NOTES ON THE DEVELOPMENT AND VARIATIONS OF THE ATLAS.[1]

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THE Cambridge Anatomical Museum contains a large series of specimens illustrating the development and the variations of the atlas, and from these I have compiled the following notes:—

I. DEVELOPMENT.

At what precise time the cartilage of the atlas first assumes its characteristic form my specimens do not definitely show. In sections of a fœtus in the fifth week the ring of cartilage seems complete, and in one of the sixth week there is a sign of the beginning of ossification on each side of the posterior arch close to the lateral mass; the articular cavities between the lateral masses and the condyles are distinct, but no definite cavity appears between the odontoid process and the tissues around it.

In the third month the cartilaginous ring of the atlas is larger than that of any of the other vertebræ. The bony nucleus in the hinder arch now appears as a stumpy, slightly-curved rod, about 2 mm. long, extending from the base of the pedicle beneath the vertebral artery (whose lumen is easily seen), and forming a considerable element of the lamina.

In a four-month fœtus the atlas measures 8 mm. coronally by 3 sagittally, and the bony rod has become 3 mm. long, its anterior end invading the articular mass. In a specimen about a week older the gristly ring has become nearly 10 mm. in breadth.

Growth seems rapid at this stage, and within the first week of the beginning of the fifth month the several muscles attached to the posterior arch can be recognised in the sections. They have appeared before this date, but are not easily separable from each other. The ring now measures 11 mm. by 5.

About a week later the vertebra measures 13 mm. by 6, and the

[1] Read in abstract to the Anatomical Society, May 23, 1893.

rod of bone is nearly 4 mm. long. By this time—*i.e.*, the middle of the fifth month—the gristly odontoid process is distinct from its fibrous surroundings, and there is a clearly-marked fissure between it and the anterior arch of the atlas in front and the transverse ligament behind. The bony rod is club-shaped, slightly dilated at its hinder end, flattened beneath the artery and nerve, and swollen again anteriorly where it enters the cartilaginous lateral mass. The unossified interval between the two bony elements in the posterior arch is about 4 mm. At this period ossification extends outwards into the cartilage of the transverse process, in front of which the vertebral artery ascends, having a band of connective tissue anterior to it.

At the end of the fifth month the atlas measures 16 mm. by 9; the bony rod has grown to 6 mm. or 7 mm. in length: and as its outer end has extended into the transverse process, the outline of this rod is somewhat *f*-shaped. More than half the posterior arch is ossified, and nearly a third of the superior articular part of the lateral mass.

Early in the sixth month the vertebral ring measures from 18 to 20 mm. by 10 to 12. The bony lateral rod is now 9 mm. long, and the osseous element in the transverse process is swollen external to the vertebral artery. Nearly half of the lateral mass is now ossified.

In one specimen (No. 8) there is a small secondary centre of ossification close to the front end of the left bony rod, and on its inner side and from it the inner and anterior part of the left glenoid cavity is being ossified.

By the end of this month the ring has grown to 25 mm. coronally by 15 sagittally, and the bony rod is 10 mm. long; the posterior cartilaginous interval being about 6 mm. At this period the transverse ligament is distinct and fibrous, starting from the cartilage anterior and internal to the end of the bony part of the arch. There is fibrillar tissue on either side of the odontoid process, which is continuous into the sheath of the anterior arch on either side.

In the seventh month the whole area corresponding to the inferior articular surface and more than three-fourths of the posterior arch are ossified, and the bony growth in the lateral mass extends in front of the vertebral artery. The hinder lip

of the glenoid cavity, which rises in front of the third stage of the vertebral artery, is also bony. The ring now measures 26 mm. by 15; in one seven-months' atlas it was 28 by 16. The bony rod has now become 11 to 13 mm. long.

By the eighth month the ring is 32 mm. by 18, with a bony rod 13 mm. long. In one atlas of this age there is a post-glenoid cartilaginous process. At the end of this month the bone has become 14–15 mm. long, and at the end of the ninth month it is 16 mm. By the period of birth the atlas has become 32 mm. by 20, and the posterior unossified gap is 3 to 5 mm. long. The area from which the transverse ligament arises is still cartilaginous, and the front boundary of the arterial foramen is fibrous, with an axial mass of cartilage cells.

As early as the seventh month the outer margin of the glenoid cavity begins to show a prominent angle anteriorly at the place where the last-named fibrous tissue is attached. This has become a definite process in the costal angle of the glenoid cavity, by the ninth month.

In none of the thirty full-time fœtuses wherein I have examined the atlas have I found any trace of ossification in the anterior arch. Meckel found a round bony nucleus in the middle of this arch in one out of thirty skeletons which he examined. As it has thus occurred only once in sixty specimens, such premature ossification must be rare. On the other hand, I found the arch entirely cartilaginous, with no trace of bone, in an infant twenty months old, although the ossification of the glenoid cavity was largely advanced, and the costal angle was thick and strong. In this specimen the posterior lip of the glenoid cavity is prolonged to overlap the vertebral artery. In the neck of a Peruvian mummied infant of about one year of age the arch is also completely gristly.

In the atlas of a child eight months old (No. 57), ossification has begun in the front arch by the formation of an asymmetrical central nucleus, wider above than below, and extending from the upper to the lower border of the arch. This nucleus is 3 mm. wide.

In atlas No. 18, from a boy aged five months, the bony nucleus measures 6 mm. by 2. Its upper edge is trilobed, and its left end may have originated from a separate centre, but if so, the

two are united. The glenoid cavity is ossified for three-fourths of its extent, and its hinder edge is fairly prominent. The bony nucleus is as broad as the odontoid process, and the costal angle is prominent.

