THE ARTERIES OF THE PONS AND MEDULLA OBLONGATA.[1]

By J. S. B. STOPFORD, M.D., *Lecturer in Anatomy, University of Manchester.*

INTRODUCTION.

THIS investigation was the outcome of an inquiry, made about two years ago, to determine the precise distribution of the bulbar branches of the posterior inferior cerebellar artery.

At first it was intended to work out the exact areas of the hind brain supplied by the individual arteries, by injecting them in a similar manner to that adopted by Beevor (20) in the case of the cerebral arteries; but it soon became apparent that the variation in origin, course, and distribution of the vessels of the hind brain made it an essential part of the work to study also the gross anatomy of these arteries in a large number of brains.

Although the circle of Willis has been repeatedly studied (Windle, Fawcett, etc.) during recent years, little attention has been directed to the exact course and relations of the vertebral and basilar arteries with their branches. No text-book or monograph gives sufficient data, even about the limits of the vertebral artery, and no attempt appears to have been made to determine the percentage occurrence of the common variations in the course of this vessel, or the accurate arrangement of its branches. Even Duret (55), whose work is quoted in references to the blood supply of the bulb and pons, made only twenty injections, and did not determine the modification in the position and size of the areas supplied by the various vessels, which is dependent to a considerable extent upon the slight variations that occur so frequently in their course. Obviously, if this work is to be of any clinical value in localising the position of arterial obstruction, it is essential to determine not only the more usual areas supplied by the vessels but also the variations.

Furthermore, as this part of the work progressed, it became manifest that the variation in the relationship between the arteries and cranial nerves was of considerable clinical importance, and, as this branch of the work has not previously been attempted, I shall have to consider it more fully in a later part of the thesis.

[1] This thesis was submitted for the degree of M.D. at Manchester, in May 1915, and awarded the Gold Medal.

Consequently, it has been found necessary to divide the investigation into three parts:—

1. The gross anatomy of the vessels of the hind brain, with special reference to their bulbar branches and relation to cranial nerves.
   In this section, also, the arrangements of the vessels forming the circle of Willis in the 150 brains examined will be briefly stated.
2. The precise areas of the medulla oblongata and pons supplied by the individual arteries and their branches.
3. The clinical significance of the two former sections, illustrated, as far as possible, by cases.

Source of Material, Acknowledgments, etc.

Professor G. Elliot Smith has kindly permitted me to make full use of all the material in his department, and I take this opportunity of expressing my heartiest thanks to him both for placing everything possible at my disposal and for his advice, assistance, and constant interest in the work.

The fresh material used for the injection experiments has been obtained from the Pathological Department of the Manchester Royal Infirmary, and I am indebted to Professor A. E. Boycott and Dr W. B. Anderton for their kindness in permitting me to procure such a large number of fresh brains.

For the opportunity of examining and taking notes on the anatomy of the vessels in a number of cases of insanity I desire to thank the Medical Officers of the Prestwich County Asylum.

The photographs used to illustrate the text were reproduced by Mr Gooding, histologist to the Anatomical Department, either from my sketches or the actual specimens. The sketches illustrating Part II. were made directly from the Weigert-stained sections of the hind brain which are the property of the Anatomical Department.

PART I.

THE GROSS ANATOMY OF THE VESSELS AT THE BASE OF THE BRAIN.

A.—Those in Relation to the Hind Brain.

The introductory statement explains the necessity for this section. Unless the gross anatomy be considered, no reason for the marked variation in the areas supplied by the individual arteries can be deduced, on account of the lack of accurate information and the disregard by previous observers of the factors which influence this variation in distribution. In addition, it is essential for clinical application to determine the percentage wherever

possible. This was indicated by Gowers (64), who appreciated the fact that variation in the course of the larger trunks entailed a corresponding variation in the origin of the nutrient arteries, and cited this as an explanation of the different clinical pictures which may become manifest as a result of occlusion of one of these trunks. The vessels of 150 brains have been examined, and the series is composed as follows:—

77 from the Pathological Department,
40 from the Dissecting Room,
33 from Prestwich Asylum.

The basal trunks in the latter series show proportionately more anomalies and variations than those of the other two, as suggested by Berkley (22).

No artery has been considered in Parts I. and II. which showed any obvious divergence from the normal as a result of arterio-sclerosis, or other pathological condition of either the vessel or neighbouring structures.

Measurements have been avoided, wherever possible, as the object of Part I. is primarily to elucidate the difficulties of the succeeding one, and to introduce the practical and clinical application of this work, an object which can only be achieved by denoting the various levels in relation to fixed and established points on the hind brain.

In the percentages, decimals have been omitted, and the results in all cases given to the nearest whole number.

The Vertebral Artery.

After piercing the dura and arachnoid, between the posterior arch of the atlas and the occipital bone, this vessel lies between the most caudal rootlets of the hypoglossal and the uppermost fibres of origin of the first cervical nerve. At this level it is in relation to the lateral aspect of the junction of spinal cord and medulla oblongata, and immediately anterior to the spinal root of the accessory, as that nerve ascends to join its bulbar part. The artery at once turns upwards to pass through the foramen magnum, and, since it also inclines antero-medially as it ascends, comes to lie anterior to the medulla and origin of the hypoglossal nerve. It usually meets the vessel of the opposite side in the region of the antero-median fissure at the lower border of the pons, where the two fuse at an acute angle to form the basilar. During this course the artery is situated in the cisterna cerebello-medullaris, and is only separated from the basi-occipital by the two membranes it has penetrated.

Size.—There was almost constantly an inequality in size of the arteries of the two sides (92 per cent.). The left was found to be larger in 51 per

cent. and the right in 41 per cent., the two being of equal calibre in only 8 per cent. In 20 per cent. the discrepancy in size was slight, but in the rest (72 per cent.) the difference was marked, and in twenty-two the vessel of one side was at least twice as large as that of the other.

