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THE CRANIO-FACIAL UNION IN MAN[1]

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TWENTY FIGURES

INTRODUCTION

Cerebral and visceral crania differ fundamentally in function and growth pattern. Cerebral cranium is primarily a passive casement for the brain and organs of smell, hearing and equilibration. Visceral cranium, by reason of its dominating feature, the jaws, is a markedly active element, concerned with the vital functions of nutrition and respiration, and the useful ones of combat and communication. Both units contribute to protection of the eye. Braincase grows rapidly, attains adult size early and is relatively stable during most of postnatal growth. Face grows slowly, to accommodate the gradual eruption of the successive dentitions, the expansion of the respiratory passages and sense organ enlargement. In the young, the facial skeleton may be affected in growth by nutritional alterations, and throughout life, it may be modified by changes in dental and muscular complement.

In order that structural adaptation be maintained constantly adequate to functional requirement, these contrasting functions and growth patterns of cerebral and visceral crania necessitate complex developmental adjustments where face is anchored to braincase. This transitional region, which may be termed the cranio-facial hafting zone, does not appear to have received particular attention in the large literature on the structure and growth of the skull in mammal and man.

[1] Read at the joint session of the American Association of Anatomists with the American Association of Physical Anthropologists, April 16, 1938, University of Pittsburgh.

The present report treats of the human phase of a study of the structural features and growth changes in this hafting zone in all the orders of mammals. This investigation was conducted upon 1,100 mammalian skulls in the Hamann Museum of Western Reserve University and several hundred human skulls in the collections of Western Reserve, the United States National Museum and Howard University. Abstracts of the findings in both mammals and man have previously appeared (Cobb, '38, '38a), and the full mammalian report will shortly be submitted for publication.

The writer desires to acknowledge with grateful remembrance his indebtedness to the late Prof. T. Wingate Todd for the Reserve material and facilities and for his critical comment upon the principal results, and to express his appreciation of the generous cooperation of Dr. Aleš Hrdlička in the loan of National Museum specimens.

STRUCTURAL UNITY OF THE SKULL

The mammalian skull must have strength to resist potentially disintegrating forces which result from: (1) the traction of the axial musculature; (2) the operation of the jaws; and (3) the weight and use of appendages such as horns, tusks or a proboscis, in animals which possess them. Adaptation to these powerful forces is generally achieved by the development of secondary bony crests, bony reinforcements and pneumatic expansions in such manner that the entire skull takes on an appearance of robust structural unity in which topographical demarcation between face and braincase does not appear and the basic capsular nature of the braincase is disguised.

All three types of force center on the braincase. The axial muscles which hold the skull to the trunk are attached to the cerebral cranium and not the face. Each jaw, the upper by bony union and the lower by muscular, is affixed to the braincase and not the trunk. Horns are attached either to frontal or parietals, and a proboscis and tusks are facial specializations which augment the ordinary strains produced by the upper jaw. Since the human skull is without accessory appendages, it is required to withstand only the traction of the axial musculature and the action of the jaws.

This structural unity of the whole skull and focus of force on the braincase is shown in the norma lateralis of the skull of a representative mammal, the Asiatic Snow Bear, Ursus isabellinus, H.M.—B 1102, (fig. 1). The architectural harmony of this skull may well be described by the modern term "streamlined." Contour of face passes indistinguishably into that of braincase and posterior reinforcements for axial traction are not obtrusive as secondary additions.

The sagittal section of the skull of another arctoid, the American Black Bear, Ursus americanus, H.M.—B 51, (fig. 2), shows that this effect has been achieved by expansion of the air passages and sinuses until the planes of the several bones are brought into a harmonious alignment which affords combined strength and lightness.

In effecting this unity of cranial design, Nature has observed no categorical boundaries between facial and cranial regions. The frontal sinuses, which as diverticula of the respiratory tract are facial structures, extend far backward over the braincase. Frontal, ethmoid and sphenoid, which are basically cranial bones and are so classified, all contribute to the face, and the pterygoid processes of the sphenoid in addition, form part of the walls of the nasal cavity.

PATTERNS OF CRANIO-FACIAL UNION

In the carnivores just examined, structural harmony of cranial and facial skeletons is achieved principally through pneumatization of appropriate regions so as to bring the bones into correct alignment for resistance to the lines of force to which they are subject. This adaptive modification is most extremely developed in the Elephant, whose skull withstands the unique loads of a huge proboscis, great tusks, a heavy dentition and an adequate axial musculature.

In certain other mammals, as for example, the Gorilla, the ıdaptation of the braincase for facial and axial loads is augnented by external buttresses in the supraorbital tori and agittal and occipital crests. This superstructure, with the nalar arches, integrates the entire skull.

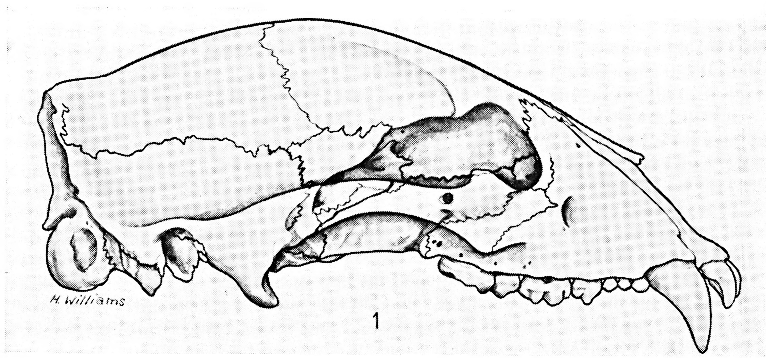


Fig. 1 Norma lateralis of skull of Asiatic Snow Bear, Ursus isabellinus, V.R.U., B–1102. A representative mammal showing harmonious architectural ıtegration of braincase and face, and sutural junctions between cranial and acial bones. Note also the cranio-facial hafting areas: median—the union of rontal and sphenoid with nasal, premaxilla, maxilla, lacrimal and palatine; osterior—the pterygo-palatine union; lateral—the temporo-malar union.

