The Neurocranial Basis for Facial Form and Pattern

DONALD H. ENLOW, Ph.D.
JAMES A. MCNAMARA, JR., D.D.S., Ph.D.

INTRODUCTION

The structure and geometric design of the face and the placement of the facial components in relation to the cranium have been established in part by a phylogenetic interaction among cerebral size, over-all brain configuration and the nature of its various contours, cranial floor adaptations to the shape of the brain, naso-olfactory adaptations to brain size and shape, the positioning of the eyeballs relative to the brain, upright body posture in relation to cranial base flexure, and maxillary-mandibular accommodation to the composite of all these interrelated features. The ontogenetic and phylogenetic development of the cerebrum, importantly, involves a range of topographic variations which appear to be associated with corresponding, characteristic differences in facial structure and topography, both among mammals in general and among specific human ethnic groups.

The purposes of this study are (1) to examine and evaluate possible morphologic relationships that may exist between the configuration and the size of the brain and the resultant positioning of the orbits and the olfactory bulbs; (2) to describe relationships between the positioning of the orbits and olfactory bulbs and the nature of brain—cranial base—facial alignment; and (3) to relate the occurrence of different facial types with these factors.

Among most tetrapods the foramen magnum is located at the posterior—most end of the cranium, and the cord extends into an essentially horizontal spinal column. The face is positioned at the anterior end of the cranium, and the orbits are directed horizontally, more or less in line with the cranial base and spinal column. The brain has a relatively straight ventral surface, and a flexure in the contiguous cranial base is not present. These various relationships are basically different from those that exist in man.

In the human skull the foramen magnum is positioned in the mid-ventral part of the cranial floor (Fig. 1a). The occipital lobes are located in sizable endocranial fossae posterior to the foramen, and the cord passes downward into an essentially vertical spinal column associated with an upright, bipedal body stance. It is only the posterior portion of the cranial base (the clivus) that approximates the general vertical alignment of the spinal column. However, the anterior portion of the cranial base associated with the frontal and prefrontal lobes has a horizontal alignment, and the underlying, contiguous face adapts to this orientation, which is essentially perpendicular to the vertical spinal axis. These various features involve a marked cranial base flexure, which is unlike the nearly straight, horizontal cranial base in tetrapods.

The flexure of the cranial floor in man is thus associated with both an upright posture and a facial placement which, in a neutral position, points toward the direction of movement.[6]

From the Departments of Anatomy, West Virginia University and the University of Michigan.

The cranial base flexure is a secondary skeletal adaptation to the shape of the brain itself which, in turn, involves differential rates and extents of growth between the midventral brain axis and the massive cerebral hemispheres. The expansion of the anterior, middle, and posterior portions of the cerebrum around a much slower-growing hypothalamus, pons, and brain stem produces a flexure of the ventral brain margin.[5] This causes a corresponding flexure during the development of the cranial base and also aligns the spinal cord in a downward-directed (bipedal) manner. A recess is created within the flexure, and this space houses the facial composite which is rotated into it by the differential growth of the different parts of the brain. The eyes and the jaws thus point horizontally in relation to a spinal cord and a skeleton which are vertical.

ENDOCRANIAL FOSSAE

The massive expansion of the brain in man has created sizable compartments in the floor of the cranium. The posterior (occipital) endocranial fossa protrudes posteriorly beyond the foramen magnum, and the latter has become "repositioned" to a midventral cranial floor location in conjunction with the downward flexure of the cranial base. The enormous anterior cranial fossa has come to overlie the greater part of the face. The anterior cranial floor also serves as the roof of the orbits and then continues to form the unique, bulbous forehead. The human face lies almost entirely beneath the anterior cranial fossa, in contrast to the face of most other mammals which is largely forward of the much smaller frontal lobes of the cerebrum (Figs. 1a, 1b, 1c).

ORBITAL POSITIONING

Two separate orbital alignment changes have occurred in the face of man (and to a greater or lesser extent in some anthropoids as well). First, the forward expansion of the frontal and prefrontal lobes accompanies a rotation of the superior margin of each orbit anteriorly. The orbital rim thus has a vertical alignment. This may occur either in conjunction with a correspondingly expanded cerebrum or independently of it (as in the sagittal cresting and massive supraorbital ridge development of the gorilla which develop as a response to ectocranial rather than endocranial factors). The vertical alignment of the human orbits, however, contrasts with the much more oblique nature of the orbital margin in most other primates and mammals (Figs. 1b and 1c). In nonhuman forms, the anterior cranial floor and the forehead lie essentially behind the orbital cavities rather than above them.

The second important change in orbital relationships is associated with the temporal lobes of the cerebrum and their displacement effects on the orbits. Just as frontal lobe expansion can accompany the orbits into more vertical positions, temporal lobe expansion "displaces" them medially toward each other. Whether either such cerebral lobe expansion or orbital rotation represents the actual, primary pacemaker for this relationship cannot be stated with certainty, as pointed out in the paragraph above. The presence of the relationship itself, however, is a morphologic and phylogenetic factor of basic importance. Among nonprimate mammals the orbits point obliquely outward (and also upward, as previously discussed). In the human face the neutral axes of the orbital cavities are directed essentially straight forward. In Figures 1b and 2b, note that convergence of the orbits toward the midline characterizes the anthropoid face in which temporal lobe (and middle endocranial fossa) expansion is also quite marked.