The left was approximately twice the size of the right in 1 case.
" " three times " " 2 cases.
" " four " " " 2 "
" " six " " " 3 "
" " eight " " " 3 "
The right was approximately twice the size of the left in 1 case.
" " three times " " 4 cases.
" " four " " " 3 "
" " six " " " 1 case.
" " eight " " " 1 "
" " twenty " " " 1 "

The right vertebral was excessively small in five cases, and both were minute in one case; Blackburn (25) found the right abnormally small in 9 per cent., the left in 5 per cent., and both in 1 per cent.

It is generally admitted that the left is the larger, and Table I. gives the results of the various observers who have investigated this point.

The great variation in the figures is probably due to the fact that many have considered "equal" those cases in which the difference in size on the two sides was only slight.

TABLE I.

Observer.	Number Examined.	Size.		
		Left Larger.	Right Larger.	Equal.
		per cent.	per cent.	per cent.
Ehrman (56) . . .	57	16	14	70
Mori (99)	35	20	2	78
Loewenfeld (92) . . .	61	39	51	10
Davy (43)	98	27	8	65
Longo (90)	50	6	6	88
STOPFORD	150	51	41	8

Lewis (160) carefully measured the diameter of the vertebral artery on the two sides, in the brains of 45 lunatics, and found the average on the left to be 3·42 mm., and on the right 3·147 mm. It is curious that practi-

cally no attention has been paid to the varying calibre of the individual vessel of either side, since so many have investigated the comparative size of the two. The present research has shown that there may be a very marked reduction in size at three points in that part of the course of the vessel which is under consideration. In fully half the cases there was a distinct diminution in diameter immediately after the vessel had pierced the dura; a second narrowing was to be found at the upper limit of its course above the origin of the anterior spinal, where the lumen was usually smaller than anywhere. The third point of notable reduction in size about midway between the other two was rare, being only found four times on each side, but is clinically of equal importance as a possible site of an embolus; and in this connexion it is of interest to note that the point of reduction in calibre in two of these four cases marked the level of the origin of the posterior inferior cerebellar artery, which in each case was unusually large and almost equal in size to the vertebral.

Site of Junction to form the Basilar.—Without exception, the modern text-books describe the lowest limit of the basilar as the lower border of the pons, and Spalteholz (126) alone gives some indication that the level of the termination of the vertebral arteries may vary, by stating that the posterior margin of the pons is "approximately" the site of the formation of the basilar. In older treatises on anatomy opinion is more divided with regard to the upper limit of the vertebral arteries; Ruysch (117) pictures the lower limit of the basilar as some distance above the lower border of the pons, and Bourgery (159) as slightly below, whilst Willis (155), Vicq d'Azyr (147), and several others represent it approximately at the lower border.

Weber (151) quotes a case of union of the vertebral arteries at a lower level than normal.

In this series the vertebral arteries were found to fuse at the lower border of the pons in 48 per cent., above that point in 20 per cent., and below in 32 per cent. As the variation, above or below, was slight in a number of cases, and was proved not to affect the distribution as it does when more considerable variation exists, it may be said that the junction was approximately *at* the lower border of pons in 73 per cent., *above* in 8 per cent., and *below* in 19 per cent. It was never found higher than a third of an inch above the more usual site; but below, it was found as far caudally as the level of the lower extremity of the olivary eminence in one case, and the mid-olivary region in five others.

Anomalies.—In two instances the right vertebral divided into two trunks for the greater part of its intracranial course:—

In No. 20 (fig. 1), immediately after piercing the dura mater, the

vessel bifurcated into equal branches which united again a quarter of an inch below the pons, so that an aperture fully one inch long was formed which transmitted all the rootlets of the right hypoglossal nerve.

In No. 114 (fig. 1) the right vertebral exhibited duplication between similar limits, but in this case the lateral division was larger than the medial, and both parts were anterior to the superficial origin of the XIIth nerve.

It is curious that such an extremely rare anomaly should occur twice in this series. Tarenetzky (136) recorded one case precisely similar to

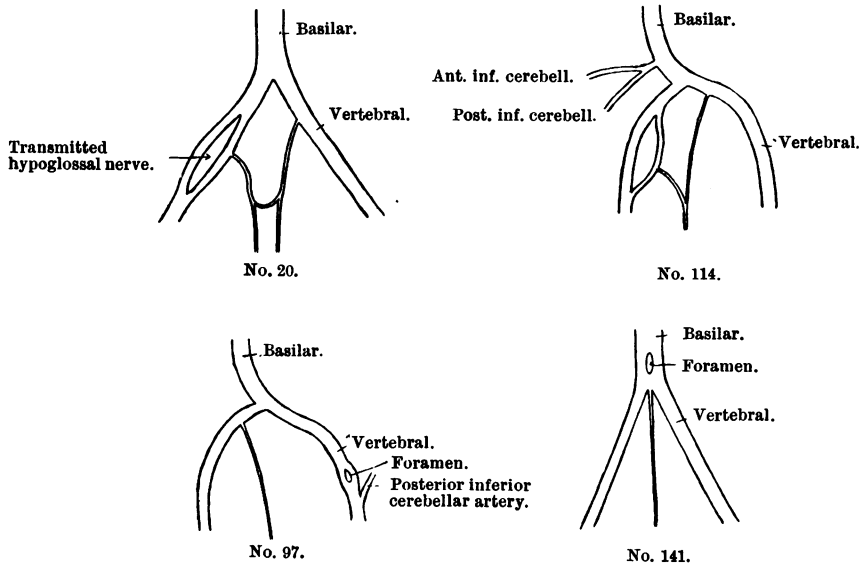


FIG. 1.—Anomalies of vertebral and basilar arteries.

No. 20; and Kadyi has reported another in which the vertebral divided into two before piercing the dura: one trunk followed the normal course and united with the other branch (which entered the spinal canal with the second cervical nerve) within the cranium.

