A CRITICAL STUDY IN CRANIAL MORPHOLOGY.

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ANATOMISTS, as a rule, apply the term intra-cranial to any structure lying within the bony framework of the skull. Practically this may be the most useful definition of the term, but exception must be taken to it on morphological grounds.

We know that, in the course of development, the human skull passes through a membranous stage, then the base chondrifies. Later we have membrane bones superadded to the cartilaginous skull, finally the cartilage is replaced, and the skull, for the most part, represented by bone.

If we wish to compare the disposition and relation of arteries and nerves in the various types of skulls, the comparison is best effected when the skull is in its embryonic condition. Suppose we choose the human skull when it is fully chondrified, and examine the course of the various nerves, we shall be much surprised and interested at the simplicity of their courses.

In order to study the relations of nerves to the chondral skull, a fœtus should be chosen between the third and fourth months. After the skin has been removed and the head soaked for some hours in running water, the various bones preformed in membrane, such as the squamosals, parietals, frontals, nasals, &c., can easily be removed without damage to the underlying cartilage.

A long series of dissections, conducted in this manner, shows clearly enough that the cranial nerves and their branches follow fairly direct courses; and the intricate paths followed by many of the nerves in the adult skull is entirely due to the modifications induced by the addition of osseous material, and the remarkable changes which occur in the branchial apparatus, the result of the transformation of an aquatic into a terrestrial animal.

The nerves most affected in this metamorphosis are the fifth, seventh, and tenth. With these three nerves our attention will be chiefly occupied.

These nerves agree in one or two important particulars, but differ in others, whilst a comparison of the points of agreement and difference leads to a conclusion of some importance.

The three nerves are in agreement, inasmuch as they develop on their main trunk, soon after quitting the brain, a ganglion; but there is considerable variety regarding the position of this ganglion. In the adult skull the ganglion of the vagus lies outside the bony skull, that of the facial is enclosed in the petrous bone, whilst the Gasserian ganglion is lodged in a compartment of dura mater, known as the cave of Meckel.

The course of the vagus, from its ganglion onward, is purely extra-cranial, but the facial traverses the curious Fallopian canal, to emerge at the stylo-mastoid foramen, whilst the subsequent course of the fifth is even more labyrinthine.

On examining the trunk of the facial nerve in a fœtus at birth, we shall be astonished to find, on removing the dura mater from the periotic bone, that the geniculate ganglion, with its petrosal branches, is exposed to view in a recess, which later becomes roofed over by a thin plate of bone. The obvious deduction from this is that the remainder of the course of the facial nerve is extra-cranial, and this is further supported by the fact that in the chondral skull the facial lies on the inner wall of the tympanum, merely covered by membrane.

In connection with this part of the question relating to the facial nerve, Gegenbaur's paper, "Bemerkungen über den Canalis Fallopii," in the *Morphologische Jahrbuch*, Bd. 11, 1876, should be consulted.

When we come to deal with the fifth nerve, we find the ganglion entirely closed in by dura mater; but the nerve enters this cave by a very distinct opening at the apex of the periotic bone.

A careful examination of these conditions led me to propound the view, that morphologically the true cranium is limited by the dura mater, and that any structure quitting the brain becomes extra-cranial at the spot where it perforates the dura mater. If this be so, then the Gasserian ganglion and its branches, including the nasal nerve, the structures in the cavernous sinus, the geniculate ganglion of the seventh with its petrosal nerves, the tympanic branch of the ninth and tenth

nerves, the internal carotid artery, from the anterior clinoid process downwards, and the meningeal vessels, must all be for the morphologist extra-cranial.

If it be admitted that structures situated between the dura mater and the osseous walls of the skulls are morphologically extra-cranial, then there can be no difficulty in dealing with the distribution of the nerves between the place where they quit the basal foramina and the spot where they emerge from the secondary osseous passages, such, for example, as the stylo-mastoid and infra-orbital foramina, the inferior dental canal, &c.

If we accept this view, then the subsequent portion of my labour becomes easy, for the intricate pathways of the distal portions of these nerves must be regarded as a species of entanglement due to increased growth of the brain, and the consequent encroachment of the cranial cavity on the face; the modification of the appendicular elements of the skull, and the addition of membrane bones.

In order to render the matter clearly, let me take each nerve-foramen in the skull-base in order. The result will be to show that when a nerve passes through an osseous opening it passes between two or more bones, or between two or more centres of ossification.

The French anatomist Serres drew attention to this in 1819, but at that time the exceptions were very numerous. Now, I shall endeavour to show that only one foramen is obdurate, viz., the foramen rotundum.