Sections of the anterior arch before it ossifies show that while its lateral portions which abut on the articular mass are made of hyaline cartilage, there is a median region in which the cartilage is invaded by the fibrous tissue which surrounds it, so that although its central core remains cartilaginous, it is surrounded by an area of fibro-cartilage, shading off into the superficial layer of fibrous tissue. The cartilage cells are smaller in this central region than in the lateral mass. A large vessel traverses the cartilage at the level where the arch merges into the lateral mass. In one section ossification appears about to begin in the superficial fibro-cartilaginous area, nearer to the ventral than to the dorsal side of the arch. Sir G. Humphry [1] describes the embryonic anterior arch as fibrous, but this statement requires to be modified in view of the present observations.

In an infant's atlas (No. 56, from a child fifteen months old), there are two bony centres, of which the left is the larger. They are separated by a deep notch above, and by a vertical linear interval in front, but they have united posteriorly where they abut on the odontoid process. The posterior arch in this atlas is widely open, and the anterior limb of the arterial foramen is unossified, although the costal angle of the glenoid cavity is distinct. The twin centres in the arch measure transversely, the right 4 mm., the left 7.

In No. 19, from a child three years old, there is a stout conical costal spur from the lip of the glenoid cavity, connected to the transverse process by a short fibro-cartilaginous band. The posterior gap of the arch is 6 mm. long. The single nucleus in the anterior arch is in shape like a very oblate patella, 10 mm. wide by 4 in vertical depth. There is a trace of a central anterior tubercle, but no sign that the centre was ever double.

In No. 22, from a boy of three and a half years, the anterior nucleus is also single, widely heart-shaped, 12 mm. wide, with a distinct median tubercle. This centre exceeded the width of

[1] *Human Skeleton*, p. 132.

the partly cartilaginous and partly bony odontoid process. There is a longer costal spur than in the last, and the posterior arch is still open.

In No. 23, from an Egyptian girl of about the same age, or perhaps rather older, probably nearly four, there is a much smaller costal process, but the anterior arch-nucleus is larger, measuring 12 by 4 mm. This atlas is singularly round, the ring measuring 49 mm. coronally by 39 sagittally. The posterior arch is as yet unclosed, but the two laminæ are practically in contact.

In the atlas from a child four years old (No. 24), there is a distinctly bilobed bony nucleus in the anterior arch. This specimen resembles in character that figured by Sir G. Humphry,[1] but the two parts are more closely united than in his specimen: in my example the left portion is 5 mm. coronally, while the right is 10. These proportions are the reverse of those shown in his figure. The original duality of the nucleus is still evident when viewed from above or from behind, but the two parts have perfectly fused below and in front. The attachment of the transverse ligament was in the interval between the lateral mass and the anterior arch. The hinder arch is not yet closed. The front end of the lateral bony arch is much lobed where it lies in the cartilage of the articular mass, and the costal process is still unossified at its junction with the transverse process.

In No. 59, from a boy aged four years and a half, the posterior arch is still open, but the laminæ are in contact. There was a thin layer of cartilage over the spinous area, overlapping the contiguous ends. The anterior arch-nucleus is still divided on a level a little on one side of the median line, the right ossicle being 9 mm., the left 7 in coronal breadth. In this case the separation is most clear behind and below. The costal processes have stretched out in front of the artery, but are still unossified to the transverse processes.

No. 25, from a girl of about the same age, shows a large central nucleus in the anterior arch, extending across the median line, and with a well-marked anterior tubercle. To the left of this is a second small ossicle 3 mm. transversely, which forms the anterior end of the left glenoid cavity. The larger bone is

[1] *Loc. cit.*, plate viii. fig. 2.

15 mm. in transverse width. The hinder arches are in contact, but not coalescent. The whole of the facet for the odontoid process is on the larger bone.

The atlas of an Egyptian boy of about five years of age (No. 26) shows a single central bone in the anterior arch, 27 mm. long, joined by a thin plane of cartilage to the primary lateral ossifications. The posterior arch is closed, and the anterior tubercle is large, and bears below an impression for the upper end of the anterior common vertebral ligament. The tubercle of the transverse process is beginning to differentiate, and the arterial foramen is nearly closed.

A specimen of about the same age shows a similar condition of the anterior arch, and a closed posterior arch, but the costal process is much smaller, leaving the arterial foramen widely open in front.

In the atlas of a boy aged five (No. 28),[1] the arch has synostosed to the lateral mass on the left, but the synchondrosis is still open on the right. Here the costal process is only separated from the transverse process by a thin layer of cartilage, and the hinder arch is closed. In a girl of six years (29), the synostosis is complete on the left, and nearly so on the right, an island of cartilage only being left. The lines of junction are marked by nearly vertical ridges. The transverse foramen is closed. This specimen shows also a trace of an ecto-glenoid sulcus. The arch is quite consolidated in a boy aged seven (No. 30), but the lines marking the synostosis are distinct. The arterial foramen is closed, but there is an apical vertical groove on the transverse process which was filled by cartilage. The sutural ridge has almost disappeared in the atlas of an Egyptian boy aged ten, and excepting a few strong vertical bars in the cancellous tissue at the site of the union, there is no sign of the original separation of the parts visible in the section of the bone.

The central arch-element is always wider along its upper border than along its lower, and forms scarcely any part of the atlanto-axial articular surface.

After birth the growth of the atlas is rapid: at the end of the

[1] Figured by Humphry (*loc. cit.*, viii. fig. 3.) The specimen figured in the same plate, fig. 2, is not in the Cambridge Museum.

first year it averages 36 mm. by 20, at the end of the second 42 by 20, at the end of the third 45 by 26, at the end of the fourth 52 by 30, at the end of the sixth 60 by 30, at the end of the eighth 63 by 47. From this onward, growth is slower. The adult male atlas averages 74 by 45; the average adult female 70 by 42. The largest male atlas in our collection is 90 by 52, the smallest adult atlas is 61 by 36.

