CONTOUR OF ORBITAL APERTURE IN REPRESENTATIVES OF MODERN AND FOSSIL HOMINIDÆ

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Broca¹ appears to have been one of the earliest observers to make a special study of the orbital aperture. To this eminent French observer, therefore, the initiation and exploitation of the orbital index are apparently due. He was soon followed by Sir Wm. Flower² who made very exhaustive observations on the orbital aperture amongst representative races of modern Hominidæ, as may be noted from the extensive tables compiled by him.

These two anthropologists were able to classify skulls into three groups according to the numerical values of their orbital indices. Since their time much controversy has been waged over the real value and significance of this index as a craniometric factor, and it is therefore important to mention the opinion of a great authority like Sir Wm. Turner³ who states that, "My observations on the orbital index in the skulls of numerous races have satisfied me that it presents a great range of variation in the same race, and that it possesses only a secondary value as a race character."

The writer's attention was first directed to a serious study of the orbital aperture in 1908 when engaged in the examination of two ancient Egyptian skeletons belonging to the XII Dynasty⁴. One of these skulls presented a very fine type with rounded orbital contours, while in the other case, which proved upon further investigation to have some degree of negroid admixture, the orbits were more quadrangular in shape, as is the general rule for the male cranium amongst the lowest races of modern Hominidæ. This observation therefore suggested that the orbital outline perhaps tended to be more rounded in character in the highest races of mankind, and quadrangular amongst the lowest racial types. The results of the present investi-

¹ Broca (P.)—*L'Indice Orbitaire*. Paris, 1876.

² Flower (W.)—*Catal. Mus. Roy. Coll. Surg.*, 2d ed., London, 1907.

³ Turner (W.)—*Trans. Roy. Soc. Edinb.*, 1903, XLI, 547-611.

⁴ Cameron (G.)—*Manchester Univ. Mus. Publ.*, 1910, LXVIII.

gation, however, show that the generalized form of orbital contour for the adult male skull in all modern races is the quadrangular, the variations of outline, both racial and sexual, depending upon the degree of "rounding off" of the four angles. In reference to this point the writer would like to state that, speaking generally, the four angles were found to be more rounded off in the higher or Eurasiatic races, than in the lower or Negro races of modern Hominidæ. This leads it should be emphasized, however, that the orbital contour was observed to be very variable even in individuals of the same race. Not only so, but further investigation showed that in the female, and in young persons of both sexes previous to adolescence, the contour was

FIG. 1 represents three crania drawn to the same scale. The orbital apertures have been enclosed within rectangular areas in order to demonstrate the four "angles" of the orbital contour and the four "unoccupied spaces." It may be noted that the relative proportions of the latter agree fairly closely in the three crania.

different from that of the adult male of the same race. It therefore became clear that other factors besides race, namely sex and age, came into action, and exerted their influence so markedly in modelling the form of the orbital aperture, that it was finally decided to confine the present investigation solely to the adult male, and leave the study of the female and the younger generation to a subsequent occasion.

In Figs. 1, 2 and 3, are represented male crania belonging to nine races, very different and divergent in type. The crania were all drawn approximately to the same scale, and were traced from photographs. A base line was drawn through the lower orbital margins for each group of three. It was found impossible, however, to get one continuous line to pass along the upper orbital margins in each group of skulls, owing to the vagaries of their outlines, so that separate lines

had to be drawn for each skull or even for each orbit. The supra-orbital notch was not utilised as the uppermost limit of the supra-orbital border, owing to its inconstancy. Vertical lines were then drawn along the inner and outer orbital margins, the idea being to enclose the orbital aperture within a rectangular figure. This plan had the effect of intensifying the quadrangular outline of each orbit, which, as previously stated, was found to be the generalized form of aperture in these nine representative racial types.

Even a superficial inspection of the nine crania in Figs. 1, 2 and 3, discloses the fact that the Tasmanian orbital contour is different from all the others. Indeed, it was the detection of this difference

FIG. 2. Note how the positions of the four "angles," and how the relative proportions of the "unoccupied spaces" agree rather intimately in these three cranial types. Note also the high orbits and therefore the high orbital indices of these crania, and compare with the low orbits in Fig. 3.

in several Tasmanian crania that mainly inspired the production of this paper. It will be noted that the lines of maximum width of the Tasmanian orbital contours lie practically in the same *horizontal* plane, the result being that their four rounded angles fit into the four corners of the dotted rectangle in a rather remarkable way.¹ Moreover, it may be further observed that the outer and inner, but particularly the lower margins of the Tasmanian orbital aperture, coincide to a considerable extent with the corresponding margins of the dotted rectangle.