Ogle (103) described a case where one of the roots of the left hypoglossal nerve completely pierced the wall of a normal left vertebral; and Anderson (6) has given an account of duplication in the lower part of the neck below the level of the third cervical vertebra.

The only other anomaly was found in No. 97, where a minute foramen (sufficiently large to admit a probe) was seen penetrating the centre of the left vertebral just above the origin of the posterior inferior cerebellar

artery. A similar condition has been described by Blackburn (25) in the case of the basilar, and indications of this anomaly in other vessels will be referred to subsequently, but no previous record of its occurrence in the vertebral is to be found.

Reference to the literature makes it clear that anomalies in this part of the course of the vertebral are of considerable rarity. Robinson (112) mentions the possible absence of the upper end of the vertebral, and Berry and Anderson (24) and Batujeff (13) have each described a case of failure of union of the two vessels, with consequent abnormal origin of the basilar.

Branches of the Vertebral Artery.

I. *Bulbar.*

No attempt has previously been made to investigate this group of branches.

They may be conveniently divided into three sets:—

A. An *upper set*, arising from the dorsal aspect of the vessel just caudal to its termination. They are most numerous in cases where the anterior spinal arises at an unusually low level, and then compensate for the deficient distribution of the latter vessel. Occasionally they are absent. When present they enter the substance of the bulb either in the antero-median or antero-lateral fissures, or else in the groove marking the junction of medulla and pons, in which position they are usually accompanied by bulbar branches from the lower end of the basilar.

B. An *intermediate set*, arising from the lateral aspect of the vertebral, about the mid-olivary region, and entering the medulla through the postero-lateral fissure.

They are very variable in size and number, and are quite frequently absent; as I have previously (30) pointed out, this variability is largely dependent upon the course and distribution to the bulb of the posterior inferior cerebellar artery.

C. A *lower set*, consisting usually of one moderately large branch, which arises from the medial aspect of the vertebral, whilst it is in relation to the lateral aspect of the medulla, and at once breaks up into a number of fine twigs, which enter the lower part of the bulb. This has been very constantly found in cases where a sufficient length of the vertebral has been removed with the brain; but it is liable to be missed by an incomplete removal of this vessel, and this is probably the reason why it seems to have been invariably omitted in previous descriptions.

II. *The Anterior Spinal Artery.*

This artery normally arises by two delicate branches, one from the medial side and upper part of each vertebral, which unite on the pyramids below to form one median branch, or else continue as two separate vessels after anastomosing. Their continuation down the ventral aspect of the spinal cord is maintained by reinforcements from various arteries at different levels. The relative position of the reinforcing arteries and other structures which pass through the intervertebral foramina has recently been studied by Swanberg (135), who has found that the vessels are imbedded in the fat which surrounds and protects the nervous elements.

The right branch of origin was found to be absent in 9 per cent., the left branch in 3 per cent., and the vessel arose by one stem from the angle formed by the junction of the two vertebrals in 3 per cent., as pictured by Willis (155).

In the cases where the vessel exhibited the more usual double origin, the right was slightly larger in 43 per cent. and the left in 46 per cent., the two being approximately of equal calibre in 11 per cent. In two instances (Nos. 28 and 147) the left branch had a double origin, and this was seen on the right side in one specimen (No. 65).

The origin in 51 per cent. on the right and 59 per cent. on the left was from the extreme upper part of the vertebral (*i.e.* in the region of the cephalic extremity of the olivary eminence); in 29 per cent. on the right and 28 per cent. on the left the origin was about the level of the mid-olivary region, and in 20 per cent. on the right and 13 per cent. on the left it was at the level of the caudal extremity of, or slightly below, the olive. The low origin of these branches did not appear to depend upon the junction of the two vertebral arteries occurring at a lower level than usual, because in the majority the basilar was formed at the lower border of the pons, or even above that level. The site of the origin of the anterior spinal is an important factor in influencing the area of the medulla supplied by the vertebral, and will be dealt with again more fully in the next section.

In 6 per cent. the right and left branches of origin remained separate, but in the remainder there were one or more transverse communications between the two, or else they fused to form one median vessel—the two alternatives occurred in exactly equal proportion (47 per cent.). The site of the communication or fusion was about the level of the lower end of the olive in 63 per cent., and almost at the junction of the bulb and spinal cord in 31 per cent., the latter level being the one more frequently found in the standard text-books. In the remaining 6 per cent. the two vessels continued their course without any anastomosis, as previously stated.

Anomalies.—Some variation in disposition was commonly found near

the origin, but this has apparently no influence upon the distribution, and reference to fig. 2 will make clear the variations met with in this series.