Terminal epiphyses at the extremity of the transverse processes are rare. I have two specimens showing these, one being the atlas of an Australian aged about eighteen.

The variable process to which I shall again refer, which projects from the hinder lip of the glenoid cavity and overlaps the vertebral artery, and for which I propose the name *post-glenoid process*, occasionally presents a separate centre. In one specimen (No. 60), from a boy aged nine, this appears as a wheat-grain-like nucleus measuring 6 mm. by 3, from whose hinder border the oblique ligament stretches to the post-arterial ridge on the lamina.

Text-books differ somewhat in their accounts of the development of this bone. Bichat describes five centres—one for the anterior arch, two for the posterior, and two for the lateral masses. Cloquet assents to this as occasionally true, but says that more frequently there are only three or four—one or two for the anterior arch, and two for the rest of the bone.

Meckel describes the anterior arch as arising by one or several nuclei, these uniting together before they join the lateral masses. He also describes a rounded posterior ossicle as occurring in the middle of the posterior arch. Humphry's account in general accords with that of Meckel, but he describes the anterior arch as sometimes formed by an ingrowth from the lateral masses, with no independent centre. The evidence for this is apparently derived from the appearances presented in some anomalies and will be discussed later, but no specimen has yet been described in which the formation of an anterior arch by such ingrowths has been seen in progress.

Humphry speaks of the soft parts of the posterior arch in the child as fibrous; it is really cartilaginous. The uniting material of the infantile costal and transverse processes he speaks of as fibrous or cartilaginous. It is usually fibrous for

the most part at its middle or thinnest portion, but with a cartilaginous core.

The other authors mainly follow Humphry. Gray speaks of the anterior arch as usually completed by ingrowth from the lateral centres, which he calls neural processes, but that occasionally a separate nucleus exists for it which joins the neural processes in front of the pedicles, or there may be two which join into one. Henle adds to this, that the bony arch of the atlas is the last in the series to close. Quain follows Meckel in giving the date of the closure as three years, and states that the union is frequently preceded by the formation of a distinct spinal nucleus.

From the study of my specimens I deduce—

1. That ossification begins early in the seventh week by two centres, one at the root of each hinder arch, and spreads rapidly backwards into the arch, more slowly forwards into the articular mass, and outwards into the transverse process.

2. About the middle of the first year ossification begins ectosteally in the anterior arch; most commonly by two unequal but closely-approximated centres, which speedily unite, sometimes within a few months of their appearance.

3. The posterior arch closes late in the fourth year. The median nucleus, described and figured by Meckel, must be an element of rare occurrence: in twenty cases in which I have sought it, I have found no trace of its existence.

4. The anterior arch synostoses to the lateral mass late in the fifth year. The line of junction is at first marked by a ridge, but this disappears in two years.

5. The limbs of the arterial foramen are variable in their dates of closure. The hinder and outer boundaries and the outer edge of the anterior boundary are ossified from the transverse process, only the anterior and inner part is costal. Closure usually takes place in the sixth year.

II. Anomalies.

A. *Of the anterior arch.*

a. The inter-glenoid interval in one specimen (48) was 11 mm., in another (49) was 27 mm. These differences are due to the extent of the encroachment of the articular facets on the arch,

not to any real shortening. The inferior inter-articular interval is also variable within about the same limits.

b. In vertical height this arch ranges from 8 mm. (No. 50) to 17 mm. (51). Its thickness also varies in the centre, owing to the varying size of the anterior tubercle. In No. 52 this is large, and projects 8 mm. in front of the arch. In 53 it projects downwards in front of the axis. This latter condition is due to the extension of ossification into the attachment of the anterior ligament. This condition is well marked in several of my specimens.

On the other hand, the tubercle may be, but very rarely, obsolete, and the arch diminished to 5 mm. in thickness as in No. 54. The form of this tubercle also somewhat varies, and rarely shows some tripartition, the median part being for ligamentous, the lateral for muscular attachment.

c. In a few specimens (35, 36, 61) there is an upward extension of the tubercle, ossification extending along the middle slip of the atlanto-occipital ligament.

d. Upward prolongations of the arch, independent of the tubercle, are common in old subjects. These are due to deeper ossifications in the structures resting on the odontoid process. In 58[1] there is a *processus articularis atlantis* like that described by Halbertsma. This is a hood-like ossification of the tissues above the articular facet for the odontoid process, over the top of which it arches. Similar but smaller processes exist in 85 and 86. In 108, in which the arch is asymmetrical, there is a tubercle directed upwards at the inner end of the right glenoid cavity, which must have touched the basi-occipital bone, as it is flat-topped.

e. The intervals between the round or oval facet for the odontoid process and the margins of the arch are variable, as are the lengths of the spaces between this cavity and the glenoid cavities on each side. When these facets approximate, they overlap the meridian of the edge of the glenoid cavity. This approximation is described by Testut, and is shown in two of my specimens.[2]

f. A median vertical division of the anterior arch is shown in Nos. 34 and 35. In the former there is a slight interval between

[1] From a long barrow, Stoke, Wilts.

[2] *Anatomie*, i. p. 76.

the two halves of the arch, which was probably filled by fibro-cartilage. This is a young bone, from a boy of about sixteen years. The hinder arch is closed, but had a median pit, also probably filled by cartilage, and the costal processes have not joined the transverse. There is a slight post-glenoid process on each side. This specimen resembles that figured by Humphry,[1] but his specimen is not in the Cambridge Museum.