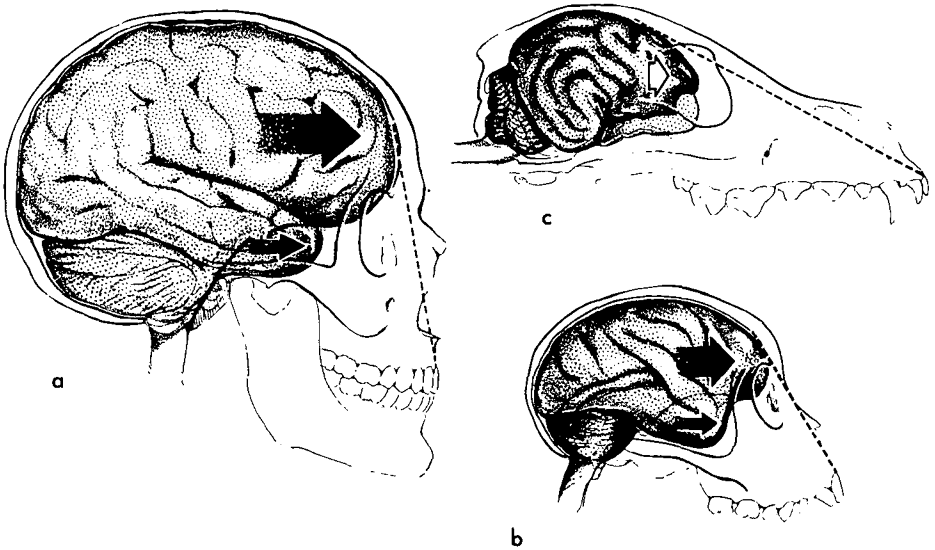

Fig. 1 Neurocranial and facial interrelationships are shown in (a) man, (b) the Rhesus monkey, and (c) the dog, a beagle. The plane of the midface is shown by a line from the anterosuperior border of the frontal lobe to the anteroinferior point of the maxillary arch. Note the extent of cerebral expansion relative to the midventral brain axis in each, and compare the corresponding degrees of cranial base flexure. In man, a recess (the facial pocket) is created by the much more marked extent of cranial base flexure. The face is rotated, in effect, into this space, and most of the shortened facial complex, including the orbits, thus lies underneath the floor of the anterior cranial fossa. In the monkey and the dog, note that the more elongate facial skeleton and the orbits are located largely in front of the frontal lobes. Compare the more perpendicular alignment of the facial skeleton relative to the vertical spinal axis in man with the essentially horizontal orientation of both the face and spine in the dog. Note the presence of (1) a much more bulbous forehead in man and (2) the vertical nature of his orbits in contrast to the more sloping forehead and oblique orbital alignment in the monkey and the dog. Relate these features to the respective extent of frontal lobe expansion (large arrows) in each species. Compare the sizable temporal lobes and the large middle endocranial fossae in both man and the Rhesus monkey (small arrows), and note the resultant medial rotation of the orbits into nearly straightforward positions in both species. The smaller temporal lobes of the dog are associated with orbits that point in an obliquely lateral direction. Although olfactory bulb displacement by the cerebrum cannot be seen in these figures, the bulbs are oriented in such a manner that the afferent fibers are largely vertical in man, oblique in the monkey, and nearly horizontal in the dog; this corresponds to the alignment of their respective midfacial regions (see Fig. 3).

In summary, the vertical orientation of the orbital rims and the horizontally-directed, parallel axes of the neutral line of vision in man are facial features related to the size and the configuration of the cerebral lobes. Among the anthropoids an obliquely upward but straight forward (medially rotated) placement of the eye sockets is associated with their smaller frontal and prefrontal lobes but sizable temporal lobes, respectively. In tetrapods, endocranial fossae as such are absent or not well developed, the cerebral lobes are not associated with either cranial flexure or orbital displacement, the orbits are oriented in an obliquely superior and lateral manner, and the wide interorbital dimension is associated with a relatively protrusive bony muzzle and nose (Figs. 1c and 2a).

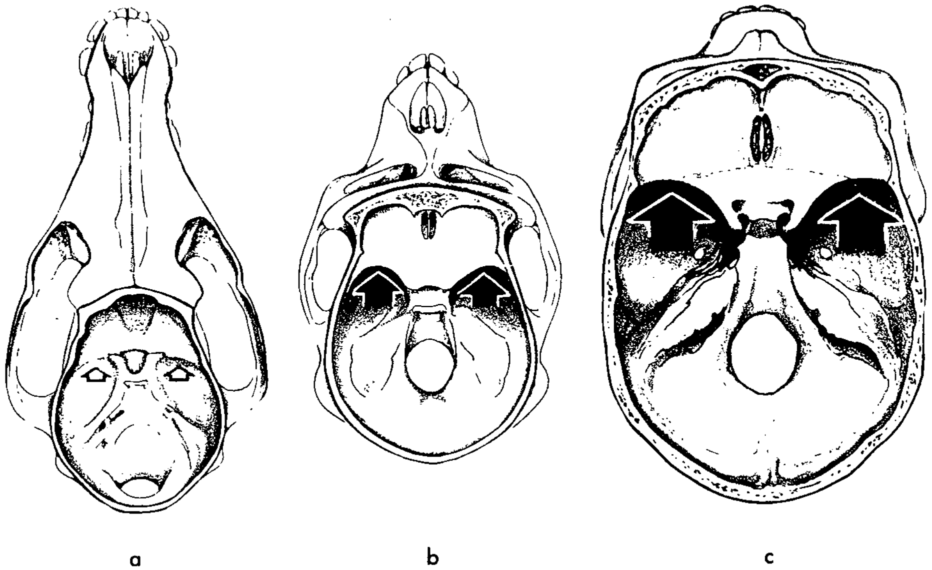

Fig. 2 Relationships among the cranial floor, the orbits, and the interorbital nasal region are shown in (a) the dog, (b) the Rhesus monkey, and (c) the human. In both the monkey and man, note the rotation of the orbits toward the midline in association with the expanded middle endocranial fossae housing the temporal lobes (arrows). Note especially the consequent reduction in the relative dimensions of the interorbital region. In contrast, the much smaller middle endocranial fossae and the obliquely lateral orientation of the orbits in the dog are associated with a relatively broad nasal bridge. In man, marked frontal and prefrontal lobe expansion has resulted in a downward rotation of the olfactory bulb and nearly horizontal cribriform plates. The olfactory bulbs and cribriform plates in the monkey are obliquely aligned, and in the dog they are nearly vertical.