The manner in which the orbital contours are orientated within

¹ The author has yet to satisfy himself as to whether this is a special feature of the aboriginal Tasmanian cranium.

the dotted rectangle in the case of the other eight crania, represented in Figs. 1, 2 and 3, exhibits on the other hand, a striking contrast to the above. Owing to the obliquity of the lines of maximum width in these, the contours are observed to be in contact with the sides of the dotted rectangle at four main points which are to be regarded as the rounded "angles" of the quadrangular type of orbital aperture. On examining these eight crania it will be seen that the positions of these rounded angles exhibit some degree of constancy. For example, in those skulls where the supero-internal "angles" are in contact with the upper sides of the dotted rectangle, the points of contact are approximately at the junction of the inner 1/3 or so with the outer

FIG. 3 displays three crania belonging to the negro races. Note that the lines of maximum width of the Tasmanian orbits lie practically in the same horizontal plane, thus reducing the "unoccupied spaces" of the rectangles to a minimum. For comparison study the obliquity of the orbits in the other two crania.

2/3. The infero-internal "angles" touch the inner sides of the dotted rectangles at about their centres or perhaps a little lower. The infero-external "angles" have their points of contact about the junctions of the inner 2/3 and outer third of the lower sides of the dotted rectangles, while the supero-external "angles" touch the outer sides of the dotted rectangle at about their centres or perhaps a little higher. It may be noted therefore that this plan yielded some rather interesting results.

On studying next the amount of space left unoccupied between the orbital contour and the angles of the dotted rectangle, it was again ascertained that there were some facts bearing a fair degree of constancy and consistency towards each other. Upon examining the tracing of the European type of skull shown in Fig. 1, it will be seen

that these unoccupied spaces have been shaded in the left halves of the Figs. in order to define their surface areas more effectively. A study of these "unoccupied spaces" in Figs. 1, 2 and 3, will demonstrate the fact that the infero-internal space is as a rule the largest, with the supero-external a close second. The infero-external space is the third largest, while the supero-internal space is decidedly the smallest. It was therefore clear as this research progressed that many facts of more than passing interest manifested themselves.

The next question to be decided was the causation of this generalised quadrangular form of orbital contour. After a careful consideration of all the facts it was ascertained that these causes came under the following headings:

1. Influence of the developing frontal and maxillary air sinuses.
2. Resistance exerted by the perivascular fascia of blood vessels and nerves.
3. Traction exerted by muscles.
4. Growth and expansion of the Brain.

Of these causes it was found that (1) and (2) acted simultaneously, while (3) and (4) exerted their own independent actions.

After a close examination of the interiors of the frontal and maxillary air sinuses in many skulls, representing the various racial types of modern hominidæ and also in the skulls of certain of the anthropoid apes, the author was able to detect numerous proofs of the action exerted by the development of these cavities on the contour of the orbital aperture. For example he was much impressed by the appearance presented by the floors of the frontal sinuses in a European type of skull, the interior of the left one represented in Fig. 4.

Extending forward on the floors of these sinuses, which it may be stated were abnormally large, two divergent ridges could be detected. I could find no previous record of the existence of these ridges in textbooks of Anatomy. They were each 12.5 mm. in length and faded away above the site of the supraorbital border exactly at the points where the supraorbital and supratrochlear nerves swept round that border. The outer ridge therefore ended immediately above the site of the supraorbital notch. Similarly, the anterior end of the inner ridge indicated accurately where the supratrochlear nerve with its accompanying vessels had swept round the bone onto the forehead in this individual. It is important to note that there were no grooves corresponding to these ridges on the anterior part of the orbital roof. On the posterior part of this roof, however, close to the

sphenoidal fissure, was a well marked groove, 13 mm. in length, for the reception of the frontal nerve. An examination of this bone specimen thus yielded us quite a fund of information regarding the anatomy of the adjoining soft tissues, for the divergent ridges provided a vivid mental picture of the bifurcation of the frontal nerve into its resultant branches. Moreover, it demonstrated also the fact that the tension on the frontal nerve trunk during the development of the frontal sinuses caused its posterior end to become actually impressed into a groove in the orbital plate of the growing frontal bone. I can

FIG. 4 exhibits a frontal sinus of the left side, the anterior wall of which has been removed in order to expose its cavity. The positions where the supraorbital and supratrochlear nerves with their accompanying vessels sweep round the supraorbital margin are indicated. The appearance presented by the cavity of this sinus suggests that during its expansion it had become bent over the above vessels and nerves, which acted as the fulcrum. This impression was corroborated by the presence of two divergent lines of "strain" on the floor and a prominent "line of strain" on the roof of this sinus. The author can find no evidence of the existence of these ridges having been previously recorded.

find no previous reference to the existence of this groove on the orbital roof. It certainly can be detected in a large proportion of crania if looked for, and it is frequently accompanied by a parallel groove for the reception of the accompanying supraorbital vessels.