Humphry is of opinion that in these cases there has been no nucleus in the anterior arch, and that ossification has taken place by an inward extension from the lateral mass. There is, however, in this specimen a faint mark on the left side as of the union of an arch centre. If this be so, the anomaly is due to a want of median union of twin centres.

In 34 the arches, anterior and posterior, are both medially open. The division in the anterior passes through the middle of the odontoid facet. This large atlas is from a male adult lunatic, and has a remarkably large canal, whose lumen is 38 mm. in sagittal diameter. It is worthy of note that in one example of this anomaly, described by Dapping, the boy was an epileptic, liable to violent spasms when his head was forcibly rotated. This specimen is in the Museum of the Infirmary at Frankenthal.[2]

Humphry describes another example of this anomaly as in the Museum of Guy's Hospital.[3] Allen records two instances,[4] and others are described by Grawitz.[5] Allen quotes Humphry as describing an instance in which one of the lateral synchondroses remained open to adult life. I can find no such case recorded by him. The reference probably is to specimen No. 29, in which one side had united before the other in a boy aged seven. The only case of persistence of these sutures known to me is the one quoted by Humphry as in the Musée Orfila, in which both of these sutures persisted to adult life.

[1] *Loc. cit.*, pl. viii. fig. 4.

[2] *Moleschott, Untersuchungen zur Naturlehre des Menschen u. d. Thiere*, 1857, iii. p. 122; *New Sydenham Society's Translation of Kussmaul and Tenner on Convulsions*, 1859, p. 108.

[3] *Loc. cit.*, 133. A second specimen, described by him as in the Cambridge Museum, was not there when I took charge of the anatomical specimens.

[4] *Jour. of Anat.*, xiv., pl. ii. figs. 7 and 9.

[5] *Virchow's Archiv*, lxxx. p. 463.

g. Absence of the whole anterior arch in the adult has been described in one unique example by Professor Dwight.[1] The arch here was replaced by ligaments which tied the lateral masses to the odontoid process.

In No. 34, as in Allen's cases, the relations of the vertebral arteries were normal. In Dapping's instance there was no trace of a sulcus for the vessel on the left side.

h. An articular facet on the middle of the upper edge of the arch, for a third occipital condyle, is shown in No. 127. In No. 62 there is a pressure-facet on one side of the median line, where this arch articulated with a projection, probably a third condyle projecting from one side of the basion.

B. *The posterior arch.*

a. Median deficiency is shown in Nos. 36, 37, and 38. In 36 the laminæ are asymmetrically directed towards each other, with an intervening gap 6 mm. wide. This was from an old person. In 37 the laminæ are also asymmetrical, the right being swollen at its end as in one of the instances figured by Gräwitz.[2] In 38 this coexists with large post-glenoid processes, which articulated with the exoccipitals. This condition is present in anencephalous fœtuses. Most commonly they exist in the form described in one adult by Allen, the whole arch being absent. In No. 16 the bony parts of the atlas consisted of a curved bar on each side, the arch being entirely open behind; the transverse process is slender, and there is a stumpy bony spur on the base of the rudimental lamina, just under the place where the vertebral artery should have been, but was not.

b. Lateral deficiency, as shown in 39, is not so common. In this the left lamina is perfect, and bears the posterior tubercle, extending across the middle line; but the right is a rudiment barely perceptible at the back of the right articular mass. A case of this kind is described by Luschka, who notes that in it the transverse process juts from the side of the articular mass on that side: a similar instance is described by Allen.

In commenting on a specimen in which this and the anomaly *Af* coexisted, and in which the costal processes and the anterior tubercle were nearly in the same straight line, Allen proposes

[1] *Jour. of Anat.*, xxi. [2] *Loc. cit.*, pl. xiii. fig. 4.

the hypothesis that the deficiency is due to disjunction, owing to the forcing of the wide parts of the condyles into the approximated front parts of the glenoid cavities by a strong extension of the head, as in face presentation. In my instances, the angles formed by these three points are respectively 124°, 130°, 135°, 137°, and 127°—sufficiently near to the normal to show the inapplicability of the hypothesis. I have not been able in a normal atlas to cause any gaping by forcible extension of the head when the posterior arch is carefully cut. It is also noteworthy that in my specimens Nos. 64 and 68, in which the three named point form angles of 162° and 170° with each other, the posterior arch is normal.

c. No. 40 has the lamina attenuated to a thread on the right of the posterior tubercle. In this case the anterior coronal angle is 135°.

d. No. 41, from a young subject, aged about thirteen years, has a median posterior depression, which was filled with cartilage; this condition was also seen in No. 35.

e. The posterior arch is often very slender, with no posterior tubercle, as in 42 and 112. In 43 there is a very slight tubercle, with a depression on each side of it. This arch is also very slender for its whole extent.

f. No. 65 has also a very slight median posterior tubercle, margined by a depression on each side, shown also in 43. In 66 there is a distinct spur projecting forward on the concave side of the arch in the median line, as well as on the posterior side.

g. The posterior tubercle is long, extended into a spine in No. 67. This is single, and 9 mm. long, resembling that figured by Allen. No. 69 has a shorter spinous process, but it is bifid at its extremity.

h. The posterior tubercle is upturned towards the occiput in No. 100. In 70, 82, and others, the whole lamina thickens gradually towards the middle line, rising towards the skull. Allen conjectures that this median thickening may be due to the presence of the hypothetical posterior nucleus, but there is no evidence of this, and traces of uprising are to be seen even where the arches are unclosed, as in Nos. 20 and 22.

i. In Nos. 71, 72, 94, and 105 there are pressure-facets for articulation with the hinder edge of the occipital foramen.