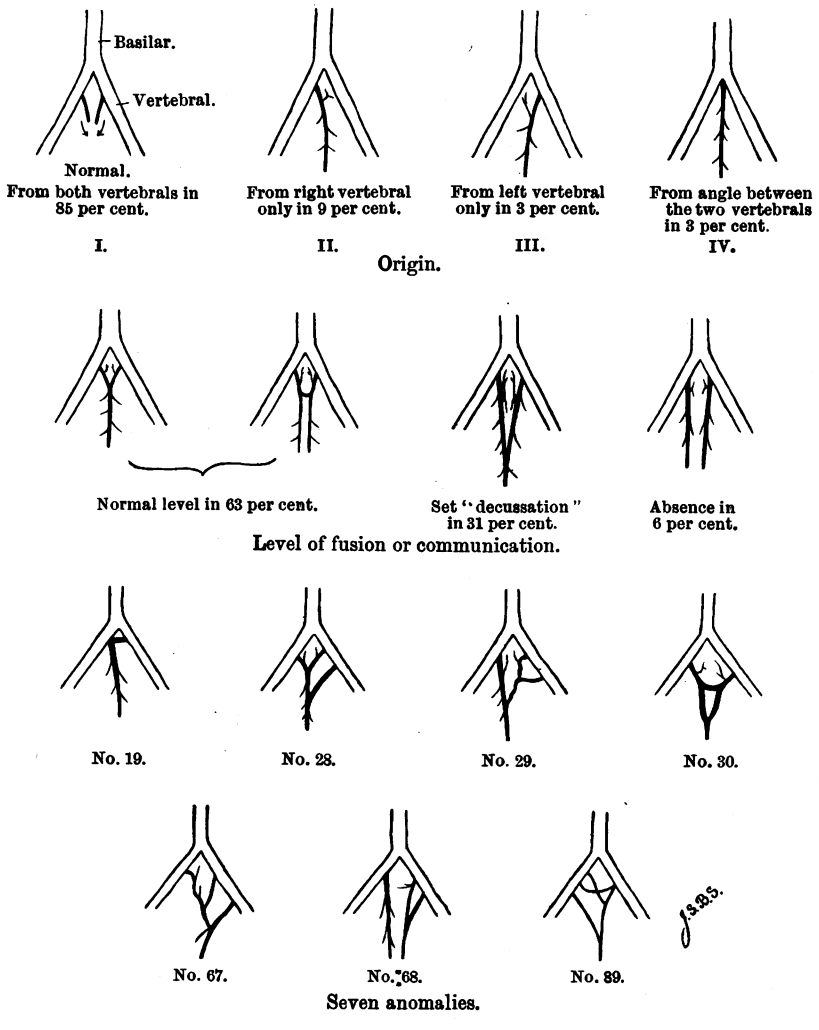


FIG. 2.—Variations of anterior spinal artery.

The *bulbar branches* of the anterior spinal may be divided into three sets:—

A. A set of branches arising from the right and left stems before fusion or communication. These break up, forming a fine network, on

the upper part of the pyramids in which their terminal filaments end. A few filaments penetrate the upper part of the antero-median fissure.

B. Branches which spring from the median vessel (or vessels) after fusion and pass directly into the antero-median fissure. This group, especially in the case of the cord, has been studied by Adamkiewicz (3) and Kadyi (82).

C. Branches from the same origin as the last which pass laterally on the pyramids, like the transverse pontine branches of the basilar, and after repeated division penetrate the pyramids or the antero-lateral sulcus. When the branch of origin of one side is absent its bulbar supply is invariably furnished by the vertebral.

III. *The Posterior Inferior Cerebellar Artery.*

The descriptions of this vessel vary within the most extreme limits. The vaguest references are generally made to its course and origin, although in recent years its precise anatomy has become of the greatest value, on account of the well-recognised group of symptoms which its occlusion produces. Robinson (112), Walsham (149), and Piersol (108) describe it as arising from the upper part of the vertebral; and almost all the text-books picture or describe it as passing more or less directly backwards around the bulb. Cruveilhier (38) gives some indication of its course when he says: "en décrivant des flexuosités remarquables autour du bulbe rachidien"; and of more recent writers Charpy (34) gives the most complete account, which is largely based on Duret's researches; whilst Wallenberg (148) has studied it more especially from a clinical standpoint. In a recent paper (30) I have attempted to give its course more accurately, and to demonstrate the influence of variation of this upon its distribution.

The posterior inferior cerebellar artery is much the largest branch of the vertebral—in three cases it was larger than the parent vessel on the right side in this series—and arises from its lateral side about the lower end of the olive. After curving round the lower border of the olive it ascends in the neighbourhood of the postero-lateral sulcus, usually posterior to the fila of the vagus and glossopharyngeal nerves, almost to the lower border of the pons, where it changes its direction and forms a loop with its convexity toward the pons. It now proceeds downwards, with a slight inclination toward the mid-dorsal line, on the restiform body and the other infero-lateral boundaries of the fourth ventricle, to just below the calamus scriptorius, where it turns outward on to the vallecula to divide into its fully described lateral and medial branches for the supply of the inferior surface of the cerebellum. In this manner the vessel makes a

loop with its convexity toward the pons on the lateral aspect of the upper part of the bulb, the ascending and more anterior limb being shorter and in relation to the postero-lateral sulcus, whilst the posterior and longer limb is in relation to the lateral wall of the fourth ventricle.

For clinical application it is necessary to realise that there is a free anastomosis on the surface of the cerebellum between the three cerebellar arteries.

The artery has been found to vary considerably in size and course even on the two sides, as many have previously noticed.

Size.—The two vessels were of equal size in 22 per cent., the right and

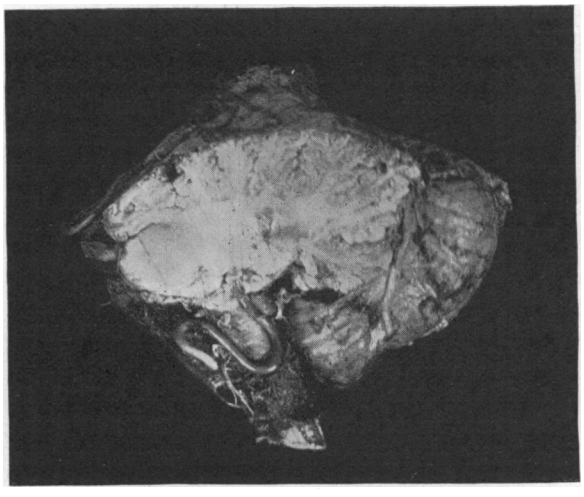


FIG. 3.— Course of posterior inferior cerebellar artery.

left were each larger in 39 per cent. In one case the left was four times the size of the right, and in another three times as large, whilst in three specimens the right was larger than the vertebral, which was unusually small, especially above the origin of this branch.

The *origin* described above as normal was found in 68 per cent. on the right side and 74 per cent. on the left. In 12 per cent. on the right and 9 per cent. on the left it arose slightly above this point, and in 17 per cent. on both sides its origin was considerably below the olive, just cephalic to the point where the vertebral artery pierced the arachnoid. In 3 per cent. on the right side it sprang from the vertebral at its termination, just before it joined with the opposing one to form the basilar.