A further examination of this remarkable frontal sinus revealed another interesting feature in the shape of a falciform buttress of bone projecting down into the cavity from the roof to the extent of 4 mm., at its center. This lay in an antero-posterior direction immediately above the ridge on the floor that presented the line of the supraorbital vessels and nerve, and terminated about half way down the anterior and posterior walls (see Fig. 4). It is thus quite clear

that the divergent ridges on the floor of the sinus represented "lines of stress" which compelled nature to furnish protective bastions in these situations. The buttress on the roof however suggested something further than this, and the best term I coin to describe this is a "ring of stress." It is thus quite apparent by this time what happened in this case, since all the evidence indicated that the expanding frontal sinus became bent downwards over the terminal branches of the frontal nerve, and this was exactly the appearance presented by the cavity; for the outer portion of the floor formed an angle of about 150° with the inner portion. The expanding frontal pole of the brain probably facilitated matters in this direction by exerting some degree of pressure or, at any rate, resistance from above.

Infraorbital canal containing the vessels and nerve in their sheaths.

FIG. 5 is a sketch of the anterior wall of a specially large maxillary sinus of the left side. Note the presence of prominent ridges and marked groinsings due to the resistance of the superior dental vessels and nerves to the expansion of the sinus. A feature of this sinus was the depth of the recess (marked *R*) the lower boundary of which was a well defined ridge containing the branches from the anterior superior dental vessels and nerve that supply the outer wall of the nasal fossa. So far as the author can ascertain, the existence and causation of this ridge do not appear to have been previously recorded.

The genesis of the supero-internal angle of the orbital aperture now becomes readily understood and appreciated; for it is produced in great measure by the frontal sinus, and therefore also the underlying supraorbital border, becoming bent over the terminal branches of the frontal nerves and their accompanying blood vessels, which form the fulcrum, as indicated by the arrows in the melanesian skull in Fig. 3. Owing to the fulcrum being situated nearer to the inner end

of the supraorbital margin the outer portion of this is most affected, and tends to become flattened out, as indicated in the skulls shown in Fig. 1, 2 and 3. Compare this condition with the rounded supraorbital margin of a young adolescent as represented in the cranium of the Grimaldi Youth (Fig. 6). The strain is evidently greatest on the supraorbital vessels and nerves, which as a result literally cut their way deeply into the bone, thus producing the supraorbital notch. Moreover if osteoblastic activity be well marked in this region a supraorbital foramen is the result, in which case the supero-internal angle of the orbital aperture becomes more pronounced, and at the same time more definitely located, at the point where the supratroch-

FIG. 6 exhibits three crania of fossil Hominidæ. The Cro-Magnon type shows the quadrangular form of orbital contour in a marked degree, while the Grimaldi cranium displays the rounded contour found in adolescents. The triangular outline of the orbits in the La Chapelle skull is very peculiar, and does not conform to the average modern contour. These three crania were traced from photographic reproductions in the *Memoirs of Bonnet, Boule and Verneau*, the use of which is hereby acknowledged. These crania are not drawn to the same scale.

lear nerve sweeps round the bone margin. In this relation the aboriginal Australian frontal bone described by Cunningham (*Trans. Royal Soc. Edin.*, Vol. 46, Pt. 2) is worthy of study, for the traction upon the supratrochlear vessels and their accompanying blood vessels had been so great in this specimen, that these structures had become deeply sunk in well marked grooves which had pinched off the inter-orbital portion of the bone to a slight degree. Moreover, it should be further noted that in the Neanderthal calvaria the supratrochlear nerve and its accompanying vessels had traversed a foramen on both sides, showing that these structures could likewise cut their

way deeply into the supraorbital margin. This is, however, a very exceptional condition.¹

Various signs of the existence of the tension on the above nerves have just been indicated. Another very important one has again to be recorded in the shape of the well-marked branching groove I have previously described on the under aspect of the orbital plate of the frontal bone into which the taut vessels and nerves become pressed. This leads me to refer to the fact that a careful dissection of the latter structures shows that they are all intimately bound together in a tissue that I have previously termed the perivascular fascia (in a paper on the pelvic fascia² that appeared 13 years ago). It is therefore not so much a question of traction upon the nerve fibers alone, as upon this general perivascular fascia and on its innumerable ramifications and attachments to the subcutaneous fascia along the ultimate distribution of these vessels and nerves over the frontal region of the scalp.