Cases of this kind have been recorded by Allen and others. In one instance of this kind noticed in the dissecting-room, I found a distinct synovial cavity in this articulation.

j. The arterial sulcus varies much in its distinctness and circumscription. The two extremes are shown in Nos. 99 and 100. In the first it is deep, narrow, with a sharp *post-arterial ridge;* in the second, as in 101, it is shallow and wide, the post-arterial ridge being placed close to the origin of the posterior rectus capitis muscle. The increased space in this case has been due to the increased size of the veins, which here formed a plexus around and behind the vertebral artery. This I have determined by injection in three other cases.

The convex margin of the posterior arch may be an even continuous curve from one transverse process to the other, as in No. 101; or, on the other hand, the arterial sulcus may be so flattened and widened that there is a distinct angle at the outer extremity of the post-arterial ridge, as in 102. In some of these cases the hinder edge from one arterial sulcus to the other is nearly transverse, as in 111 and 112. In these cases the arch is usually slender. When it is thick and rounded, as in No. 109, the laminæ generally join at an angle medially. In some, the laminæ join at a sharp angle with no curvature, as in 114.

C. *The post-glenoid process.*

The post-glenoid process is a variable tongue-shaped outgrowth from the hinder and outer lip of the glenoid cavity. When large its upper surface comes in contact with the jugular ridge of the occipital bone. This condition is shown in No. 91, in which there was a considerable area of occipital contact outside the capsule of the true condylo-glenoid joint. A post-glenoid process is present in 21 per cent. of atlases in some degree, and as we have already seen, may have ossified from an independent centre. From its hinder edge there is usually a fibrous band, the oblique ligament, separable from the rest of the posterior atlanto-occipital ligament, and continued backwards to the post-arterial ridge on the lamina. This is shown in Nos. 90 and others. In 7·5 per cent. of bones this ligament is ossified, and forms a bridge over the vertebral artery and the sub-occipital nerve. The bridge is chiefly formed by the extension of ossifica-

tion into the ligament from the post-glenoid end, as can be seen in 92 and 60, where it is incomplete behind; sometimes it grows from the laminar end, as in 93, but this is rare, although, on theoretic grounds, one would have expected this to be the normal arrangement, as there is little doubt of the general accuracy of Cleland's theory that the post-arterial ridge is morphologically identical in position with the superior oblique processes of the other vertebræ.

Ossification of the oblique ligament is bilateral in 3·4 per cent. of adult bones. It is single and right in 2·4 per cent., single and left in 1·7 per cent. When this ossification coexists with an occipital articulation of the post-glenoid process, it exactly reproduces the conditions of a superior oblique process comparable with that of other vertebræ. This condition is seen in No. 95. This is a comparatively young bone: as the synostotic vertical ridges of the anterior arch have not yet disappeared.

D. *The inferior articular process.*

Owing to the mechanical relations of the atlas to the axis, the inferior articular process cannot be represented in its typical form. There is occasionally a line crossing the under side of the lamina behind the level of the exit of the second cervical nerve, which indicates its position. At the outer extremity of this line, which approximately corresponds to the outer end of the post-arterial line, there is often a small *infra-laminar spur* jutting downwards, outwards, and a little forwards, which may end in a point, or else is continued to the back of the transverse process, thus forming the hinder boundary of a *posterior lateral foramen.* The former condition is shown in 102, the latter in 103. The size of the foramen is very variable, as is also the thickness of the bridging spicule, which may be single or double. A posterior lateral foramen is present in 10 per cent. of bones. In 2·5 per cent. it is on both sides, in 4·2 per cent. on the left, in 3·3 per cent. on the right. When the opening is small, I have found a minute vein passing through it. In 103 it transmitted a much larger vein and a small branch of the vertebral artery. In another specimen found in 1887 in the dissecting-room, it transmitted the occipitalis major nerve, which then turned downwards to wind round the lower

border of the obliquus inferior, thus resembling the instance described by Schwegel.[1]

E. *The superior articular cavity.*

This cavity on each side for the occipital condyle is so unlike the other vertebral articulations, that it cannot be considered as in series with them, hence I propose to call it the *glenoid cavity of the atlas.* It participates in the characteristic variability of the bone. Its surface may be completely divided into two, as in 109 and 110. This I have found in 3 per cent. on both sides; in 2·7 per cent. on one side, as in No. 87. Partial division by a notch on the inner side, as in 105, is very much more commonly present. This is a mechanical, not a morphological division. We have seen that there is a certain part of the glenoid cavity ossified from the anterior arch, but this does not correspond with the anterior portion of a divided glenoid cavity, than which it is much smaller.

In a normal glenoid cavity the curvatures of the fore and hinder portions are such that the cavity may be conceived as formed by the apposition and continuity of two concave surfaces —an anterior, whose surface looks upwards, backwards, and inwards; and a posterior, whose surface looks upwards and inwards, often a little forwards as well. In these cases of division the interval is a non-articular area across the line of union of these two surfaces.

On the outer side of the glenoid cavity there is in 18 per cent. of atlases an *ecto-glenoid groove* for the attachment of the capsular ligament (as in 84). In some cases the articular lip of the glenoid cavity is bevelled towards this (as in 55 and 108), giving an additional surface for contact with the occiput. Internal to the glenoid cavity, and behind the tubercle for the transverse ligament, there is an *ento-glenoid fossa*, filled in the recent state by a minute Haversian body, enclosed in a loose villous fold of synovial membrane. This pit is sometimes very deep, and its fundus is bored with fine holes, through which diploic veins escape. Indeed this area, and the outer surface of the lateral mass towards the arterial foramen, are the two chief regions in which vessels enter and leave the bone. The Haversian

[1] *Zeitschrift für rationelle Medècin*, 3 Reihe, v. 311.

body is pressed backwards in flexion of the head, forwards in extension. The hinder limit of this ento-glenoid fossa is a strong ridge of very solid bone, which descends from the hinder extremity of the glenoid cavity to the innermost part of the inferior articular surface.