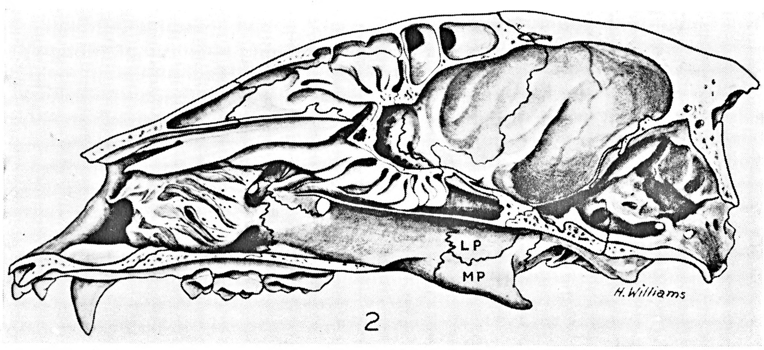


Fig. 2 Sagittal section of skull of American Black Bear, Ursus americanus, '.R.U., B–51. Illustrating role of pneumatization in structural integration cited . figure 1. Note small braincase and backward extension of frontal sinus. ertical cribriform plate of ethmoid, as prepituitary limb of cranio-facial axis, ›rms angle greater than a straight angle with postpituitary limb.

The human skull, on the other hand, is characterized neither by marked pneumatization nor external reinforcements. Yet its cranio-facial union is very strong. This is dramatically obvious in the performance of the circus aerialists in which one performer, swinging by his legs, holds his partner suspended from a gadget held in his teeth (fig. 3). Since the

Fig. 3 Strength of cranio-facial union as demonstrated by circus performers in familiar act. Skull is held to trunk by axial muscles and sternomastoid. These attach only to braincase. Clamped jaws also are affixed only to braincase, the upper by bony union, the lower by the masticatory muscles. Weakness in cranio-facial union or in junction between segments of brain case, would, under strains of type illustrated result in disintegration of the skull.

axial musculature and sternomastoid which hold the skull to the trunk are attached only to the braincase, and the clamped jaws also are attached only to the braincase, in respect to both bony and muscular union, the skull, under conditions of unusual strain such as in the acrobatic performance described, would be torn asunder if: (1) the braincase itself were not firmly knit together; and (2) the face were not strongly united to the braincase.

Because these requirements are very definitely met, the explanation of this efficiency might naturally be sought in arrangements peculiar to the human skull, particularly in association with the most distinctive human features, the enlarged braincase and reduced face. Here, indeed, the answer is found. The semiglobular form of the human cranium and the thickening and close interlocking of its bones afford it unusual stability for withstanding both axial traction and the strains of the jaws. The smaller lighter human facial skeleton permits decreased hafting areas and requires relatively little development of secondary bony reinforcements.

HUMAN HAFTING UNITS

The conditions in Man are readily studied by reapposing the disarticulated bones of a young skull. The form and extent of the articular surfaces indicate the functional importance of the respective sutures.

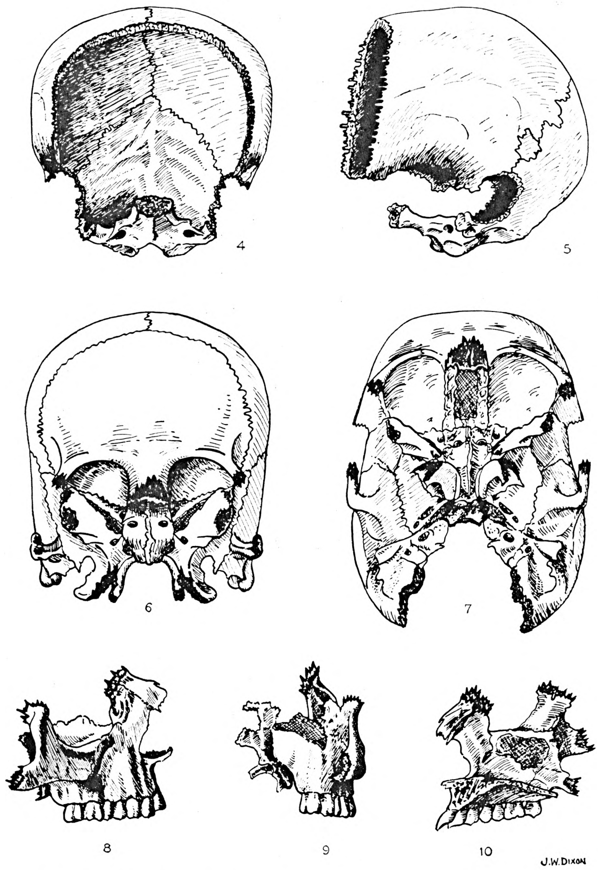
In respect to the cranio-facial union, the bones of the skull consist of three functional groups, two cranial and one facial. The cranial units are a parieto-occipital or axial unit and a fronto-spheno-temporal or cranial hafting unit. The axial unit consists of the occipital and the two parietal bones. It serves for the attachment of the skull to the trunk, on the one hand, and on the other, furnishes an attachment area of great stability for the cranial hafting unit, composed of frontal, sphenoid and the two temporals, to which the facial unit, in turn, is affixed. The facial unit, or facial hafting unit, is comprised of maxilla, nasal, malar and palatine. Lacrimal and ethmoid bones are not of importance in the cranio-facial hafting because of their thin and fragile character.

