo maxillary growth, they also exemplify a general process which is universally true. This paper presents, for the first time, a biologically valid method for the study of maxillary bone growth, per se, which does not require prior implantation of metallic markers. As such, it provides the opportunity for an extension to clinical practice of previously well-established research methods.

SUMMARY

The human maxillary bone is studied by the method of functional cranial analysis. One of the individual cranial components of this bone complex, the basal bone, is analyzed in detail in a cross-sectioned growth study of an Eskimo population. The stability of the infraorbital canal relative to the cranial base is demonstrated. Correlated macro- and microscopic growth changes in both the functionally-dominant soft tis-

sue matrices and in the secondarily responsive skeletal units of the maxilla are discussed.

Having established the biological bases for the spatial stability of the infraorbital canal relative to the cranial base and, in addition, the stability of the infraorbital foramen relative to other maxillary components, a method of study is presented which will a) permit analysis of growth changes of the maxilla relative to the cranial base, and b) permit analysis of intramaxillary growth changes. This latter method is shown to correspond well with the growth data now available for this bone.

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