ORBITAL POSITIONING, THE SIZE OF THE KEY INTERORBITAL SPACE AND THE LENGTH OF THE SNOUT

The displacement of the orbits toward the midline, as described above, imposes an important changing relationship between the orbital and the nasal regions in man as well as anthropoids. With such medially-rotated, straightforward orbits, the interorbital dimension becomes significantly reduced in actual as well as relative dimensions (Figs. 2b and 2c). The interorbital region itself is the internal root of the naso-olfactory area and, also, it is the structural base for the projecting external bony nose.

The breadth of the nasal bridge establishes a structural limit on the possible length to which the external bony nose or snout can protrude.[5] Their respective dimensions are related, and any reduction in the transverse dimension of the nasal bridge must be accompanied to a greater or lesser extent by a corresponding reduction in bony snout length, since over-all nasal protrusion cannot exceed the structural limitation imposed by the breadth of its architectural base. A wider interorbital base can support a longer nose, mechanically as well as physiologically; a more narrow nose, among mammals in general, tends to be proportionately shorter.

NASAL AND MAXILLARY ARCH RELATIONSHIPS

The muzzle of any mammal is comprised of a combined nose and upper jaw. These two functionally different parts are structurally inseparable. The floor of one constitutes the roof of the other, and only a slight degree of horizontal divergence or offset between them is possible. This can occur in the form of a soft tissue (not bony) snout or proboscis that projects beyond the jaws, as in the faces of the proboscidean and the human. Many mammals have a short fleshy portion of the nose that protrudes slightly ahead of the bony maxillary arch. In some others, conversely, the maxilla projects for a short distance beyond the nose, as in a number of anthropoids. Nevertheless, any marked protrusion or retrusion of one must be accompanied by an approximately matching change in the hard tissue components of the other since they are, in effect, contralateral sides of a common base (the hard palate). Reduction in nasal protrusion, as outlined in the preceding paragraphs, is thus complemented by a corresponding reduction in upper as well as lower jaw and dental arch length. As will be seen below, at least two other basic, closely related factors are also directly involved in the establishment of over-all arch length.

OLFACTORY LOBE POSITION AND THE NATURE OF FACIAL ALIGNMENT

Mutually and directly interrelated with the factors outlined above, the marked expansion of the frontal and prefrontal cerebral lobes in man has produced a direct downward displacement of the olfactory bulbs into an extreme horizontal position (Fig. 2c). The extent of this displacement is unique among mammals, and it is basic to a series of other important relationships.

The olfactory bulbs in most nonprimate mammals have a very nearly vertical orientation and lie anterior to the cerebral hemispheres. A relationship exists between the size of the cerebrum, the alignment of the olfactory bulbs, and the corresponding, over-all alignment of the facial plane. As a general rule, the facial profile is approximately perpendicular to the cribriform plates (these plates are used in the discussion that follows to represent the alignment of the olfactory bulbs in any given species). Several examples are shown in Figure 3. It is seen that the over-all facial profile, the length of the snout, and the length of the upper and lower arches are closely dependent upon two factors: (1) the relative size and the configuration of the frontal, prefrontal, and temporal lobes of the cerebrum, and (2) the resultant orientation of the anteroventral side of the frontal lobes and the contiguous olfactory bulbs. In the rodent the facial plane extends in an essentially horizontal manner perpendicular to the very nearly vertical cribriform plates. When the olfactory lobes are displaced (rotated) into a more oblique position by the frontal lobes, as in the anthropoid, the facial plane becomes correspondingly more oblique in nature. Its horizontal dimension and the extent of snout projection are necessarily shorter as well. The latter change, as previously mentioned, is also related to the decreased interorbital dimension as the orbits become medially rotated due to temporal lobe expansion (along with the intervening ectocranial musculature within the temporal fossa). In man, the extreme horizontal nature of the cribriform plates in conjunction with the much more massive expansion of the frontal and prefrontal lobes appears to be related in a direct way to the distinctively vertical facial profile. This upright face is further complemented by the bulbous, vertical forehead also produced by the expansive cerebrum.

THE UNIQUE NASAL REGION OF MAN

With reduction in the relative size of the nose, particularly the olfactory portion located within the restricted interorbital segment, the relative size of