Axial unit (figs. 4, 5). We see here the occipital and parietals strongly joined together by the markedly denticulate sagittal and lambdoid sutures. This firm unit presents four strategically located articular surfaces for the solid fixation of the cranial hafting unit in front.

The arciform, limbous and denticulate coronal sutural surface firmly locks frontal bone above, and the basilar synarthrosis, sphenoid below. The temporals are securely held in place by strong forceps formed by the parieto- and occipito-mastoid sutures which clasp the mastoid portions of these bones.

The development of this sutural clamp is a very striking functional adaptation, for the region in the fetus is the membranous site of the postero-lateral or mastoid fontanelle, which closes between 12 and 18 months after birth. As masticatory activity increases in force and volume with the successive appearance of the respective cheek teeth, the downward pull of the masseter as well as the various thrusts of the mandibular condyle throw progressively greater strain on the temporal and tend to wrench it loose. Thickening of the adjacent bones plus the development of jagged articular surfaces transform the area about the mastoid from a thin membranous wall in the fetus to a powerful clamp in the adult. This clamp, with the spheno-squamous suture in front, locks the temporal securely in place. The harmonal squamous suture is of insignificant value in this connection.

Cranial hafting unit (figs. 6, 7). This skeletal unit, composed of frontal, sphenoid and temporals, is a strong structural entity. Both fronto-sphenoid and spheno-squamous joints are strong. The fronto-sphenoidal articulation consists: (1) of paired large triangular areas at the posterior part of the junction of squama and orbital plates of the frontal, for corresponding areas on the great wings of the sphenoid, which surmount wedge-like thickenings of bone reinforcing the wings behind the sharp angle between the orbital and temporal surfaces; and (2) of thickened posterior borders of the orbital plates of the frontal for the lesser wings of the sphenoid. The two areas are in the same transverse line and together constitute a limbous suture, the bevel being from within downward and forward at the jugum and laterally,



Figs. 4, 5 Axial Unit. Frontal and lateral views. Unit composed of parietals and occipital held together by the strong denticulate sagittal and lambdoid sutures. Serves for attachment of axial muscles below, and of cranial hafting unit in front, at coronal and parieto- and occipito mastoid sutures and basilar synarthrosis. Note "forceps" clamp on mastoid formed by occipital and parietal.

Figs. 6, 7 Cranial Hafting Unit. Frontal and basilar views. Unit composed of frontal, sphenoid and temporals (see text). By attachment to axial unit behind makes firm stable base of braincase for fixation of face in front. Note sutural surfaces for facial attachment in the three hafting areas: median, for fronto-maxillonasal union; posterior, for pterygo-palatine union; lateral, for fronto-malar and spheno-malar unions.

Figs. 8, 9, 10 Facial Hafting Unit. Lateral, posterior and medial views. Unit composed of maxilla, malar, nasal and palatine (see text). Three bony struts radiate from alveolar arch, terminating in areas for cranial attachment. Struts are anterior, frontal process of maxilla and adjacent nasal; lateral, key ridge, bifurcating above into malar arch and postorbital bar; and posterior, pyramidal process of palatine.

Figs. 4 to 10 Structural Units of Skull Concerned in the Cranio-Facial Union.

while it is downward and backward in front of the free edge of the lesser wings. The articulating surfaces of both bones are markedly denticulate throughout their entire extent, thus additional strength is imparted to the joint.

The spheno-squamous suture holds temporal to sphenoid. Above, on the temporal surface of the greater wing, it forms the downward continuation of the squamous suture. This portion is a weak joint, with the surfaces showing slight denticulation below. Here the bevel is the same as in the squamous suture proper, with the squama of the temporal considerably overlapping the greater wing.

Passing over the ridge separating temporal and infratemporal fossae, however, the bevel is reversed, so that the greater wing undershoots the in-curved or horizontal portion of the squamous. Here the contiguous surfaces are broad, thickened and very denticulate and the joint is consequently strong. The petrous also participates in the spheno-temporal union through a small area at the angle between petrous and squamous.

Braincase as a whole. The integration of axial and cranial hafting units along the sutures described (figs. 5 and 7), results in the very strong and stable unit the human cerebral cranium is known to be. This strength is indirectly reflected in the facts that in archeological and in hard used student study skulls that have been knocked about a laboratory for a long time, the face will often be found broken off, but the braincase still intact.

Facial hafting unit (figs. 8, 9, 10). The junctions of maxilla with malar and pyramidal process of palatine are strong. The maxillo-nasal joint is in itself weak, but the nasals of the two sides wedged between the maxillae form the summit of a strong arch and present a broad denticulate articular surface for the frontal. The median palatine suture is formed between sometimes broad but not strongly interlocked surfaces. The transverse palatine articulation tends to be even less sturdy. In fact, it appears that the palatal shelf does not contribute significantly to the strength of the facial skeleton or the cranio-facial union.

Since the stresses exerted upon the upper jaw are the result of mandibular force received upon the occlusal surfaces of the maxillary teeth, it would be expected that the four bones of the facial hafting unit would be molded into a structural entity in such manner as to afford firm fixation for the alveolar arch and that specializations for cranial attachment would radiate from the arch to the sites of cranio-facial union.

Figures 8, 9, and 10 show that this is the case. The alveolar arch derives its stability from the contiguity of the two sides in front, from anchorage of the pyramidal process of the palatine by the pterygoid process behind, and above from bony struts manifest in the frontal process of the maxilla and adjacent nasal bone anteriorly, and the key ridge of the maxilla laterally. The centrally placed stout pillar formed by the key ridge divides the thrusts it transmits between the postorbital bar and malar arch. The posteriorly projecting pyramidal process of the palatine supports the tuberosity of the maxilla.