On investigating the Anatomy of the maxillary sinus along lines similar to those adopted in the case of the frontal sinus, several signs of traction upon the perivascular sheaths of certain neighbouring vessels and nerves likewise became manifest. Some of these manifestations are indicated in Fig. 5, which is a drawing of the front wall of an unusually large maxillary sinus, of the left side, studied from the interior. In this specimen a strong buttress of bone extended downwards from the front end of the infraorbital canal, and was so prominent that it projected backwards into the cavity of the sinus to the extent of 9.5 mm. at its upper end. This almost immediately bifurcated into outer and inner branches, of which the outer conveyed the middle superior dental nerve, while the inner transmitted the anterior superior dental vessels and nerve to their distribution. The "groining" of the sinus wall between all these ridges was very pronounced.

On studying the inner ridge it was found to divide again into two, one branch containing the vessel and nerve to the front teeth, while the other curved inward toward the outer wall of the nasal fossa (Fig. 5). A more intimate examination of the latter elicited the interesting fact that it represented the line of the canal which conveys the minute twig of the anterior superior dental nerve that supplies the outer wall of the nasal fossa. By the way I have been unable to find any reference in textbooks to the existence of this ridge, which

¹ Schwalbe (G.)—*Der Neandertalschädel*. *Bonner Jahrb.*, 1901, CVI.

² Cameron (J.)—*J. Anat.*, 1907, XLII, 112-125.

undoubtedly can be detected in a large proportion of cases. Fig. 5 shows that it forms the lower boundary of a well-marked recess (*R*) which in this specimen was 9 mm., in depth at its center while its oval opening measured 19 mm., in height and 9 mm., in width.

On opening up the infraorbital, the middle superior dental and the anterior superior dental canals in a fresh dissection, it will be noted that on removing the bony wall, their periosteal lining remains *in situ* as a tubular sheath to the canal, the vessels and the nerves, being intimately adherent to these through their perivascular sheaths. If these tubular sheaths be pulled upon, it will be observed that they display a considerable degree of toughness and strength, and could therefore offer an appreciable amount of resistance during the expansion of the cavity of the maxillary sinus in early life. Fig. 5 exhibits signs of this resistance which was clearly instrumental in producing the strong buttresses already described as projecting markedly into the sinus cavity. The actual specimen showed even secondary "groining" on the bone, branching off between the main projections, and all indicating "lines of strain" just as in the case of the frontal sinus.

A study of the mode of development of the infraorbital canal likewise added further testimony to the existence of this traction on the perivascular sheaths of the corresponding vessels and nerve. In the early developmental stages, as is well known, the latter structures are exposed on the orbital floor, but as the maxillary antrum expands they become buried deeper and deeper in the infraorbital border just as in the case of the supraorbital vessels and nerve, only the action is always more pronounced in this case. The result is of course the production of the infraorbital canal and foramen. The arrow that is shown directed downwards and inwards in the Melanesian cranium in Fig. 3, indicates the direction of the traction, and also the upward pressure of the expanding maxillary antrum, the combined result of which is to flatten the lower orbital margin, and at the same time drag it downwards and inwards, thus producing the infero-external and infero-internal angles of the orbital contour, which are a fairly well marked feature in the crania represented in Figs. 1, 2 and 3.

The supero-external and infero-internal angles of the quadrangular orbital contour are not usually so apparent, but their production is the sequel of that of the previous two, and they have been already indicated in the crania exhibited in Figs. 1, 2 and 3. The crania exhibited in these figs. certainly suggest that the outer portions of the

orbital apertures have been deliberately pulled bodily downwards, and this effect is rendered more convincing if these orbital contours be compared with those of the Grimaldi youth shown in Fig. 6. The latter, it may be noted, still exhibit the rounded outline of early adolescence, and contrast markedly with the fully mature adult condition manifested by all the others. This traction on the outer portions of the orbital aperture is probably assisted by the action of the muscles of mastication, particularly the masseter and temporal which by their powerful contraction must exert a considerable downward pull upon the zygomatic arch and the bones of the temporal fossa of the young growing skull. These bones it may be noted are in more or less intimate structural continuity with the outer orbital wall, and must exert a certain amount of indirect traction upon that also. This may partly explain the marked quadrangular outline of the orbital aperture in the negro races, for it is a well-recognized fact that the muscles of mastication are very powerfully developed in some of these lower types of modern hominidæ.