The curvatures of the glenoid cavities are very variable. Sometimes the anterior part has its aspect directed backwards and very little upwards, giving rise to a very deep cavity, as in 119; in others, as 114, the plane is very nearly horizontal. The curve of the hinder portion is much less variable than is that of the anterior.

The anterior extremities of the glenoid cavities in 100 atlases present the following varieties in the lengths of their intervals: —In 1 it was 10 mm.; in 2, 12 mm.: in 4, 14 mm.; in 9, 15 mm.; in 9, 16 mm.; in 10, 17 mm.; in 18, 18 mm.; in 10, 19 mm.; in 9, 20 mm.; in 9, 21 mm.; in 6, 22 mm.; in 5, 23 mm.; in 5, 24 mm.; in 2, 25 mm.; and in 1, 26 mm.

The intervals between the posterior extremities of these cavities, measured between their mid-points, are also subject to variation, and these are more erratic than those of the anterior, owing to the difficulty of discounting the post-glenoid processes. These distances are—

31 mm. in 1	35 mm. in 15	39 mm. in 7	43 mm. in 2
32 „ 2	36 „ 8	40 „ 13	44 „ 4
33 „ 3	37 „ 9	41 „ 7	48 „ 3
34 „ 2	38 „ 13	42 „ 9	50 „ 2

The axes of the glenoid cavities, measured from the foremost and inmost point to the middle of the hinder edge of the articular cavities, met when prolonged anteriorly at angles, which varied as follows:—

32° ... 1	42° ... 4	52° ... 3	60° ... 2
35° ... 2	45° ... 9	55° ... 3	62° ... 1
38° ... 4	47° ... 6	56° ... 5	63° ... 1
40° ... 3	50° ... 5	58° ... 2	

In those atlases whose hinder arches were unconsolidated, these angles were large—63°, 56°, and 53°. In No. 34, open in front and behind, the angle was the largest in the series—70°.

F. *The arterial foramen.*

This foramen remains open on both sides in ·2 per cent. of atlases; on one side in 1·6 per cent. This is due to the deficient development of the costal process. In 44 the vascular space is wide and the costal process small; in 45 the left is widely open, the right nearly closed; in 47 the right is closed, while the left is open; in 46 the left has closed, but the right is open, as it is also in 102 and 77.

Luschka, in speaking of this anomaly, states that one or other of the bony limbs of the transverse process may be absent or imperfect; but I have never seen any case in which the transverse process portion was unequivocally absent. In No. 147, which shows this condition, I suspect that the process, whose surviving piers are thread-like, was broken in cleaning the bone. In general, the transverse element is of much more compact bone than the costal, which, though often large, is usually soft and cancellous. The transverse process being ossified from the posterior and the terminal extremity, could scarcely have, under any condition, a primary attachment to the costal element, even though in some, as in No. 87, the costal portion may be double the thickness of the transverse process. In some, as 80 and 81, the root of the transverse process is reduced to a very slender narrow plate. In size the hole varies within wide limits.

G. *The transverse process.*

Genuine bifidity of the lateral process, comparable with that of the other vertebræ, is very rare. In No. 78 the true transverse process projects nearly horizontally from its root, its extremity being on a plane behind the foramen. The tip of the costal process here makes a small anterior projection, corresponding to its homologue in the lower vertebræ.

Spurious bifidity, involving only the transverse process element, is exemplified in 77 and 79, resembling the specimen figured by Allen. In No. 117 the end of the transverse process is 16 mm. wide. In these cases it is obvious that the anterior inferior tubercle has nothing costal in its nature.

H. *Gleno-transverse bony arch.*

In Nos. 82 and 83 a bony arch, from the posterior superior tubercle of the transverse process, stretches to the outer border

of the glenoid cavity, bridging the gap through which the anterior division of the sub-occipital nerve passes forwards between this arch and the costal process. This reproduces the condition seen in the ungulate atlas. I have occasionally found a slender fibrous cord (the *gleno-transverse ligament*) in this position where there was no such ossification, as in No. 146. In Nos. 61 and 84 only the outer end of this is ossified. In 87 the glenoid end is bony, and this process represents a variety of the post-glenoid process. The edge of this gleno-transverse bridge, like that of the ossified oblique ligament, occasionally presents a groove for some of the overlying veins of the sub-occipital plexus.

There is often a rough cavity on the back of the upper and outer tubercle, to which the obliquus inferior is attached, and from the tuberous end external to this the obliquus superior arises. The margin of this extremity is sometimes prolonged into a spur, as in No. 88.

Coexistence of ossification of the gleno-transverse ligament and of the oblique ligament are not common. This condition is shown in No. 83 on the right side. In 82 the former is ossified on the right, and the latter on the left. In 94 the two ossified ligaments start from the back of a post-glenoid process, from which the oblique runs backwards and the gleno-transverse forwards. In No. 64 the three bridges coexist—oblique, gleno-transverse, and posterior lateral. In this case the anterior branch of the sub-occipital nerve escapes under the first, the posterior under the second bridge.

III. Assimilation or Abnormal Attachment of the Atlas to the Base of the Skull.

A. *Atlanto-occipital fusion.*

Congenital fusion of the fœtal cartilage of the atlas to that of the occipital region. This has been described by Solger.[1] The specimen of this in the Cambridge Museum is one which was the subject of a meningocele. This condition is excessively rare, as even in cases of anencephalia the bones and

[1] "Ueber abnorme Verschmelzung knorpeliger Skelettheile beim Fötus," *Centralblatt f. allgemeine Pathologie u. patholog. Anatomie*, 1890, p. 124.

cartilages of the occiput and atlas are usually distinct, even though those of the other cervical vertebræ may be fused (as in the specimen No. 2013 in our Pathological Museum).