It will be noted that these bony struts are strategically placed for resisting the strains put upon the teeth and that the ends of the bony bars present strongly-toothed articular surfaces for union with the cranium. It is on these areas of contact that the strength of the cranio-facial union depends.

HAFTING AREAS

The articulated cranial and facial hafting units shown in figures 6 to 10, demonstrate by the exposed rugged articular surfaces that the structurally significant cranio-facial union is effected in five sites located in three areas, namely: a median area, the fronto-maxillonasal junction; a lateral area, the temporo-malar, fronto-malar and spheno-malar junctions; and a posterior area, the pterygo-palatine junction.

In all the orders of mammals these three areas of cranio-facial union may be distinguished. In their most generalized form, as illustrated by the Snow Bear (fig. 1), the median area consists of the union of nasal, premaxilla, maxilla, lacrimal and palatine with frontal, and the union of palatine with orbito- and alisphenoids; the posterior area, of the pterygo-palatine union; and the lateral of the temporo-malar union. In the Mammalia the posterior union is frequently confluent with the median.

The median area, excepting the higher primates, is consistently the most extensive and important. The lateral (Sloth) or posterior (Musk Deer) junctions may be absent or vestigial. Variation in the strength of one area is generally compensated by inverse change in one of the other two.

In this respect, the striking features of the human hafting are marked reduction of the median area, extension of the lateral, and localization of the posterior.

In the human median area, three of the five bones of the generalized pattern no longer figure in the articulation with the frontal. Premaxilla is missing, lacrimal has become too fragile and palatine has lost contact with the frontal. Further, contact of palatine with orbito- and alisphenoids has been lost. Thus the median area, though strong, is greatly reduced in number of components and in extent.

This reduction, however, is compensated by increase of attachments in the lateral area. Here are not only a postorbital bar, formed by union of malar process of frontal and frontal process of malar at the fronto-malar suture, but also a spheno-malar attachment formed by the junction of a thin backward partition from the malar with the greater wing of the sphenoid. The postorbital bar is common in Ungulates and other orders, and the sphenomalar partition is found in the Anthropoids as well as Man. The small braincase and large face of the Great Apes, however, in which also the median area is reduced, apparently require the especial development of the postorbital bar, and its prolongation above, the supra-orbital torus, a feature unnecessary in Man with the opposite characters, large braincase and small face, and a consequent increased stability of the cranial hafting unit.

The human pterygoid processes from a comparative standpoint are well developed and the rough area for articulation with the palatine at their lower ends indicates concentration of the posterior hafting strength in that region.

THE MAXILLARY TUBER

It has been indicated above that the posterior hafting area was concerned with the support of the tuberosity of the maxilla. Before proceeding to the growth changes in the hafting areas it will be necessary to devote special attention to this structure.

The most important new feature which demands strengthening and adjustment in the hafting zone during growth is the appearance of the successional dentition. The provision of space and fixation for the permanent molars while growing and after eruption is the most difficult requirement to be met.

The maxillary tuber is a bony sac in which the permanent molars grow. After these teeth have developed and moved into place, the tuber may disappear (Wart Hog), form the support of a bullous expansion of the lacrimal (Pecora), become a solid bony protuberance (Man), or a prominence excavated by the maxillary sinus (Man).

Because the space within the maxillary wall for growth of all the successional dental sacs is limited and because the crowns of the permanent teeth must be cast full size before eruption[2], growth in all the dental sacs cannot spurt at the same time. We find that adjustment to this restriction is accomplished in two ways. First, the growth spurts of the separate teeth are staggered so that while the maxilla itself is slowly growing, individual crowns grow to full size and erupt leaving new space behind in which their adjacent fellows may grow rapidly in turn. Nevertheless, certain upper teeth grow faster than the upper jaw so that the latter is expanded by them temporarily as though the jaw were a rubber balloon, an excellent evidence of the remarkable plasticity of living bone.

[2] Excepting hypsodont molars, tusks and rodent incisors.

This may be noted in the skull of a young Chimpanzee, Pan sp. H.M.—B 1183, figure 11, in which the teeth succeeding the milk dentition produce bulging, upward into the nasal fossa, medially into the maxillary antrum, and externally.

As the permanent molars have no predecessors, and in front the maxillary wall is closely packed with teeth succeeding

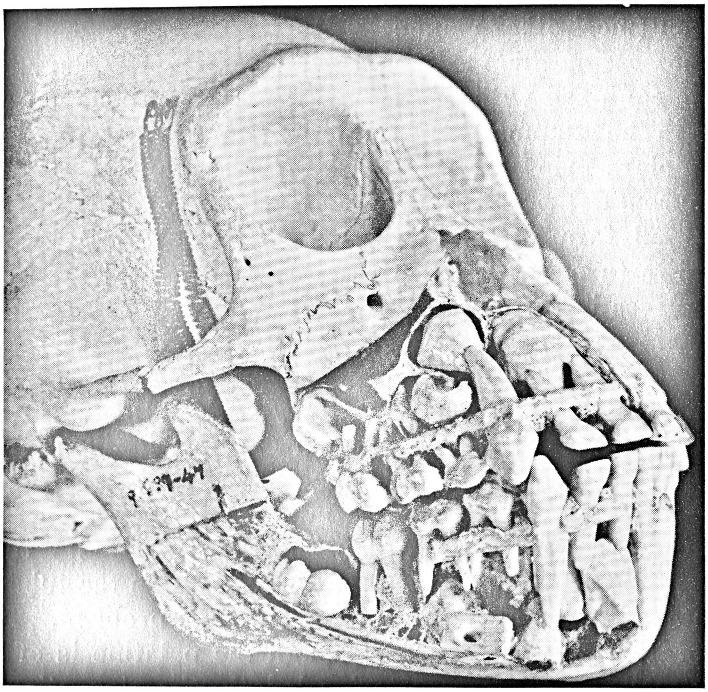


Fig. 11 Skull of young Chimpanzee, Pan sp., W.R.U. B–1183. Showing ballooning of maxilla by growing dental sacs. Maxillary wall may be seen to bulge upward into nasal fossa, medially into maxillary sinus, and externally. Note backward extension of maxillary tuberosity to accommodate growing molars is part of same phenomenon.

the milk dentition, the maxillary tuber is forced to project backward into the infratemporal fossa while the contained molars grow in successive spurts prior to their eruption and gradual accommodation in the dental arch through forward growth of the maxilla.