Its *course* followed precisely that described as normal in 58 per cent.

on the right side and 49 per cent. on the left; but in 6 per cent. on the right and 19 per cent. on the left the convexity of the loop only ascended as high as the mid-olivary region. As this minor variation will be seen not to affect the distribution, for practical purposes it may be stated that the more usual course is found in 64 per cent. on the right and 68 per cent. on the left. In 5 per cent. on the right and 4 per cent. on the left the vessel failed to form any loop, and curved almost directly backward to the calamus region. In the final group the artery curved backward and caudally to the spinal cord or directly outward on to the cerebellum; in either case it usually failed to provide any bulbar branches; this configuration was found in 31 per cent. on the right and 29 per cent. on the left, and is curiously the one most in accordance with the standard descriptions.

Absence.—This artery is not infrequently absent, and was found wanting on the right side in 15 per cent., on the left in 6 per cent., and on both sides in 3 per cent. Blackburn (25) found the right absent in 5 per cent. and the left in 3 per cent. When absent, the bulbar branches are almost invariably supplied by the vertebral, but in one of the above cases the anterior inferior cerebellar artery provided branches for the postero-lateral sulcus, whilst in another the internal auditory artery compensated for the deficiency. The cerebellar branches were found to be replaced by the anterior inferior cerebellar in all cases of absence.

Anomalies.—An abnormal origin was noted three times, and in each case it was on the right side.

In Nos. 89 and 131 the artery arose from the lowest limit of the basilar, in the latter case in common with the anterior inferior cerebellar. Longo (90) found both posterior cerebellar arteries, on each side, arising from the basilar in one case in his series of fifty.

In No. 24 it had a double origin from the right vertebral, the lower one at the usual level and the upper one at the mid-olivary region; the two roots embraced a few fila of the hypoglossal as they converged to form the main arterial trunk.

In No. 137 a small foramen, exactly comparable to the one described in connexion with the vertebral, was found in the artery of the left side. Twice on the right, and in a similar number on the left, the vessel had a somewhat unusual course, as it proceeded to the dorsal surface of the bulb and then ascended at the side of the fourth ventricle up to the pons before passing on to the cerebellum, thus forming a loop in the reverse direction.

Branches.

The most important and interesting are those which supply the medulla oblongata.

A. *Bulbar.*—Branches are supplied to the bulb by both limbs. The ascending limb provides between two and seven minute branches to the region of the postero-lateral sulcus, whilst the descending limb supplies a variable number of branches to the region of the medulla, with which it comes into relation. Frequently the latter group of branches is entirely absent.

B. *Cerebellar.*—The medial and lateral terminal branches have been seen to anastomose freely with the other cerebellar arteries, but they have not been studied in any detail.

C. The *Choroidal* branch to the plexus of the fourth ventricle has not been fully studied, but in a large number of specimens used for injection it was found to arise from the upper limit of the loop in the region of the cerebello-pontine angle.

D. The *posterior spinal* in this series has been found to be more frequently a branch of this vessel than of the vertebral, as discussed in the succeeding paragraph.

IV. *The Posterior Spinal Artery.*

This artery has been included as one of the branches of the vertebral, because that is the origin most frequently stated, but it is not in accordance with the findings in this investigation. Duret (55) and Dana (41) describe its origin as from the posterior inferior cerebellar, but others give the vertebral, although Henle (72) and Vicq d'Azyr state that it sometimes arises from the other vessel.

Unfortunately this artery was found intact in a much smaller proportion of specimens than was the case with any of the others, and consequently the percentages cannot be so accurate or valuable. Nevertheless, the figures are sufficiently convincing to be of assistance in the determination of the question of origin.

On both sides it arose from the posterior inferior cerebellar in 73 per cent., and on the right side it sprang from the vertebral in 18 per cent., and from the same artery on the left in 20 per cent.

In 9 per cent. on the right and 7 per cent. on the left it had a double origin, being in communication with both the vertebral and the posterior inferior cerebellar artery.

It was seen to arise most commonly from the posterior inferior cerebellar artery just before the latter vessel extended to the cerebellum; and almost at once divided into an ascending ramus, which proceeded upward on the posterior columns to the region of the calamus scriptorius, and a descending ramus, which passed downward behind the posterior roots, to be reinforced in a manner similar to the anterior spinal.

The vessel was absent on one or both sides in a large percentage of cases, but it is quite impossible to give any reliable figures.

The ascending ramus was also very inconstant.

Numerous minute bulbar branches are given by both rami, when present, to the posterior columns and their nuclei.

The Basilar Artery.

The basilar artery, formed by the junction of the two vertebrals, extends from the caudal to the cephalic borders of the pons in the cisterna pontis. It lies on the ventral aspect in the median groove, which is produced by the prominences formed on each side by the pyramidal fibres and not by the pressure of the vessel, as may be demonstrated by the presence of this groove in cases where the basilar is deflected some distance from the median plane. It is only separated from the basisphenoid by the arachnoid and dura.

The *origin* has been considered in the references to the level of the junction of the vertebral arteries. In four instances the basilar appeared to be formed almost entirely by the right vertebral, and in a similar number by the left; this was the result of the great discrepancy in size between the two vertebrals in these cases.

Size.—At its origin the vessel is almost invariably larger than either vertebral, but there is a gradual and apparent diminution in size as it is traced to its termination. In three specimens there was an unusually marked and rapid reduction in calibre.

Termination.—Normally the artery ends at the upper border of the pons by dividing into the two posterior cerebrals. In two cases this division was just below the upper border, and in two others it was fully half an inch below.

The basilar has been found to follow a more constant course than any other vessel studied in this series, and at the same time it has been seen to exhibit manifestation of arterial disease much more frequently than the others.

Anomaly.—No. 141 showed a small foramen immediately above the origin, exactly similar to that once described in the case of the vertebral and posterior inferior cerebellar arteries.

Foramina have also been noted in this vessel by Blackburn (25), Longo (90), and Rendall (111).