A study of the orbital contour in certain types of fossil hominidæ was found to yield some points of interest. The Obercassel Cromagnon male skull, the La Chapelle male skull, and the cranium of the Grimaldi youth, were chosen as representing three very divergent types, and these are exhibited in Fig. 6.¹ The orbital apertures of the Obercassel cranium are seen to present the generalised quadrangular contour in a marked degree, the lines of maximum orbital width being placed very obliquely as in the lower types of modern Hominidæ. This is important in view of the statement at the end of the preceding paragraph; for the zygomatic arches and jaws of this cranium were very strongly developed, thus suggesting indirect traction by massively developed muscles of mastication on the outer boundaries of the orbital apertures.

The contour of the orbital apertures in the La Chapelle cranium was found to present very distinctive features. The lower margins, as seen in Fig. 6, exhibit oblique flattened outlines, the result being that there are unusually large wide spaces between them and the infero-internal angles of the dotted rectangles. The general effect thus produced is a somewhat triangular orbital contour, this appearance being exaggerated by the deficiency in the inner margin of the left orbit. I have certainly been unable to discover a modern type

¹ These crania are not represented on the same scale.

of cranium with orbital contours at all comparable to those of the La Chapelle cranium.¹

The Grimaldi cranium is of special interest in reference to the present investigation for it provides a means of comparing the orbital contour of the early adolescent male type with that of the adult male type of skull. This fact is merely mentioned in passing, as the orbital aperture in the female sex and in childhood is to form the subject of a future study, as previously remarked. However, the observer's attention may be directed at this stage without impropriety to the fact that the orbital apertures in the Grimaldi youth are seen in Fig. 6 to be rounded in character with a relatively high orbital index, and in fact conform to the adult female type, a condition found to be the general rule in early adolescents of both sexes.

MAIN CONCLUSIONS

The generalized form of orbital aperture in the adult male skull of modern races is represented by a quadrangular contour, individual variations of outline depending upon the degree of "rounding off" of the four "angles."

If the orbital apertures be enclosed in a rectangular figure with horizontal and vertical sides, it will be found that the four "angles" of the quadrangular orbital contour are in contact with the sides of this rectangle at fairly well defined points.

The surface areas of the "unoccupied spaces" between the orbital contour and the angles of the rectangular figure are capable of some degree of comparison in different crania.

The main factors in the production of the quadrangular form of orbital aperture are as follows:

- (a) Influence of the developing frontal and maxillary air sinuses;
- (b) Resistance exerted by the perivascular fascia of the neighboring blood vessels and nerves;
- (c) Traction exerted by muscles;
- (d) Growth and expansion of the brain.

In a large proportion of crania projecting buttresses of bone can be found in certain definite sites inside the frontal and maxillary air sinuses, indicating "lines of stress" in these cavities produced by the resistance of the "perivascular fascia" of neighboring blood vessels and nerves to the expansion of these cavities. No previous record of these ridges has been found by the author.

¹ See papers on this subject by the writer in *The Canadian Magazine*, Oct., 1917, and *Trans. of the Royal Society of Canada*, Vol. XII, Series 3, 1918.

The supero-internal "angle" of the quadrangular orbital contour is produced in great measure by the frontal sinus (and therefore also the supra-orbital border) becoming bent over the terminal branches of the frontal nerve and their accompanying blood vessels and perivascular fascia which form the fulcrum.

The resistance offered by the perivascular fascia of the supra-orbital vessels and nerve to the expansion of the frontal air sinus in a downward direction is evidenced by the production of the supra-orbital notch and of an occasional groove on the posterior part of the orbital roof, the existence and causation of which do not appear to have been previously recorded.

The buttresses of bone thrown out as a result of the resistance of the perivascular fascia surrounding the blood vessels and nerves in close relation to the maxillary sinus, are frequently very pronounced and complex.

The infra-orbital canal is produced by the resistance of its contents to the upward expansion of the maxillary sinus, thus causing the vessels and nerve with their perivascular fascia to become buried deeper and deeper in the growing bone, and at the same time flattening out the lower orbital margin, the result of which is to produce the infero-external and infero-internal angles of the orbital aperture.

A study of the orbital contour in lower forms of modern Hominidæ and in certain types of fossil Hominidæ suggests that the downward traction exerted on the outer portions of the orbital aperture is probably assisted by the action of the muscles of mastication, particularly the masseter and temporal.