When the maxillary tuber protrudes thus backward into the infratemporal fossa, it may be in one of three positions: (1) intermediate, between malar arch and pterygoid process and supported by neither (Four-Horned Antelope, Camel); (2) lateral, being pulled to the side and sacrificed for strong malar arches (Tiger); (3) medial, apposed to palatine and deriving support from this bone and the pterygo-palatine junction (most other mammals, Man).

In possessing this medial anchorage of the maxillary tuber, Man is equipped with the strongest and most common adaptation in the Mammalia for the support of the growing permanent molars prior to their eruption. In Man the pterygoid and pyramidal processes together undershoot the maxillary tuber and form an inclined plane on which the successive molars in turn glide downward on their occlusal surfaces to their places in the dental row.

TUBER AND REDUCED LENGTH OF PALATINE

Jaws may be increased in length by prolongation of maxilla, including premaxilla, prolongation of the palatine, or both. Either extension will provide space for a lengthening dental row. The infratemporal fossa must be large enough to accommodate the backward expansion of the maxillary tuber.

In animals, such as most Ungulates, in which the tuber has the intermediate anchorage this presents no problem. Infratemporal space is ample, for though the palatine is of relatively moderate antero-posterior length, the elongation and rapid growth of the maxilla characteristic of these types provide room for the molars at such rate that the tuber never projects backward to an unwieldy degree.

Because the medial anchorage involves the apposition of the maxillary tuber to the palatine, the tuber, on the one hand, gains support from the palatine, but on the other, has a limitation imposed upon the distance it can project backward determined by the antero-posterior length of the palatine.

If the palatine is long as in our Snow Bear (fig. 1), the tuber as it grows may extend freely backward in horizontal plane with the occlusal surfaces of its tooth germs approximately parallel with those of the functioning teeth. In animals with medial anchorage below the Platyrrhine monkeys, excepting a few specialized forms, the palatine is of sufficient antero-posterior length to permit the tuber to expand freely backward in this horizontal plane.

In the Monkeys, Anthropoids and Man, however, the length of the palatine is so reduced that the tuber lacks sufficient space in which to extend directly backward. Consequently the dental sacs are forced to ride obliquely upward and backward toward the spheno-palatine foramen and the crowns of the contained teeth face obliquely backward instead of vertically toward the occlusal plane.

In these Primates the huge expanse of palatine visible on the lateral aspect of the Snow Bear's skull (fig. 1), has become reduced to the small lateral surface of the pyramidal process, familiar in Man.

PALATINE LENGTH AND CRANIO-FACIAL AXIS

This palatine reduction appears to be associated with change in the cranio-facial axis of Huxley (1867). This axis, it will be recalled, consists of a postpituitary limb which traverses the cranial floor behind the sella turcica and a prepituitary limb which follows the floor in front of the sella. In animals with a palatine long in antero-posterior dimension, the cribriform plate approaches the vertical in position and the angle between the two limbs of the axis, the cranio-facial angle, is greater than a straight angle. In Monkeys the axis is almost a straight line and in the Anthropoids and Man the prepituitary part of the cranial floor has become bent downward over the face, forming an angle of about 142 degrees in the apes and one between 120 and 130 degrees in modern man. This bending of the anterior cranial floor squeezes, as it were, the hinder part of the face and results in a great reduction in the antero-posterior length of the palatine, thus decreasing the space available for the expansion of the tuber.

The relative proximity of their cranio-facial angles suggests that the growing tuber would be nearly as cramped in the Anthropoid as in Man, and on comparison, the relative degree of crowding and the positions of the growing teeth in the maxillary tuber of young human and anthropoid skulls appear about the same.

TUBER ACCOMMODATION IN ANTHROPOID AND MAN

Todd ('30) has shown that this dental congestion in the tuber is relieved in the Anthropoids and in Man in two different ways. Up to about the stage of four human years growth proceeds in the same manner in both Anthropoid and Man. The forepart of the braincase moves forward carrying with it the maxilla and so making room for the backward expansion of the tuber. The brain ceases to grow at about this time in the Anthropoid, however, and thereafter significant backward expansion of the tuber cannot occur. Space is provided for the molar teeth by the forward growth of the maxilla which slides from beneath the braincase.

In Man, on the other hand, the braincase continues to move forward and provide space for the backward expansion of the tuber until adulthood, the frontal contour from nasion to prosthion remaining vertical. Thus the reduction of the palatine is compensated in the Anthropoid slightly by forward growth of the braincase but mostly by maxillary extension, and in Man entirely by forward growth of the braincase.

GROWTH CHANGES IN THE HAFTING AREAS

Figure 12, a textbook figure of a fetal skull, compared with figures 4 to 10 shows the magnitude of the changes in all the areas important to the cranio-facial union between human fetus and adult. The significant feature is that in the absence in Man of large sinuses, crests and tori, the safe and efficient operation of the jaws with full dental complement is contingent upon coordinate development of sagittal, lambdoid, coronal, basilar, parieto- and occipito-mastoid, and spheno-squamous articular areas as well as localized facial development.