The only other abnormalities of the basilar which have ever been reported are:—

(1) The presence of a median septum in the interior denoting incomplete fusion during development, which has been noted by Blackburn and many others.

(2) The presence of a band which traverses the lumen in a transverse direction; this was seen seventeen times in ninety-eight autopsies by Davy (43).

(3) The presence of a communicating branch, generally of considerable size, between the internal carotid and the basilar, as reported by Elliot Smith (124), Decker (45), Incoranto (79), Duret (54), and Blackburn (25).

No attempt has been made to search for the former two anomalies, as it would have damaged the vessels too severely to permit the injections to be performed later.

From De Vriese's (49) work on the ontogeny of the basilar, and Beddard's (16, 17, and 18) studies of the arteries at the base of the brain in other vertebrates, it is easy to explain all the anomalies of this vessel, as they appear without exception to indicate its formation from the two most caudal branches of the internal carotid.

Branches.

I. *Pontine.*

These may be divided, according to course and disposition, into two sets:—

A. A *median* set, composed of minute branches arising from that surface of the basilar lying in contact with the pons, which at once enter the substance of the brain along the median groove. Duret (55) subdivided this set into three groups, but no advantage can be gained by this; nor did my own observations justify it. Certainly they are more numerous caudally, where many enter the sulcus between the pons and bulb together with branches from the vertebrals, and again at the cephalic extremity of the basilar; but between these points they are generally found continuously, with no suggestion of any definite grouping.

B. A set of *transverse* rami which extend laterally and subdivide as they proceed into smaller branches which penetrate the ventral surface of the pons at right angles to the parent vessel. These vessels were generally arranged symmetrically on the two sides, but were variable in size and number. Normally an unusually large branch was seen to extend to the trigeminal nerve, which it supplied in a similar manner to the "radicular" arteries of Duret. If the meninges and vessels were removed, small orifices for the entrance of these vessels could be seen on the surface between the superficial transverse pontine fibres.

From embryological research and comparative study there is good reason to conclude that these transverse rami are arranged segmentally.

II. *The Anterior Inferior Cerebellar Artery.*

This vessel normally passes laterally, and somewhat caudally, from its origin over the ventral surface of the pons towards the cerebellar hemisphere of its own side, on to the anterior part of the inferior surface of which it extends to anastomose with the posterior inferior cerebellar. In the region of the cerebello-pontine angle it almost invariably passes between the pons and the facial and auditory nerves, close to their superficial origin. In two cases (Nos. 27 and 65), the vessel formed a complete arterial loop around these two nerves before it approached the inferior surface of the cerebellum. In one case the vessel was double on both sides. Blackburn discovered this eight times in 220 examinations.

The size and course of this vessel and the level of its origin from the basilar are variable even on the two sides; the variation in the former two depends largely upon the size and distribution of the posterior inferior cerebellar.

The left was *absent* on two occasions, but both in only one case (No. 131).

Size.—The arteries on the two sides were equal in calibre in 15 per cent., the right was larger in 48 per cent., and the left in 37 per cent. In six the right was very considerably larger than the left.

Origin.—In 85 per cent. the two were seen to arise at the same level; of these 78 per cent. arose from the lower third, 17 per cent. from the middle, and 5 per cent. from the lower limit of the basilar.

Including the 15 per cent. where the vessels of the two sides gained origin at different levels, it may be said that:—

	Right.	Left.
Origin was from lower third of basilar in .	75 per cent.	73 per cent.
„ „ middle „ .	16 „	21 „
„ „ lower limit „ .	9 „	6 „

On the right side the artery was found to arise from the vertebral twice and on the left side once.

In one case, on the right, the vessel had a common origin with the posterior inferior cerebellar from the lower end of the basilar; this has been previously noted by other observers several times.

Relation to the Abducent Nerve.—At the present time this neurovascular relation is clinically of very considerable interest; yet our anatomical knowledge of the subject is unfortunately incomplete and far from satisfactory.

The only previous investigation of this relation was made by Cushing (40), and his conclusions were based on only fifty-nine observations. As he failed to differentiate between the relations of the anterior inferior cerebellar and the internal auditory arteries, no object can be served by comparing his results.

Only two treatises—those of Charpy (34) and Cruveilhier (38)—on anatomy refer in the text to this relationship. Both describe the artery as lying sometimes ventrally and sometimes dorsally to the nerve, but omit any reference to the frequency of the occurrence of either. Bardeleben (9), Howden (74), Macalister (93), Rauber (110), Robinson (112), Sappey (118), Spalteholz (126), Thane (139), Toldt (142), Vicq d'Azyr (147), and Antonius and Caldani (7) all picture the artery as ventral to the nerve; whereas Turner (144), Walsham (149), Deaver (44), and Charpy (34) illustrate the reverse, although only the latter makes any reference in the text.

The present investigation has shown the artery ventral on both sides in 74 per cent., and dorsal in 8 per cent., and there is a difference in this neuro-vascular relationship on the two sides in 18 per cent.

Taking all into account, the right was ventral in 86 per cent. and dorsal in 14 per cent., whilst the left was ventral in 81 per cent. and dorsal in 19 per cent.

It is necessary at this point to realise that when the artery lies in the dorsal position, the abducent nerve may be compressed against the basi-sphenoid by the vessel, as the former structure proceeds toward the cavernous sinus.

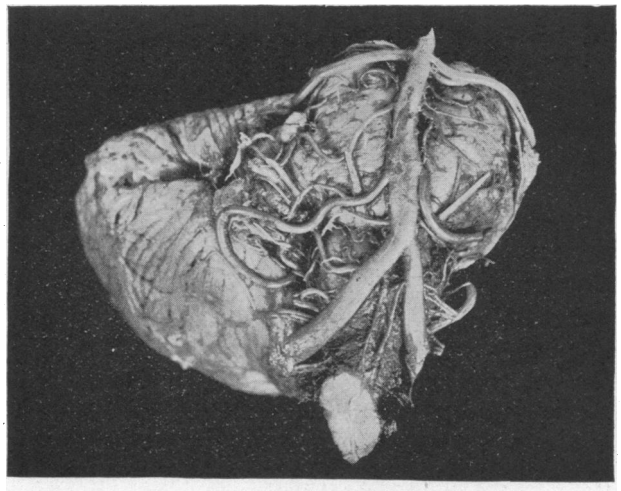
In five cases on the right and three on the left the artery was too far forward to bear any relation to the nerve.