B. The whole ring of the atlas may become inseparably united to the edge of the foramen magnum. An instance of this form is recorded by Schiffner.[1] In this case only half the skull is preserved, and the transverse process alone is free. The bony union is remarkably perfect, as shown in the figures of pl. x.

In one Cambridge specimen which is comparable with this (*Path.*, 1893) there is perfect fusion of the right side of the anterior arch, of the articular processes, of the true transverse process, and of the posterior arch with the contiguous part of the occipital bone, so that were this only a half specimen, fusion would be as complete as in Schiffner's case; indeed, the transverse process and the paroccipital are so far blended into a single process that it juts down from the skull and apparently touched the transverse process of the axis, for which it has a facet. The costal process of the right side alone is free and unattached to the transverse. The costal process on the left side is rudimentary. There had been a vertebral artery on the left side, but none on the right; and there can have been no sub-occipital nerve on this side.

C. The articular process and posterior arch, or part of it, may be fused with the contiguous parts of the occiput, while the central part of the anterior arch is separated from the basi-occipital by a small interspace. There is an example of this in the Cambridge Museum (No. 125), from the Romano-British cemetery at Hampden Hill, Somerset.

In this specimen the anterior arch is complete, but has an immature appearance, being swollen in the centre, but slender on each side where it joins the lateral mass. The facet for the odontoid process is very small; but that process ascended behind the arch and on each side abuts on a projecting process from the inner border of the occipital condyle, the ossified lateral occipito-odontoid ligaments. These processes present flat articular faces where they touched the odontoid. These surfaces are so directed as to converge upwards and forwards, but they do not unite. Posteriorly each of these occipito-odontoid

[1] *Virchow's Archiv*, lxxiv. p. 320, 1878.

process continues backwards as a ridge which extends to the inner and posterior border of the inferior articular facet, in front of the place of exit of the second cervical nerve. The interval between the anterior arch and the basi-occipital is a narrow transverse slit. The condyles of the occipital bone and the superior articular processes are perfectly united, and the anterior condylar foramen for the hypoglossal nerve appears between the front border of the atlantic border and the edge of the jugular process.

The arterial canal on the right side is open, as the costal process ends in a slight knob, which articulates with the paroccipital process. Between this costal process and the paroccipital there is a canal for the passage of the anterior branch of the sub-occipital nerve. The true transverse process articulates by its extremity with the exoccipital behind the jugular foramen, but the canal for the vertebral artery intervenes, and passes, as usual, behind the ankylosed condyle, opening by a distinct round hole internally, like that figured in Schiffner's plate.[1]

The posterior arch is complete, and ankylosed to the hinder lip of the foramen magnum. There is a posterior condylar foramen on each side, and a second venous foramen through the bony junction between the contiguous lips.

On the left there is no interruption in the fusion of the posterior arch and the occipital bone. The posterior element of the transverse process is on this side ankylosed with the occipital behind the paroccipital process, and stretches out to impinge on the paramastoid of the temporal by a convex surface. There is a paracondylar canal[2] from the posterior condylar foramen forward. The vertebral artery on this side must have been small, and must have ended here, as there is no continuation of the canal between the atlantic lamina and the occipital bone, and no perforation. The left sub-occipital nerve, if present, must have come out with the 2nd cervical, unless it escaped through the posterior condylar foramen. The costal process is slender, and its extremity is joined to the transverse process by a very fine bony spicule.

[1] "Ueber die Architectur des Schädelgrunds in der Norm, und bei Assimilation des Atlas," *Virchow's Archiv*, lxxiv., 1878, pl. x. fig. 2.

[2] Grünbaum, *Jour. of Anat.*, vol. xx., 1892.

The skull belonged to a young male adult, about 20. The basilar suture is unclosed, but the wisdom-teeth are newly cut, and the molars are very slightly worn.

In many respects this resembles one of the three instances recorded by Boxhammer,[1] in which condylar fusion had occurred in the skull of an adolescent aged 17. There was a round atlanto-occipital opening above the anterior arch in this case, and the left transverse process was free, while the right was ankylosed to the skull. In a similar case, described by Luschka,[2] the upper edge of the anterior arch was also adherent, but the posterior arch was only present for its left half, which was fused to the occipital bone, while the right half was quite undeveloped behind the level of the sinus atlantis. In this case the articular fusion was not complete on the left side.

A corresponding want of development was present in the case described by Sommer.[3] In this instance the atlas was rudimental; the posterior arch only represented by its roots behind the articular mass.

In one of the specimens from the Berlin Museum, figured by Grawitz,[4] the posterior arch is fused as in the Cambridge instance, but the transverse process seems free (No. 10,605). In another example, from a young child, the posterior arch is completed by a fibrous cord. In another, as in Luschka's case, the posterior arch was ununited behind, but the two laminæ were both developed. In a fourth example the posterior arch is adherent, but the anterior arch is medially interrupted.

The specimen described by Langerhans,[5] from a boy five years of age, was interesting, as one of very early union. The posterior arch had ankylosed to the edges of the foramen magnum on the left side, while yet the synchondrosis between the anterior arch and the lateral portion was unossified.

D. The articular processes may be ankylosed to the occipital

[1] "Die angebornen Synostosen den Enden der beweglichen Wirbelsäule," *Zeitschrift für rationelle Medicin*, iii. Reihe, Bd. 15, p. 1.