The growth changes in the hafting area over the period of eruption of the permanent teeth may be followed on three skulls of different origin, portrayed by orthodiagraphic tracings of normae frontalis and lateralis in figures 13 to 20. These tracings were made with the usual technique with the

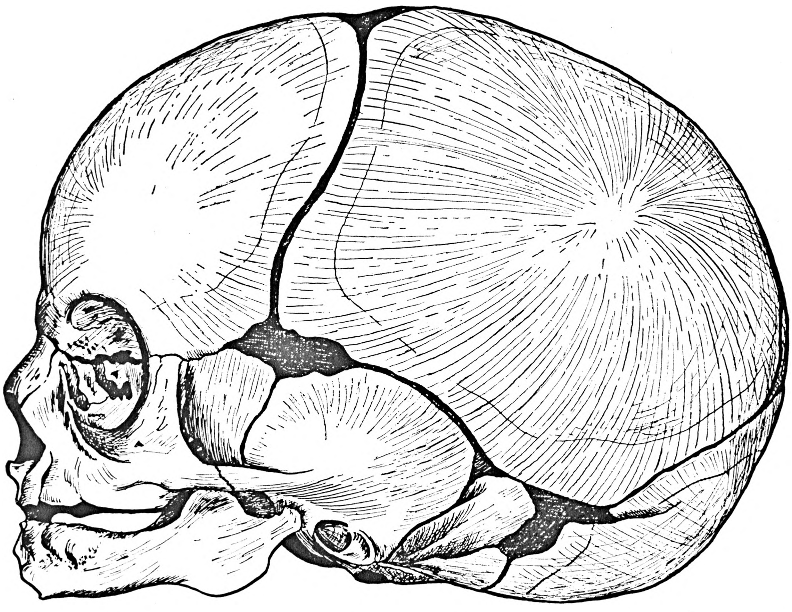
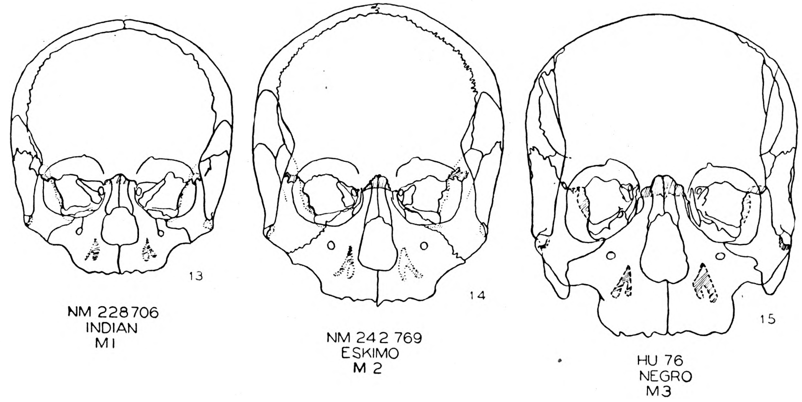
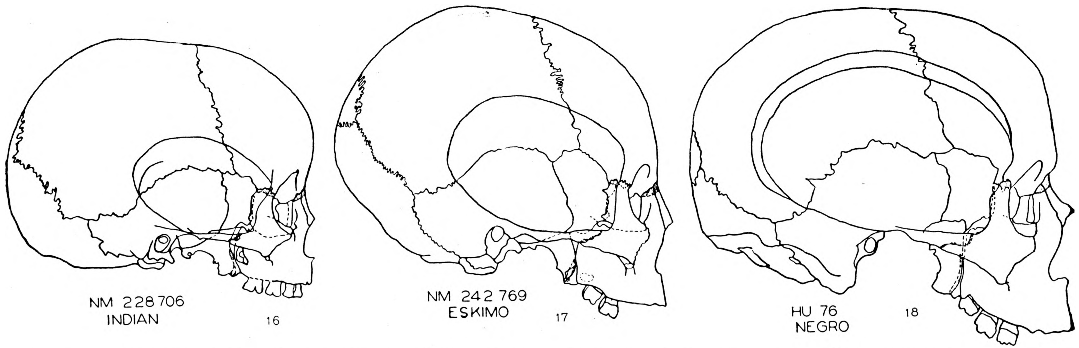


Fig. 12 Skull of newborn, after Sobotta, to show condition of important hafting areas in early life. For contrast with figures 4 to 10. Note membranous nature of coronal, sagittal and lamdoid structures and ununited portions of occipital and temporal. Mastoid fontanelle occupies site of powerful ''forceps'' suture.