1. *Optic.*—This foramen marks the confluence of the orbito- and pre-sphenoid centres.
2. *Sphenoidal Fissure.*—This results from the confluence of the orbito-, ali- and pre-sphenoid, completed externally by the frontal.
3. *Ovale.*—This at birth is a notch in the posterior border of the ali-sphenoid, converted into a foramen by the periotic capsule.
4. *Auditory.*—This foramen marks the line of confluence of the pro-otic and opisthotic centres.
5. *Jugular.*—This is formed by the basi- and ex-occipital completed externally by the periotic capsule.

6. *Ant. Condyloid.*—This is a notch in the ex-occipital, but is converted into a foramen by the basi-occipital.
7. *The Foramen Magnum* is bounded by four distinct centres, squamo- basi- and the two ex-occipitals (fig. 1).

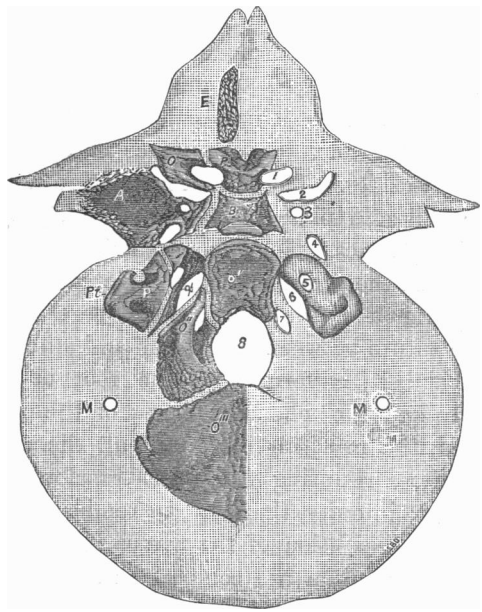

FIG. 1.—The mode of formation of the foramina in the base of the skull. The shaded parts represent the primitive cartilage. *E*, ethmoid ; *P*, pre-sphenoid ; *O*, orbito-sphenoid ; *A*, ali- and *B*, basi-sphenoid ; *P*, pro-otic ; *Op*, opisthotic ; *Pt*, pterotic ; *O'O''O'''*, the occipital nuclei. The numbers 1–8 refer to foramina in the following order : — Optic, Sph. Fissure, Rotundum, Ovale, Auditory, Jugular, Ant. Condyloid, Magnum. *M*, the mastoid foramen. The figure 5 is on the periotic capsule.

The foramina considered in the foregoing section may be regarded as the true apertures of exit for the cranial nerves; the remainder are perhaps best looked upon as adventitious, in that they are the direct result of the addition of osseous elements to the primitive cartilage cranium. Their mode of formation fully bears out the relation previously mentioned, that nerve-foramina mark the confluence of independent ossific centres, or lie between distinct bones. Each will be separately considered.

The anterior ethmoid foramen, transmitting the nasal branch

of the ophthalmic division of the fifth, occupies the suture between the os planum and the frontal bone. The slit beside the crista galli, which transmits this nerve to the nasal fossa, is formed by the lateral and mes-ethmoid centres.

The holes in the malar bone, for the passage of the malar branches of the second division of the fifth, are situated in the line of confluence of the three nuclei for this bone.[1] The infra-orbital canal marks the line of confluence of the malar and maxillary centres, whilst the naso-palatine nerves pass through minute canals, formed by the confluence of the pre-maxillary bones of opposite sides. The posterior palatine canal is a space between the pterygoid plates of the sphenoid, the palate, and superior maxillary bones. The spheno-palatine, as *its name implies*, is a notch in the palatine bone, completed by the sphenoid. The temporal branch of the fifth nerve emerges from the orbit by way of the suture between the malar and ali-sphenoid; and the pterygo-palatine, is formed by the root of the internal pterygoid plate and the sphenoid process of the palate bone.

To my mind, the most instructive of all the cranial nerve-foramina are those resulting from the transformation of the branchial arches; in order, therefore, to render this part of the matter clear, the disposition of the nerves in a dog-fish and in a human chondro-cranium are compared in the accompanying drawings (figs. 2 and 3).

In the case of the dog-fish the essential parts are the palato-quadrate bar, which is suspended from the skull by ligaments, and the hyomandibular cartilage. This supports the Meckelian cartilage; posterior to it is the hyoid arch, followed by the series of branchial bars (fig. 2).

In the human chondro-cranium we find three bars represented, the anterior, which is the equivalent of the palato-quadrate of the shark; Meckel's cartilage; and the hyoid bar. No branchial arches behind this are developed, except the distal end of the thyroid.