Anomalies.—Absence and the irregular origin from the vertebral have been referred to previously. The only other anomaly met with was perforation of the abducent by the artery, a condition which occurred twice (Nos. 116 and 137) in this series, and in each case was on the left side. Nearly three years ago this condition was noted on both sides in a specimen in our own dissecting room by Mr T. P. Kilner, formerly a Demonstrator of Anatomy in this Department, but this has not been included in the 150 brains described. Valenti (145) first observed this abnormal relation, and more recently Cushing (40) discovered it three times in fifty-nine brains, and in each case it was on the left side.

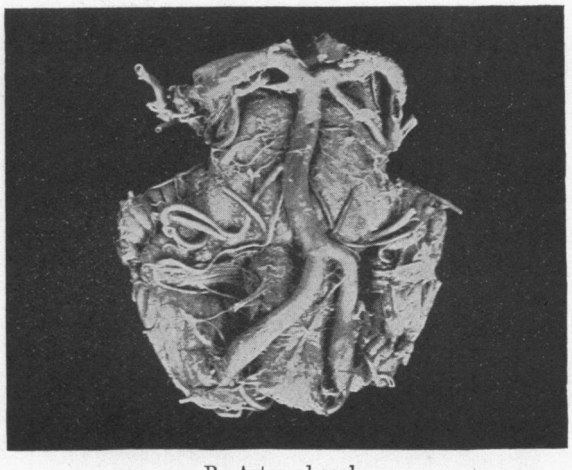
Consequently in the six examples cited above, it was present five times on the left only and once it was bilateral.

No effort appears previously to have been made to elucidate or explain the etiology of this anomaly; but, in the light of the researches of

Belogolowy (21) in the chick, and Bremer (28) and Elze (58) in the human embryo, it is not difficult to appreciate the cause of its presence.



A. Artery ventral.



B. Artery dorsal.

FIG. 4.—Relative position of VIth nerve and anterior inferior cerebellar artery.

The above researches have shown that the abducent originally arises by many roots which are arranged segmentally. Normally in man the intermediate ones alone remain, but persistence of the others may occur and

constitute aberrant roots, which have been fully described by Bremer. Between these segmentally arranged roots transverse branches of the basilar have been seen by Elze and Bremer; from this it would appear likely that, in cases of perforation of the VIth nerve, the anterior inferior cerebellar passes between the true root and an aberrant one.

A very complete bibliography of the morphology of the abducent and other nerves supplying the eye muscles has been given by Neal (101).

This emphasises Cunningham's (39) statement—"Nerves are the most conservative of all structures which go to build up the human body. They

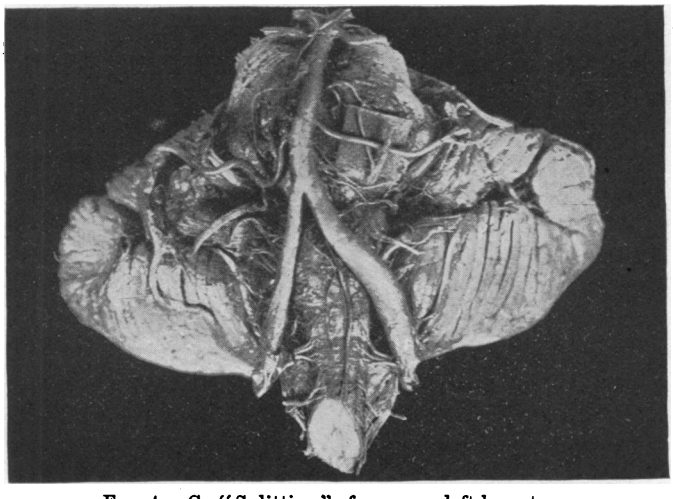


FIG. 4.—C. "Splitting" of nerve on left by artery.

cling most tenaciously to old traditions, and travel most pertinaciously along the old beaten paths."

It is interesting to notice that the plates of many of the older writers (Vicq d'Azyr, Caldani, etc.) represent the abducent as formed by two distinct roots, of which the more medial is smaller.

Branches.

A. *Pontine.*—A few branches were given to the more caudal and lateral part of the pons, in a similar manner to the perforating rami of the transverse pontine branches of the basilar.

B. *Bulbar.*—In a few cases small branches were given to the upper part of the postero-lateral sulcus, when this region was incompletely supplied by the posterior inferior cerebellar. Quite frequently branches enter the sulcus between the pons and the bulb.

C. *Internal Auditory.*—Full reference will be made to the origin of this artery in the next paragraph.

D. *Cerebellar.*—Chiefly destined for the supply of the inferior surface of the cerebellum together with the posterior inferior cerebellar artery.

III. *The Internal Auditory Artery.*

The presence of this artery was somewhat inconstant, but no accurate percentage could be given owing to the frequency with which it is damaged in the removal of the brain. As a branch of the basilar, it is undoubtedly more frequently absent than present.

It is customary to describe it as arising from the basilar and as passing laterally and slightly caudally to reach the auditory nerve, which it accompanies into the internal auditory meatus.

Origin.—The conclusion drawn from this examination is that it arises more frequently from the anterior inferior cerebellar than the basilar, as in 64 per cent. on the right and 62 per cent. on the left it was given off by the former artery. It is usually seen to arise at the point where the anterior inferior cerebellar leaves the brachium pontis and extends on to the cerebellum, a point where the artery is in close relationship with the auditory and facial nerves.