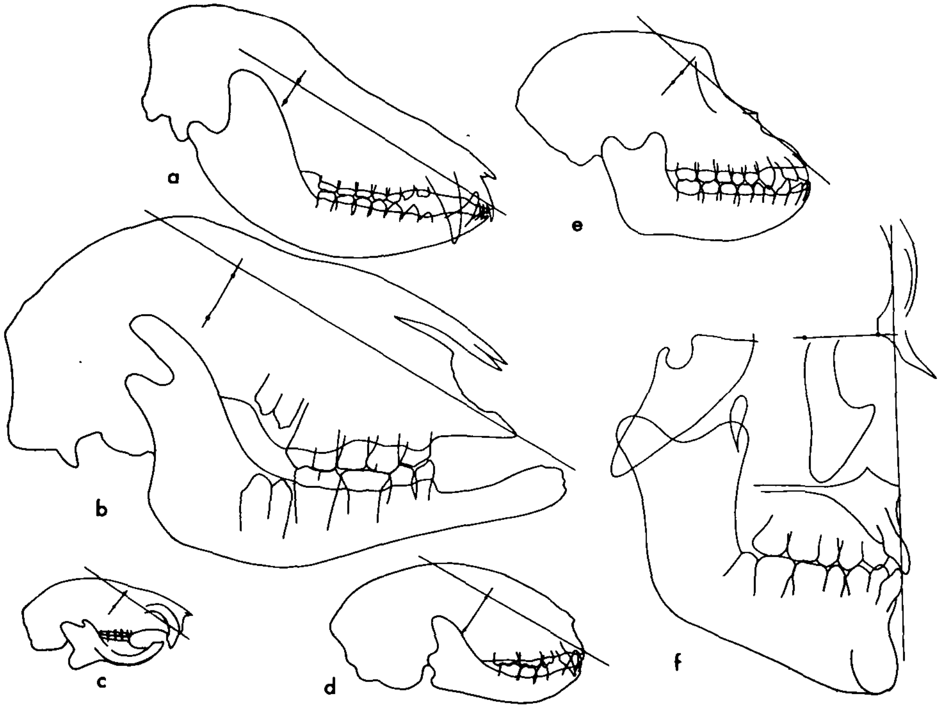

Fig. 3 Cribriform plate and midfacial plane relationships are shown in the (a) opossum (*Didelphis*), (b) sheep (*Ovis*), (c) gray squirrel (*Sciurus*), (d) house cat (*Felis*), (e) pig-tailed macaque (*Macaca*), (f) man. Lead markers were used to identify the anterior-posterior boundaries of the concave cribriform plate in lateral headfilms, and a line was drawn between these markers (shown as dots in the headfilm tracings). A line then was drawn from the anterosuperiormost point on the endocranial surface of the frontal bone (or of the olfactory fossa in those species in which the olfactory bulbs protrude well beyond the cerebrum) down to the anteroinferiormost point of the premaxilla (superior prosthion). This represents the "midfacial" plane as described in the text. In each species, note that the midfacial plane is oriented in an approximately perpendicular manner to the plane of the cribriform plate regardless of muzzle length. The cribriform plate is dependent upon the placement of the olfactory bulbs which, in turn, are variably placed according to the size and the configuration of the cerebrum. The alignment of the face itself, finally, is determined by the orientation of the floor of the anterior cranial fossa and the plane of the olfactory bulbs. Note the extreme downward alignment of the cribriform plane (olfactory bulbs) in the human skull and the associated perpendicular alignment of the vertical midfacial plane.

the olfactory bulbs themselves has become correspondingly and markedly reduced both in the anthropoids and man. The occurrence of downward-displaced, relatively small olfactory bulbs complements both the shortened extent of nasal protrusion and the greatly decreased interorbital space. Significantly, the sensory nerves of the olfactory mucosa have become vertically aligned in man as they converge superiorly toward the cribriform plates, in contrast to the more horizontal nature of their distribution among nonprimates. The human nasal region, with its soft as well as hard tissues, has an essentially vertical over-all disposition with a vertical dimension that actually equals the horizontal length. The nasal chambers and the respiratory mucosa occupy a unique location that is enclosed almost entirely within the vertically elongated and laterally widened face (the latter is due to lateral cerebral expansion and forward orbital rotation). The nasal chambers extend laterally well into the suborbital regions. These relationships are in contrast to the projecting snout of most tetrapods in which the nasal chambers lie largely anterior to the orbits and within the sizable interorbital boundaries.

SUMMARY OF INTERRELATIONSHIPS AMONG THE NASAL COMPONENTS, THE JAWS, THE EYES, THE OLFACTORY BULBS, AND THE BRAIN

1. Together with the phylogenetic enlargement of the temporal lobes of the cerebrum (and the middle endocranial fossae), the orbits are positioned (rotated) toward the midline. The interorbital distance becomes correspondingly reduced (see 3 below). The face becomes markedly widened because of the lateral expansion of the various cerebral lobes and the forward rotation of the lateral orbital rims.

2. In conjunction with the phylogenetic enlargement of the frontal and prefrontal lobes, the orbits are positioned into a more vertical orientation together with a nearly vertical forehead. The latter is also produced by this same factor of cerebral expansion.

3. As the interorbital span becomes proportionately reduced, the anterior extent of nasal protrusion becomes correspondingly shortened.

4. A shortened upper dental arch accompanies the horizontal reduction of the nose.

5. A shortened lower jaw accompanies the horizontal reduction of the nasomaxillary complex.

6. A downward rotation of the olfactory bulbs to a horizontal plane is produced by the enlargement of the frontal and prefrontal lobes.

7. The facial plane is approximately perpendicular to the olfactory bulbs (and cribriform plates). The more vertical orientation of the human nasal chambers and the facial profile in general thus conform to the horizontal displacement of the olfactory bulbs and the resultant vertical distribution of the olfactory nerves.

8. The increasing vertical nature of the nasal region also accompanies the proportionate reduction of horizontal nasomaxillary protrusion and reduction in the breadth of the nasal bridge (3 above). A flattened, vertically disposed, orthognathic facial profile is the summated, composite result in man. The eyes are directed horizontally while the spinal cord is aligned vertically, a combination set up by the cranial base flexure caused by differential brain expansion. The facial composite is placed within the recess or "pocket" formed by this flexure.

All of the above features are related and mutually complementary, and the interdependent, cumulative, composite nature of these contributing factors is emphasized.