[2] *Anatomie*, i. 36.

[3] "Zur casuistik der Atlas synostosen," *Virchow's Archiv*, xciv. p 1.

[4] "Beitrag zur Lehre von der basilaren Impression des Schädels," *Virchow's Archiv*, lxxx. p. 463.

[5] *Virchow's Archiv*, cxxi., 1890, p. 373.

condyles while the arches and transverse processes are free. This, the commonest condition, is an acquired pathological condition due to osteitic or arthritic inflammation. An example occurs in our Museum, in which there is also atlanto-axial ankylosis (*Path.*, 1894), and a rudimentary left costal process. In another specimen (No. 126), the skull of an ancient Peruvian from Cerro del Oro, this ankylosis is complete. There is a wide atlanto-occipital gap anteriorly, and the four condylar foramina are normal. The oblique and check ligaments were unossified, and the paroccipital processes are small. There are a few bony spicules around the ankylosed surfaces, but few other traces of disease. The upper edge of the posterior arch is thick and upturned, extending towards the wide foramen magnum. The whole atlas appears to have slipped a little forward, so that the anterior arch appears in norma basilaris to lie on a plane in front of the anterior lip of the foramen, and the plane of the foramen magnum extends behind the prominent posterior tubercle of the atlas. This skull was that of a middle-aged man.

Cases of this kind are far from rare. Lombroso records finding such ankyloses in 0·84 per cent. of the skulls in the Beinhaus at the battlefield of Solferino, and Legge found 5 cases out of 780 in a graveyard at the city of Camerino.[1] Lombroso also records finding this condition in 4 out of 51 criminal skulls, while De Paoli found it in 2 out of 4 criminals. In our Cambridge collection the percentage is 0·14.

Other cases of ankylosis are recorded by Casprzig;[2] Serger;[3] Sommer[4] gives three cases, including the one described by Casprzig, in the Museum of the Allenberg Asylum. There are also older cases, one described by Gurlt, referred to by Realde Columbus,[5] and another described by Morgagni.[6]

This, the first case recorded in detail, was noticed in the autopsy of a stiff-necked Paduan.

Ankylosis is also described by Schwegel (*Zeitschrift für rationelle Medecin*, xi. p. 290); Solberg (*Allgemeine Zeitschr. für Psychiatrie*, 1867, xxiv. p. 1); Bogstra and Boogaard (*De Schedel met ingedrukte Basis*, Akad. Proefschrift, Leiden, 1864, and *Nederlandsch Tijdschrift voor Geneeskunde*, Amst., 1865, 2de Reeks, i. 91). See also Virchow,

[1] *Archivio di Psichiatria*, 1883, iv. p. 384.
[2] Inaugural Dissertation, Greifswald, 1874.
[3] Inaugural Dissertation, Halle, 1888.
[4] *Virchow's Archiv*, lxxxix. p. 423, and *ibid.*, 119, p. 362.
[5] *De re Anatomica*, i. 15.
[6] De hedibus ca Morborum Epist. 79.

"*Beiträgen zur physischen Anthropologie der Deutschen*" *Berlin Akad.*, 1876, p. 340.

E. Another method whereby fixity of the atlas to the skull may be produced is by the attachment of the transverse process to the jugular process of the occipital bone. This may take place in one of three ways:—

1. By the meeting of a down-growing paroccipital process of the skull, with an up-growing spur from the atlas: a case of this kind is described by Allen (*Journal of Anatomy*, vol. xiv.). In this instance the processes had ankylosed at their place of meeting. In my specimen No. 74 the two portions are separate.

2. The processus paroccipitalis may be a down-growing column from the occiput, starting close to the outer edge of the exoccipital next to the occipito-mastoid suture, and touching the upper surface of the transverse process of the atlas, which is not raised to meet it, either articulating with it by a flat surface or ankylosed to it.

In the skull of an Egyptian (No. 127), this paroccipital process is a thick styliform column, 20 mm. long by 11 mm. thick, which ends in a flat facet that articulates with a similar facet on the transverse process of the atlas.

A similar process, 24 × 13 mm. in length, is shown in another specimen (occip. No. 16), from an English skull, and there are several paroccipital processes of lesser size in our Museum.

Examples of this mode of union are figured by Sandifort (*Mus. Anat.*, II. xiv. 31, and *Exercitationes Academiæ*, i. p. 10); Meckel ("*de Duplicitate Monstrosa*," *Archiv f. Physiol.* i. p. 644, pl. vi. fig. 37; also *Anat. u Physiol. Beobachtungen und Untersuchungen*, p. 178); Tesmer (*Rudolphi, Obs. Osteolog., Berlin*, 1812); Knape (*Schupte, de luxatione spontanea atlantis et epistrophei, Berol.*, 1816.

3. The up-growth of a styliform process in the form of a pillar-like elongation form the posterior superior angle of the transverse process of the atlas, to articulate or to ankylose with a normal paroccipital process, is a third method of union.

Examples of this are shown in specimens Nos. 73 and 74 in our Museum, and cases are recorded by Leveling (*Observ. Anat. rar.*, p. 134, pl. v. fig. 1), by Sandifort (*loc. cit.*, fig. 3), and by Allen (*loc. cit.*, p. 5, pl. ii. fig. 2).

These cases are due to ossification in the ligamentous apparatus between the transverse process and the jugular pro-

cess, and are extensions outwards of the ossification which forms the gleno-transverse bridge, with which they may be continuous. In No. 60 the pillar from the transverse process turns inwards towards, but does not quite touch the outer edge of the glenoid cavity.

Atlanto-axial ankylosis and ossifications in the transverse ligament shown in several specimens in our Museum, such as 1896 (*Path.*), are always the results of disease.