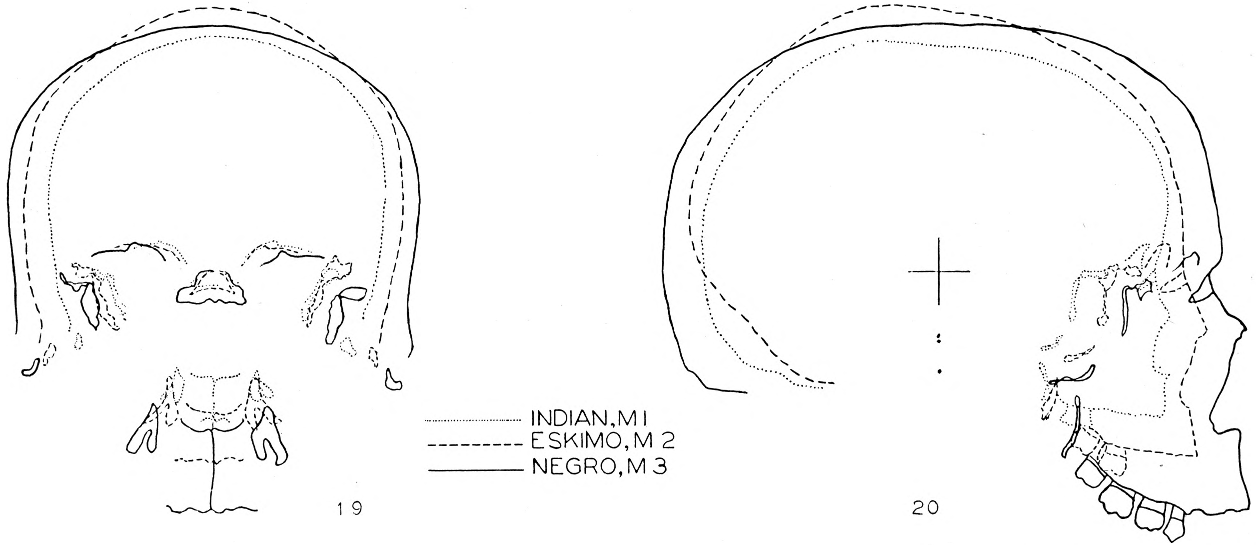
Reserve craniostat and millimeter graph paper. In frontomalar, spheno-malar and to a less extent temporo-malar regions, lateral and anterior views do not show the changes completely because of variable obliquity in these articular surfaces, but a satisfactory qualitative picture is obtained. Skull N.M. –228706 is of an Indian, showing the first permanent molar in position; skull N.M. –272769 of an Eskimo, in





Figs. 13, 14, 15 Orthodiagraphic tracings of normae frontalis to show character of hafting areas after eruption of first, second and third molar teeth.

Figs. 16, 17, 18 Tracings of same skulls in norma lateralis.



Figs. 19, 20 Superimposed tracings of hafting areas and cranial outlines of normae frontalis (figs. 13 to 15) and normae lateralis (figs. 16 to 18). Note growth between first and second molar stages in lateral and posterior areas (see text); growth between second and third molar stages in medial area and in elongation of pterygoid processes. Also production of curve of occlusal plane (Spee) by arrested descent of maxillary tuber containing erupted third molar, below pterygoid process.

which the second permanent molar has erupted; and skull H.U. –76 of a Negro, with all three molars in place. The racial heterogeneity excludes the possibility of stock peculiarity in the results described.

It is evident that in comparison with the amount of growth which cranium and face respectively undergo, the changes in the hafting sites are relatively small, indicating excellent placement of these areas. The details may be seen by examining together the tracings of the separate skulls, figures 13 to 18, and those of the series superimposed, figures 19 to 20.

In figures 13 to 15, the outlines of norma frontalis are with nasia on the same horizontal. In figures 16 to 18, the outlines of norma lateralis are with nasia on the same horizontal in the nasion-parallel or Krogman's plane, that is, a plane through nasion parallel to the Frankfort plane which itself passes through the lower margin of the orbit and the top of the ear-hole.

Between the eruption of the first and second molars, an interval of about 6 years, there is relatively little change in the medial hafting area, the frontomaxillonasal union. Between the appearance of the second and third molars, an interval of about 7 or 8 years, there is marked extension of this medial area. This means that the greatest growth about the medial site occurs during adolescence. This qualitative change may be demonstrated in any stock.

This we associate with respiratory development rather than with dental needs, because, on the one hand, the postorbital bar has already completed its major growth as the next paragraph shows, and on the other, Todd ('30) has demonstrated that the age period from 16 to 19 years in the male is one witnessing important downward expansion of the face to meet the increased respiratory needs of the rapidly growing body. The same periodicity in vertical change is exhibited by the posterior hafting described below.

It is possible also, that because African series of skulls generally show a greater interorbital (bi-dacryonic) distance than North European series, the Negroid medial hafting is larger and stronger than the Caucasoid, a feature to be associated with broader development of nose, palate and dentition. This point requires information on the comparative racial area of the medial hafting as determined by bi-dacryonic and dacryo-nasion measurements and is being investigated for subsequent report.

In the phyletically more recent portion of the lateral hafting, the frontomalar (postorbital bar) and spheno-malar articulation, the opposite condition is noted. Here the greater growth occurs in the interval between the first and second molars and there is little change between the second and third.

This we may relate to dental and masticatory development, for which the malar arch, the postorbital bar and the latter's continuation, the supraorbital torus, undergo compensatory strengthening. In Man the greater portion of this change has occurred by the time the second molar is fully erupted. In many human subjects the third molars fail even to erupt.

The lateral hafting proper or the temporo-malar articulation has the same functional relationships as the fronto- and spheno-malar sites. Consequently, when the latter areas are superposed, there is shown considerable downward and lateral growth of the malar arch, with some increase in size of the lateral hafting area, between first and second molar stages, but the frontospheno-malar and temporo-malar areas coincide in the drawings of the second and third molar stages.

Similar growth periodicity is shown by the maxillary base of the zygomatic arch, measured from the inferolateral orbital margin to the lower end of the maxillo-malar suture. Here there is much growth between first and second molar stages but practically none between second and third molar stages.

Since both postorbital bar and zygomatic arch proper are processes of this bony buttress of which the key-ridge is the under side, and the unified form of the three represents masticatory modification, all the changes described are in perfect harmony.

Collateral supportive evidence here is supplied by the routine craniometric measurements, bizygomatic width and fronto-malar width, which show significantly greater increase between first and second molar stages than between second and third molar stages.

The posterior or pterygo-palatine hafting presents several features of special interest. The first is that the vertical descent of this union is greater between the second and third molar stages, a fact which correlates with the greater enlargement of the medial hafting during this period for respiratory purposes. On the other hand, the greater increase in the size of the articular area occurs between the first and second molar stages when masticatory changes are progressing rapdily.