A glance at the two drawings, with the nerves diagrammati-

[1] In the discussion which followed the reading of this paper, Professors Macalister and Thane admitted the existence of two nuclei for this bone, but regarded the third as occasional or rudimentary. Even if this be so, it does not invalidate the principle urged here. Observations on the ossification of the facial bones are very difficult.

cally represented in relation, is sufficient to render the fundamental agreement obvious. The nerves chiefly concerned are part of the fifth, the seventh, ninth, and tenth; and the student of human anatomy knows full well that it is precisely these

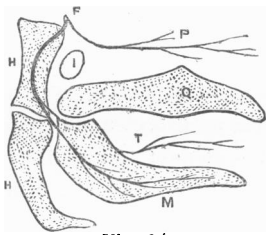

Fig. 2.

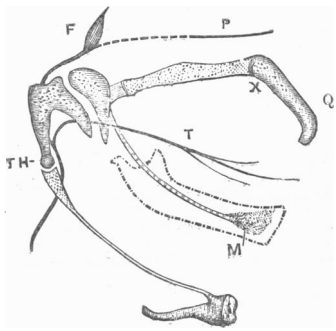

Fig. 3.

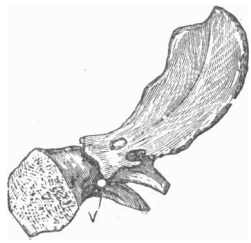

Fig. 4.

FIG. 2.—The appendicular elements of the skull of a dog-fish, showing the relation of the facial nerve.

FIG. 3.—The same parts in the human chondro-cranium.

FIG. 4.—The mode by which the Vidian canal is formed.

Q., palato-quadrate bar; *M.*, Meckel's cartilage; *H.*, hyoid bar; *T.H.*, tympano-hyal; *Hy.*, hyomandibular; *F.*, facial; *P.*, palatine (Vidian) nerve; *T.*, chorda tympani; *V.*, Vidian canal.

nerves which run complicated courses, and emit their branches in such apparently extraordinary situations. The precise homology of the various branches in the two forms is of little importance in the present argument, and will not be insisted upon, but the general plan of the nerves is in striking accordance.[1]

The details of the modifications in the relations of the nerves

[1] I have not ventured to encumber this paper with a detailed account of the metamorphosis of the palato-quadrate, Meckelian, and hyoid bars in man. Those interested in this will find an account of it in my little work on "Ligaments."

in the chondral and osseous conditions of the human skull may be given as follows:—

The Fifth Nerve.—Of the various branches of this nerve, which in the adult pursue complicated courses, few follow so extraordinary a course as the nasal branch. In the osseous skull it enters the orbit by way of the sphenoidal fissure, and quits it through the anterior ethmoidal foramen. The nerve re-enters the skull, but lies outside the dura mater, and gains the nasal fossa by way of the slit beside the crista galli, and lies between the nasal bones and the mucous membrane covering it. In the chondral skull its course is almost as direct as in the dog-fish. The complication arises in this method: the ossification of the frontal and the nasal bones separates it from the integument, so that in early life the nerve pursues its course between bone and cartilage; gradually the pressure of the nasal bone brings about absorption of the underlying cartilage, so that eventually the nerve lies between bone and mucous membrane. The expansion of the cerebrum leads the frontal bone to encroach upon and overlap the ethmoidal region, and thus buries the nasal nerve in the process. The conclusion is obvious: from the time this nerve passes the sphenoidal fissure, although it re-enters the bony cranium, its course is strictly extra-cranial. The osseous labyrinth which hides the second division of the fifth results from the addition to the chondral skull of the superior maxilla, and need not further detain us, as the facts speak for themselves.

The construction of the Vidian canal presents much that is interesting. The first suspicion that the great superficial nerve (Vidian) is of morphological importance suggested itself to my mind upon observing its relatively large size in the embryo as compared with its insignificance in the adult. Elsewhere I have endeavoured to show that the internal pterygoid plate is an adventitious element of the skull, inasmuch as it is an ossification of the anterior (ventral) end of the Eustachian cartilage, which, on its detachment from the parent cartilage, fosters itself on the sphenoid. The mode of construction of the canal is after this fashion: the internal pterygoid plate fuses at first with the ali-sphenoid; when the latter joins the lingulum the pterygoid also anchyloses with it. The coalescence of these three elements

with each other leaves a chink, as represented in fig. 4. The effect of this is to bury the Vidian nerve, which up to this period passed, as shown in fig. 3, freely above the bar. That portion of the nerve which intervenes between the geniculate ganglion and the canal, like the small superficial petrosal, is within the bony cranium, but outside the dura mater, hence it is, strictly speaking, extra-cranial.