OLFACTORY BULB AND FACIAL PLANE RELATIONSHIPS

As described above, the alignment of the midface (nasomaxillary complex) is related in a direct way to the olfactory bulb/cerebral hemisphere displacement relationship and the orientation of the paired cribriform plates. In Figure 3, headfilm tracings from different species representing several taxonomic groups are shown. Metallic markers were used to identify the anterior and posterior ends of the concave cribriform plates, and a line was drawn through these two points. A second line was then drawn from the anteriormost point on the endocranial side of the frontal bone (representing the forward edge of the brain) down to the anteriormost point of the premaxilla (superior prosthion). This line is used in the present study to represent the plane of the midface. While an exhaustive survey of all major mammalian groups (including those with bizarre facial types) has not been made, more than thirty species representing different rodents, lagomorphs, marsupials, primates, carnivores, and artiodactyls have been studied to date, and all show an approximately perpendicular relationship between these two planes in adult animals. Thus, those species in which a relatively small anterior cranial fossa exists (such as the opossum or rat) are characterized by a more horizontal frontal region and vertically oriented olfactory bulbs (and cribriform plates). Their elongated, protrusive nasomaxillary region extends anteriorly perpendicular to the plane of the cribriform plates established by the cerebrum. Note that the line from the anteriormost point of the cerebrum passes approximately perpendicular to the cribriform plate and intersects the anterior and inferiormost point of the premaxilla (prosthion). The orbits are pointed in a nearly superior manner, and a broad interorbital dimension is present. The spinal cord projects posteriorly from a flat, nearly straight cranial base. The nasal region lies largely in front of the orbits, and the orbits lie anterior to the cerebrum.

In the monkey (Figs. 1b and 2b) note the relationship between the larger anterior and, especially, middle endocranial fossae and the convergence of the orbits toward the midline so that they face nearly straight forward. Note also that the orbits are more vertically inclined for the same reason (Figs. 1b and 3e). A much reduced interorbital span is present. In any mammalian species, as the forehead expands to a more sloping, vertical position and as the cribriform plates rotate to a more oblique alignment, the midface correspondingly "rotates" to a matching, more inclined, obliquely upright plane. A lessened extent of anterior muzzle protrusion also necessarily occurs because of the more vertical orientation of the midfacial plane (the line from the anteriormost point of the cerebrum to prosthion, approximately perpendicular to the cribriform plate). In the skull of the monkey note that the spinal cord projects obliquely downward and backward from a moderately flexed cranial base. The decreased interorbital distance, reduced nasal bridge, and lessened extent of anterior nasal protrusion are accompanied by proportionately smaller olfactory bulbs. The more vertical disposition of the facial composite also involves the development of a complete orbital floor and a sizable suborbital (maxillary) sinus. Upper and lower dental arch reduction occurs in conjunction with nasomaxillary shortening, and the posterior ends of the maxillary arches have become located in a relative position that is more posterior (a downward and backward "rotation" of the arches). These relationships, together with the presence of a cranial base flexure, have carried the upper and lower jaws much closer to the foramen magnum and have reduced the skeletal boundaries of the pharynx.

In the human skull (Figs. 1a and 3f) note that the massive expansion of the cerebrum and the enlargement of the cranial floor compartments are related to marked downward flexure of the cranial base. As a result, the foramen magnum points inferiorly and the facial components face anteriorly. The human forehead is notably bulbous and essentially vertical. The orbits, correspondingly, are oriented vertically and they point straight forward, features which are linked to frontal and temporal lobe expansion, respectively. The nasal bridge (interorbital base) is narrow. The anterior protrusion of the snout is reduced proportionate to both interorbital decrease and downward olfactory bulb displacement. The olfactory bulbs are displaced into a horizontal position, and the midface is "rotated" into a correspondingly vertical plane in conjunction with this olfactory alignment position (Fig. 3f). The nasal chambers (that portion lined with mucosa, not integument) are enclosed almost entirely within the face, between and below the orbits. A complete orbital floor is present, and expansive suborbital maxillary sinuses occupy the space created by the vertically disposed facial composite. The upper and lower jaws are proportionately reduced in relation to (1) the extent of horizontal olfactory realignment, (2) the resultant extent of reduction in nasal protrusion, which is also directly related to the size of the interorbital dimensions, (3) orbital convergence and the extent of decrease in the interorbital distance, and (4) the extent of corresponding temporal and frontal lobe expansion.

HUMAN MIDFACE AND OLFACTORY BULB ALIGNMENT RELATIONSHIPS IN CLASS I, II, AND III INDIVIDUALS

A total of 147 lateral headfilms from 66 Class I, 45 Class II, and 36 Class III untreated individuals at least fifteen years of age were analyzed. The midfacial plane was represented by a line passing downward to superior prosthion from the anteriormost point on the meningeal (endocranial) side of the forehead, representing the forward margin of the brain. This midfacial plane was selected because the purpose of our study was to correlate the nature of facial form and pattern with the size and configuration of the underlying brain. To use a "nasion-prosthion" plane to represent the midface, thus, would be meaningless. A second line was then drawn to represent the plane of the cribriform plate, as shown in Figure 3f. This line extends from the posterior edge of the olfactory fossa to the intersection of the roof of the nasal chamber with the floor of the anterior cranial fossa, which identifies the anterior end of the concave olfactory fossa (Figs. 4 and 5). As noted in previous paragraphs, the plane of the cribriform plate and the midfacial plane are perpendicular, or very nearly so, in all of the mammals that have been analyzed in the present study. The angle formed by these two lines in our Class I, II and III human sample was measured. In the Class I group the average value for 26 females was 89.9°, and for 40 males, 89.7°. In the Class II group 27 females had an average value of 89.4°, and 18 males had an average value of 89.3°. In 17 female Class III individuals the average value was 89.1°. The average for 13 males was 89.9°, and in 6 Class III's of unknown sex, the average was 90.3°. Of the entire sample including all classes ninety-seven per cent were within a 87.5° to 92.0° range. In this varied, adult sample, thus, the alignment of the midface approximates a perpendicular to the olfactory bulb within ±2.5° range of variation. Significantly, no essential differences were found among the three Class groups.