The lateral normae of figures 16 to 18, and 20 reveal important features concerning the occlusal plane of the cheek teeth and downward extension of the pterygoid processes. The medial anchorage of the tuber with the characteristic mode of growth of the molars and the reduced palatine have been discussed.

The lateral normae show a secondary effect of the cramping of the tuber and the obliquity of the molars as they slide into place. Passing through figures 16 to 18, we note that in these specimens only the first molar reaches the occlusal plane of the cheek teeth. In the young Eskimo (fig. 17) the first molar is not yet completely vertical in position, and the second, though fully erupted is still higher than the first and is directed obliquely backward. Before adulthood this condition might or might not have become corrected. The adult male Negro of about 35 years in figure 18 has certainly completed his facial growth, but the occlusal surfaces of the three fully erupted molars, instead of forming with the premolars a horizontal plane, curve upward and backward in what has been called the curve of Spee.

We see that this curve is due to the arrested descent of the molars. It is essentially a human character of very common occurrence. We have noted a well marked case in a Chimpanzee. In those human skulls in which the last two molars attain the horizontal plane, the tuber pushes downward beyond the pterygoid processes. This is the condition typical of the Anthropoid, in which the molars generally all reach the horizontal occlusal plane, but the pterygoids attach well above the bottom of the maxillary tuber. The pterygoids are left behind, as it were, in the vertical descent of the tuber.

Although this failure of pterygoid growth to keep pace with tuberous descent, typical of Anthropoids, sometimes occurs in Man, so that the human molars fall in horizontal occlusal plane, more frequently the tuber with its contained third molar fails to descend lower than the end of the pterygoid process, so that the latter has the appearance of holding the tuber in a stage of arrested descent and the molar occlusal surfaces form the curved contour called the curve of Spee.

Additional light on the factors associated with this "curve" should be derived from investigation of the relationships between the degree of the curvature, the vertical length of the alveolar process and the length of the pterygoid processes.

SUMMARY

1. The contrasting functions and growth patterns of cerebral and visceral crania necessitate strong structural integration of these elements and progressive developmental adjustments where facial skeleton is united to cranium.

2. In the Mammalia generally this structural integration is achieved by pneumatization of the skull, principally through expansion of the paranasal sinuses, by the development of bony reinforcements, crests and tori, with proportionate strengthening of the malar arches, and by combinations of these.

3. The human skull, considered comparatively, is characterized neither by marked pneumatization, nor prominent bony reinforcements. Its functionally adequate cranio-facial union derives its strength from the distinctive features of human skull, the enlarged, semiglobular braincase and the reduced face.

4. The braincase receives its stability from its capsular form and its thickened and closely interlocked bones. These constitute two units, an axial and a cranial hafting unit.

5. The axial unit is composed of occipital and parietals. Sagittal, and lambdoid sutures firmly join these bones. It affords strong attachment for the axial musculature below and for the cranial hafting unit in front.

6. The cranial hafting unit is comprised of frontal, sphenoid and temporals. Firm denticulate sutures unite these elements. This entity is securely locked to the axial unit by the strong coronal and occipito- and parieto-mastoid sutures and the basilar synarthrosis. In front the cranial hafting unit presents strategically placed articular surfaces for the facial hafting unit.

7. The facial unit consists of maxilla, malar, nasal and palatine. These are structurally harmonized by bony struts radiating from alveolar arch to cranium, represented by the frontal process of maxilla and adjacent nasal anteriorly, the keyridge and its upper prolongations laterally, and the pyramidal process of the palatine posteriorly.

8. Cranio-facial union is effected at five sites in three regions: a median area, the fronto-maxillonasal junction; a lateral area, the temporo-malar, fronto-malar and spheno-malar junctions; and a posterior area, the pterygo-palatine junction.

9. These three areas of cranio-facial union are common to all the Mammalia. Conspicuous features of the human hafting are marked reduction of the medial area, extension of the lateral, and localization of the posterior, characters found also in the Anthropoids, but the heavy post-orbital bar and supraorbital torus of the Apes are rendered unnecessary in Man by the increased size and stability of the braincase and the great reduction in the size and robusticity of the face.

10. The buttressing of the skull for masticatory requirements and the provision of space and fixation for the permanent molars while growing and after eruption are the most important features which demand hafting zone adjustments during growth.

11. The maxillary tuber is a bony sac for the accommodation of the growing permanent molars. During growth the tuber in the Mammalia may: project directly backward in

the infratemporal fossa; be drawn laterally to the malar arch; or be apposed medially to the palatine. This medial fixation affords greatest support to the tuber and is the type possessed by Man.

12. The antero-posterior shortening of the palatine, common to the higher Primates but well marked in Man, results in extreme limitation of the space available for backward growth of the tuber, so that the dental sacs are forced to ride obliquely upward and backward and the crowns of the tooth germs face obliquely backward instead of vertically toward the occlusal plane. The shortening of the palatine appears consequent to reduction of the cranio-facial angle in Man.

13. Hafting area growth changes between fetus and adult, and over the period of eruption of the permanent teeth are described. In comparison with the amount of growth which cranium and face respectively undergo, changes in the hafting sites are relatively small indicating excellent placement of these areas.

14. Between first and second molar stages growth occurs in lateral and posterior areas with little change in the medial. This is associated with masticatory adaptation.

15. Between second and third molar stages medial area grows considerably and pterygoid processes elongate. This is considered principally respiratory modification.

16. Arrested descent of the maxillary tuberosity below the inferior end of the pterygoid process topographically produces the curve of Spee.

17. The maxillary tuberosity may be a shelter for tooth germs, a solid eminence or an expansion of the maxillary sinus.

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