The same line of argument applies to the inferior dental nerve. In the chondral skull its course is simplicity itself; but when the ossific nuclei for the lower jaw invest the Meckelian cartilage, the coalescence of six ossific nuclei disguises its original simple path.

The Facial Nerve.—So long as the branchial bars retained their original function in any degree, the course of this nerve is in conformity with the remaining branchial nerves; but on the transformation of the proximal portion of the hyomandibular cleft into a tympanum, profound modifications ensued. The extent of this modification is clearly indicated by the fact that in the chrondral stage of man's skull the nerve lies in a groove on the outer wall of the periotic cartilage, and the chorda tympani flits between the hyoidean and mandibular bar. In the adult skull the complex course of both nerves is too well known to need description. It may be mentioned, however, that the stylo-mastoid foramen is bounded by three ossific nuclei; they are the epiotic, tympanic annulus, and the tympano-hyal. The "iter chordæ anterius" is a chink between the squamosal and the tympanic elements of the temporal bone.

In the same way may we account for the otherwise perplexing passages of the tympanic branches of the glossopharyngeal and vagus nerves. In the cartilaginous periotic capsule these nerves pursue the simplest possible courses; but when they become hidden by the tympanic bone, and embedded among the intrinsic ossification of the otic capsule, complexity displaces simplicity.

An impartial survey of the facts, which have been stated in the foregoing pages, is sufficient to show that the almost endless complication which characterises the mammalian skull must be a direct result of the evolution of the highest skull from a simpler form. The two chief factors in producing complexity

are the gradual increasing volume of the brain, especially of the cerebrum, and the suppression of the branchial apparatus.

At first the cerebrum lies in the same horizontal plane as the primary vesicle; in time it is seen to rotate backwards, and, in the higher types, overlaps dorsally, anteriorly, and laterally the underlying vesicles. The increase in size ruptures the vault of the chondro-cranium, so that it is covered by membrane. To gain space, the enlarging cerebrum invades the facial portion of the skull and appropriates the ethmoidal region. Laterally it dips among the branchial appendages, and claims part of their territory. Hence the Gasserian ganglion and its branches, the nerves in the cavernous sinus, and the geniculate ganglion, with its petrosal ramifications, are drawn into the space between the dura mater and the middle fossa of the skull.

The opinion that the dura mater should be regarded as the limit of the primitive cranium has a pathological value as well as an anatomical import, for it serves to explain, what on other grounds would be inexplicable, the occurrence of dermoid cysts lying in the folds of the dura mater. If we remember that the integument and dura mater are actually in contact in many situations, at that period of life when formative energy is at its height, the mystery vanishes. The discussion, however, of this part of the question is foreign to the purpose of the paper.

It must have struck many, in studying the arteries, that the external carotid distributes itself exclusively to the exterior of the head and neck, if we except the meningeal branches. It is a remarkable fact that the arteries which supply the dura mater are, with one exception (the branch from the vertebral) derived from the external carotid; and it is very significant they are all distributed to the outer aspect of this membrane, and lie between it and the bony framework. Morphology cannot derive much evidence from arteries; nevertheless, when cautiously cross-questioned, facts of value may in some case be elicitedfrom them. I think it is so in the present instance.

Concluding Remarks.—It affords me peculiar pleasure to find that in the views expressed in this paper I do not stand alone. As has already been mentioned, Gegenbaur, in 1876, drew attention to the fact that the course of the facial nerve, from the hiatus outwards, is extra-cranial. My earliest views

on this matter were published in July 1883 in the *Journal of Anatomy and Physiology*, vol. xviii., in a paper "On the Ossification of the Temporal Bones," and full attention was drawn to the reasons for regarding the dura mater as the limit of the true cranium. Some further observations were published in the same *Journal* (October 1883) in connection with the anatomy of the chimpanzee, chiefly in regard to the nerve-foramina. In March 1884 Dr Albrecht, in a communication to the Société d'Anatomie Pathologique de Bruxelles, *Sur les Spondylocentres épipituitaires du Crane*, has put forward an opinion that the ali-sphenoid is to be regarded as a facial bone, and that the space between the petrous bone and the orbito-sphenoid (practically the middle fossa) is extra-cranial. Finally, he states that all structures outside the dura mater are extra-cranial; but unfortunately, the general conception is disguised under the complexity of a new, and, to my mind, unnecessary terminology. In this paper I have simply extended, by the introduction of additional evidence, the views enunciated briefly in 1883.