One purpose of this study was to investigate the possibility that the basis for retrognathic and prognathic types of facial profiles might lie, in part, in the manner of variable olfactory bulb orientation in particular individuals. No such relationship was found, however. Significantly, it was observed that the midface does not actually protrude to any greater extent in the Class II than in the Class III individuals relative to the cranium (Fig. 6a). As shown in our previous studies,[6,7] the anatomical basis for the different kinds of facial profiles is of a multifactorial, composite nature, and a large number of vertical and horizontal relationships among the many parts of the cranial

Fig. 4 To demonstrate the anterior and posterior limits of the olfactory fossa (arrows) as seen in lateral headfilms (Fig. 5), a dried skull has been sagittally sectioned at a plane along the base of the crista galli. The right cribriform plate, prior to removal, extended along the base of the crista between the two arrows. This is the floor of the olfactory fossa. Note that the inner (mucosal) surface of the nasal region continues without interruption onto the ventral side of the floor of the olfactory fossa.

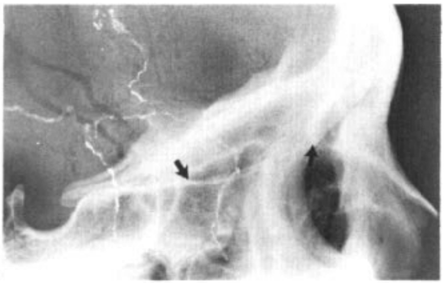

Fig. 5 This x-ray shows a lateral view of the anterior cranial fossa and the nasal chamber of an unsectioned, dried skull to correspond with the view seen in Figure 4. The anterior and posterior limits of the olfactory fossa are shown by arrows. A line drawn between these two points represents the "cribriform plane" as used in the present study. The anterior limit of the olfactory fossa can be located at that point where the cribriform plate joins the frontal bone (anterior arrow). Note that the roof of the nasal chamber also leads directly into this point. The posterior edge of the olfactory fossa is identified by the change in contour of the anterior cranial floor at this point.

floor, ethmomaxillary complex, and mandible contributes in an aggregate, cumulative manner to facial form, balance, and the basis for malocclusions. In Figure 6a the tracings of a Class III and a Class II individual are superimposed on their cribriform plates. Note the close similarity in the alignment of the midfacial planes between these two occlusal extremes. Significant differences are seen, however, in their various mandibular relationships, and these are largely the causes of their respective prognathic and retrognathic profiles. These relationships include over-all midface height, the vertical cranial floor and ramus composite dimension, posteroanterior ramus breadth, relative mandibular corpus length, ramus-to-corpus angulation, and the posterior segment of the cranial floor-to-maxilla angulation.

Although the angular relationship between the midfacial plane and the cribriform plate is relatively constant, as shown above, the angular relationship between the posterior part of the anterior cranial floor (as represented by a plane from condylion to the sphenoethmoidal junction or other comparable planes) and the cribriform plate is quite variable. Because similar types and ranges of upward-aligned and downward-aligned cribriform variations and midface alignments relative to the posterior part of the cranial base were found among all Class I, II, and III facial types, olfactory bulb alignment and resultant midface positioning, thus, do not appear to directly contribute to the developmental basis for malocclusions. The various mandibular relationships, as outlined in the previous paragraph, are the primary factors involved in predisposing a retrognathic or prognathic type of profile.

A "GROWTH ZONE" CONCEPT

A comparison of the midface-to-brain relationship among the different mammalian skulls in Figure 3 shows that the length and the angle of the midface in any given species or indivi-

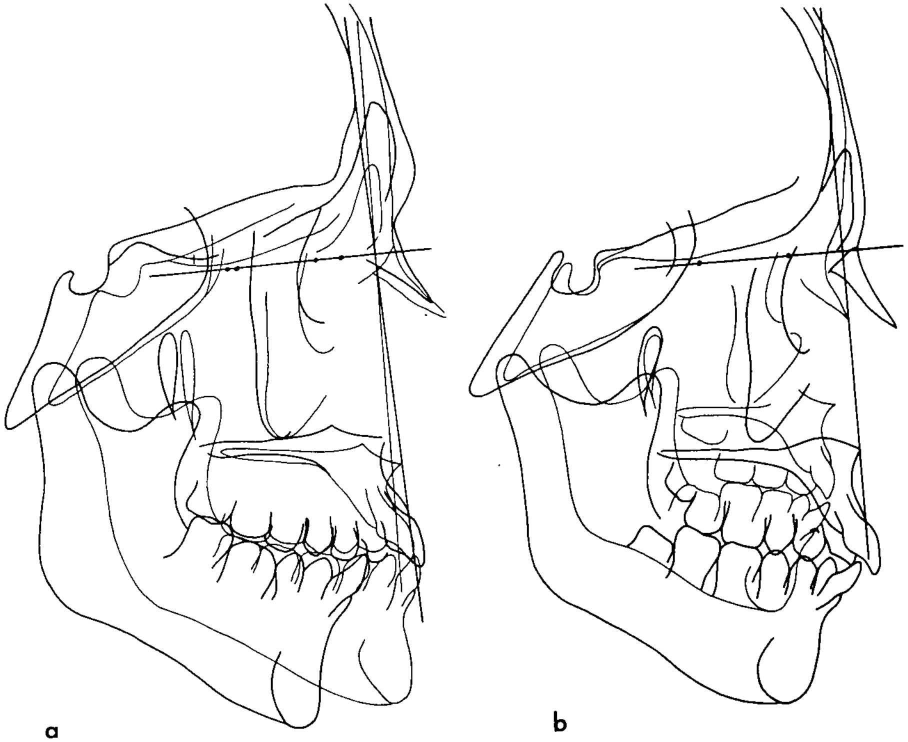

Fig. 6 In (a), the cribriform planes of a Class II adult and a Class III adult were superimposed. Note the similarity in the alignment of their respective midfacial planes. The maxillary arch itself of the Class II individual is not disproportionately protrusive as compared with the Class III. The fit of the mandible relative to the cranium and to the vertical dimension of the ethmomaxillary complex underlies the basis for these malocclusions.

In the serial headfilms shown in (b), the anterior cranial fossa of a six year-old child is superimposed over the anterior cranial fossa of that same individual after over-all facial growth had ceased (the size and configuration of the anterior fossa changes very little between these two age levels). The cribriform planes closely coincide, and a line from the endocranial margin of the forehead perpendicular to the cribriform plane intersects (or at least will pass very close to) superior prosthion in the adult. This feature allows one to forecast the approximate adult position of prosthion and the midfacial plane.

dual are closely related to the size and/or configuration of the brain and the consequent alignment of the olfactory bulbs. It is suggested that these factors establish a circumscribed zone within which the growth of the midface takes place. Note that the anterior edge of the brain defines, in effect, the corresponding anterior margin or boundary of this growth pathway for the nasomaxillary complex. The bottom (occipital part) of the brain, also, appears to be related to the ventral margin of the growth corridor. During the period of facial growth the nasomaxillary complex expands within and finally up to this boundary but does not exceed it to any material extent. When the face attains adult size, superior prosthion will have come to lie either on or very close to the line passing from the endocranial surface of the forehead perpendicular to the cribriform plate (Fig. 6b), which is the edge of the growth zone and the approximate forward and inferiormost limit up to which growth can proceed. This boundary is not violated regardless of facial or skull type; all Class I, II, III, orthognathic, prognathic, retrognathic, dolichocephalic, and brachycephalic individuals have been found to conform to it. A Class II individual, for example, does not possess a nasomaxillary complex that "grows farther forward" than a Class I child in a relatively uncontrolled, disproportionate manner. The size and the placement of any individual's midface is, in effect, determined or programmed by the corresponding size, placement, and configuration of his own cerebral hemispheres and the resultant position of the olfactory bulbs. Beyond this, his facial profile is affected by the nature of the individualized "fit" of his mandible to this particular cranial floor-midface combination.

Because (1) a maximum limit exists in the growth of the midface; because (2) this limit is observed and attained by the different kinds of facial patterns; and because (3) the boundary of this limit can be identified and located before adult size is reached, the adult location of the forwardmost point of the maxillary arch and the actual adult midfacial plane may be forecast during childhood. Superior prosthion, as an anatomical point, has been customarily regarded as a highly labile, unstable landmark that is subject to adaptive responses to many intrinsic morphologic and morphogenic factors (such as tooth size). Our present study, however, suggests that the anterior-inferior edge of the adult midfacial skeleton is not randomly placed with respect to the anterior cranial floor. During growth, this area of the midface does not behave in a regionally independent manner. Its adult location represents the cumulative result of many growth-contributing factors (dental arch size, tongue, lip form, muscle activity, etc.) that combine to produce a total, composite growth expression of the nasomaxillary complex up to its established limit. This limit, as previously suggested, appears to be the margin of the "growth zone" determined, at least in part, by the brain-olfactory bulb pattern.

Because the floor of the anterior cranial fossa undergoes little change during the six to fifteen year period, the midface plane, as defined previously, can be drawn on the headfilm tracing of a growing child, and this plane will not appreciably change with continued aging. In the young child, superior prosthion will fall far short of this line. Headfilm tracings of that same child after fifteen years of age, however, will show that prosthion comes to lie on or very close to the line (Fig. 6b).

HUMAN AGE, SEX, AND ETHNIC RELATIONSHIPS BETWEEN BRAIN SHAPE AND THE FORM OF THE FACE

The two basic extremes of skull (brain) shape, dolichocephalic and brachycephalic, are related to the more open (horizontal) and closed (upright) types of cranial floor flexure*, respectively, as schematized in Figure 7. These relationships, in turn, establish the basis for a chain of other factors that have characteristic topographic results in the configuration of the face.

The more closed type of cranial floor flexure associated with the brachycephalic skull places the nasomaxillary complex in a more posterior and superior relative position (Fig. 7b), in contrast to the dolichocephalic type in which the midface is placed more anteriorly and inferiorly (Fig. 7a). The mandible is aligned forward and up-

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* This refers to the entire cranial floor, including the lateral parts of the middle and anterior cranial fossae overlying the mandibular condyles and the upper and lower arches, and not merely the midventral segment as visualized in lateral headfilms.

ward in the first instance and downward and backward in the second. These features underlie the characteristic predisposition among the ethnic groups having a brachycephalic type of head (e. g., Japanese) for a more prognathic type of facial form. The Caucasian dolichocephalic groups (as in the northern European) have a population tendency toward a more retrognathic type of facial pattern. Class III malocclusions characterize the former group, and Class II malocclusions are more prevalent among the latter.[7]

The positioning and the relative proportions of the facial parts with respect to the anterior and posterior segments of the cranial floor account for several basic, characteristic types of facial features. In Figure 5c the upper part of the ethmomaxillary complex protrudes, proportionately, well beyond the anterior cranial fossa. This feature is more noticeable in (1) the adult of any given ethnic group, (2) the male of any ethnic group, and particularly, (3) adult male Caucasians. The topographic result is a sloping forehead with large frontal sinuses, a sizable glabella, a high nasal bridge, and recessed-appearing cheekbones. A horizontal dimensional differential be-

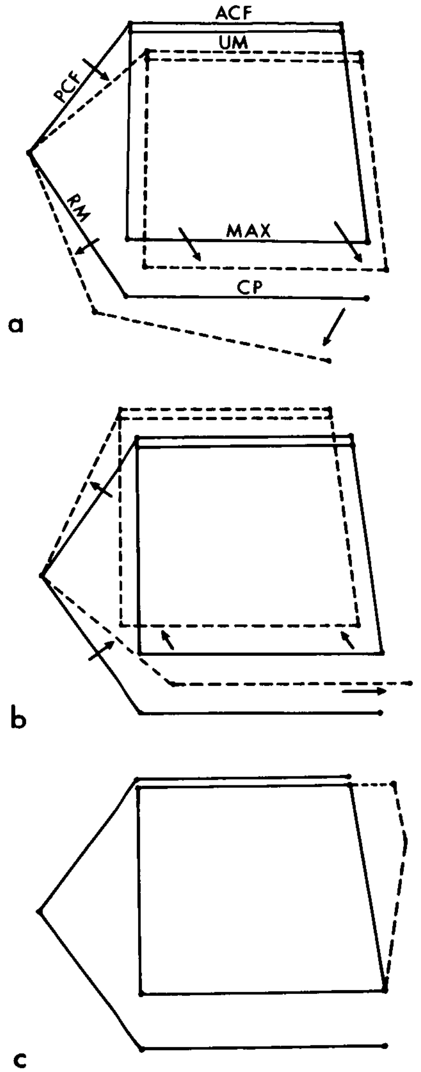

Fig. 7 Model (a) shows the effects on facial topography of a more open cranial floor flexure. A more horizontally inclined alignment of the posterior part of the anterior cranial base (PCF, which is the middle endocranial fossa associated with the temporal lobe) relative to the anterior cranial fossa (ACF, associated with the frontal and prefrontal lobe) has the effect of placing both the upper ethmomaxillary region (UM) and the maxillary arch (MAX) in a more anteriorly protrusive position. It also lowers both regions relative to the condylar junction of the ramus (RM) and PCF. This causes a downward and backward rotation of the ramus and a retrusion of the mandibular corpus (CP). Thus, the maxilla is displaced anteriorly while the mandible is displaced in an opposite, posterior direction.

Figure b illustrates the effects of a more upright alignment of PCF. The maxilla is displaced superiorly and posteriorly, while the whole mandible rotates anteriorly and superiorly.

Figure c schematizes the topographic effect of a dimensional differential between the anterior cranial fossa (ACF) and the upper nasomaxillary region (UM). A forward protrusion of UM relative to ACF is the basis for a more sloping forehead, a larger frontal sinus (thereby separating the fixed inner table and the protrusive outer table of the frontal bone), a higher nasal bridge, and a hooked or aquiline type of nose. See text for specific age, sex, and ethnic relationships.

tween the anterior cranial fossa, the maxillary arch, and the upper ethmomaxillary region produces a characteristic bent, "Roman" or aquiline type of nose.

In contrast to the above, if the upper ethmomaxillary region does not protrude differentially beyond the anterior cranial fossa, a more upright, bulbous forehead with smaller frontal sinuses, more prominent-appearing cheekbones, a lower nasal bridge, and a shorter nose results. These features characterize (1) ethnic groups with a brachycephalic headform, (2) most females, and (3) the immature male of any given ethnic group.

Among the Caucasians, two general facial "types" exist: the vertically "long" and the vertically "short" faces. The latter are characterized by a rounder head form, a more upright cranial floor and, usually, a more erect body stance. This contrasts with the longer skull form, more obtuse cranial floor, and a tendency toward a somewhat stooped posture among the long-faced individuals. The latter are characteristically more retrognathic in facial profile due to the forward relative placement of the nasomaxillary complex by the more open cranial floor flexure, and the downward and backward rotation of the mandibular ramus caused by the relatively long vertical midface and open cranial floor flexure.

The key feature among long-faced Caucasians that tends to offset the characteristic population tendency toward retrognathia is a horizontally wide ramus[8]. This feature provides dimensional compensation that partially or entirely balances the effect produced by the more obtuse flexure of the cranial floor, the relatively long midface, and the resultant backward and downward rotation of the whole mandible. Individuals that have a severe Class II type of malocclusion characteristically lack this compensatory feature.

The black ethnic groups, like many of the Caucasian groups, have a dolichocephalic headform with the consequent forward and downward placement of the maxilla. Also, they have a compensatory type of horizontal ramus dimension that serves to offset the forward alignment of the cranial floor flexure. The extent of this feature characteristically exceeds the cranial floor (middle endocranial fossa) equivalent dimension and produces a resultant protrusion of the mandibular corpus. This, in turn, causes a displacement (tipping) of the anterior maxillary region by the mandibular incisors and consequent bimaxillary protrusion that is a distinctive feature associated with this craniofacial combination.

While the headform and cranial flexure patterns of the Negro are similar to that of the Caucasian, the upper ethmomaxillary pattern is more oriental-like since the counterpart dimensions between the upper face and anterior cranial floor are such that a more vertical forehead, smaller frontal sinuses, low nasal bridge, short nasal protrusion, and prominent cheekbones are characteristic.

SUMMARY

The massive enlargement and the lobated configuration of the human brain are associated with a flexure of the cranial base, upright body posture, forward-pointing orbits, positioning of the orbital rims vertically, and a displacement of the olfactory bulbs into a horizontal position. Among mammals in general, the plane of the nasomaxillary region is oriented approximately perpendicular to the olfactory bulbs (cribriform plates). This relationship is retained in man, so that the vertical plane of the midface is perpendicular to the horizontal cribriform plates. Convergence of the orbits toward the midline, associated with the enlarge-

ment of the cerebrum, necessarily reduces the relative dimension of the interorbital space. This is related, in turn, to the reduction of the snout since the interorbital region represents the structural base for the nose. The reduced extent of nasomaxillary protrusion also relates to the more vertical disposition of the facial plane associated with olfactory bulb displacement, as just described.

Department of Anatomy,
West Virgina Univ.
Morgantown, W. Va. 26506

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