In 13 per cent. on the right and 10 per cent. on the left it was seen to spring from the basilar immediately above its origin, in 20 per cent. on the right and 18 per cent. on the left it came off from the junction of lower and middle thirds, and in 3 per cent. on the right and 10 per cent. on the left it was derived from about the middle.

Size.—It is generally quite small, but in one case it was unusually large. The vessels of the two sides were equal in size in 15 per cent., in 50 per cent. the right was larger, and in 35 per cent. the left.

Relation with Abducent Nerve.—Clinically this relation cannot be so important as that in the case of the anterior inferior cerebellar. In the first place, on account of its diminutive size, the risk of compression or strangulation of the VIth nerve must be materially reduced even in those cases where it does arise from the basilar (36 per cent. on the right and 38 per cent. on the left); and secondly, its frequent origin from the anterior inferior cerebellar prevents the possibility of any intimate relation between the two structures occurring in 64 per cent. on the right and 62 per cent. on the left. In those cases where this neuro-vascular relation could be considered, it was found that the artery passed dorsal to the nerve in 10 per cent. on the right and 16 per cent. on the left. In one of these, on the left, the artery arose from the anterior inferior cerebellar on the

medial side of the nerve; but in every other case the origin from this artery was lateral to the nerve and generally at the point previously described, so that the two were never intimately related to each other. It is of interest to notice that both the internal auditory and the anterior inferior cerebellar arteries take the dorsal course more frequently on the left. *Both* these arteries were seen to pass dorsally in the same specimen on the right side in 6 per cent., never on the left alone, and only in one instance on both sides. Cushing (40) states that sometimes both arteries may be dorsal on one side, but it is unusual to find it on both sides, and these figures support that supposition.

Branches.

A. The main vessel supplies the auditory nerve and the internal ear.
B. Occasionally a few bulbar, pontine, or cerebellar branches are to be seen.

IV. *The Superior Cerebellar Artery.*

The presence, origin, and course of this artery were all found to be very constant.

It arises from the basilar, close to the point where it bifurcates to form the posterior cerebral arteries, and, after extending laterally immediately caudal to the oculomotor nerve, curves round the crus cerebri to gain the superior surface of the cerebellar hemisphere of its own side. On the surface of the cerebellum it divides into numerous branches, which freely anastomose with the other cerebellar arteries. The injection experiments have proved that there is quite a free communication between the cerebellar arteries of the two sides, and this anastomosis must be an important factor in preventing softening of the cerebellum in many cases of occlusion of one or more of these arteries.

In the case of the cerebral arteries a similar anastomosis was found by Beevor (19) to exist in the pia mater.

Size.—The arteries of the two sides were of equal size in 33 per cent., in 31 per cent. the right was larger and in 36 per cent. the left.

Diminutive size, or absence, of one or other cerebellar artery is invariably provided for by an increase in calibre of one of the others, so that there appears to be a compensatory provision for the supply of a more or less definite volume of blood to the cerebellum.

The *origin*, as stated, was found to be very constant. In 94 per cent. it was at the upper limit of the basilar, practically at the upper border of the pons, just caudal to the point where it divided into the posterior cerebral arteries. In 6 per cent. the origin was slightly caudal to this

point, so that the relationship to the oculomotor nerve was more remote. In one case the right superior cerebellar sprang from the basilar at the junction of its upper and middle thirds.

The vessel was only *absent* once, and then only on the left side, when is was replaced by branches from the posterior cerebral. Longo (90) quotes a similar example, but Blackburn (25) found the vessel constantly represented in the 220 he examined.

Duplication.—The vessel was found to be double in a large number of cases; in 12 per cent. the right only, 16 per cent. the left only, and 3 per cent. on both sides. Once on the left it was represented by three vessels. Blackburn found it duplicated on the right only in 2 per cent., left only in 1 per cent., and on both sides in 1 per cent. In about 4 per cent., on each side, the artery was found to divide into two immediately distal to its origin.

The explanation of duplication of the cerebellar vessels necessitates only a passing reference to Mall's (94) research on the development of the intracranial blood-vessels, by which he proved that the cerebellar arteries are represented primarily by a cluster of branches, but later become reduced to a single vessel. Persistence of more than one of these branches will result in duplication, and similarly the explanation of double origin, as described in the case of one posterior inferior cerebellar artery, becomes clear. In a previous paper (134) I discussed the anomalies of the renal and spermatic vessels, and many of the opinions expressed there may be applied to the present question.

Branches.

A. *Pontine*.—The artery was found to give frequently a few irregular branches to the pons as it extended laterally from its origin.

B. *Mesencephalic.*—These have not been studied, as they were very fully described by Alezais and d'Astros (5).

C. *Cerebellar.*—Destined chiefly for the supply of the superior surface of the cerebellum.

V. *The Posterior Cerebellar Artery.*

This branch of the basilar will be briefly referred to in the section on the arteries forming the circle of Willis. The two vessels at their origin form approximately an angle of 90°.

B.—The Circulus Arteriosus (Willisii).

This significant anastomosis, between the intracranial branches of the internal carotid and basilar arteries, is situated in the cisterna inter-

peduncularis. It has been very systematically and extensively studied by many observers, which was to be expected in view of its great anatomical, physiological, medical, surgical, and even pathological interest. The more recent and extensive investigations have been performed by Blackburn (25), Windle (157), Fawcett and Blackford (59), De Vriese (50), and Longo (90), in man, and by Beddard (16, 17, and 18) in other mammals.

My own observations on this arterial circle will be briefly stated and then tabulated, together with those most recently made (see Table II.).

All the vessels comprising the circle of Willis were intact in 105 specimens, and there was a complete circular anastomosis in 98 (93 per cent.) of these, the deficiency in six of the remainder being due to the absence of the posterior communicating on one or the other side. One would expect this to be the vessel most frequently absent, because its importance is relatively much greater during the early weeks of intra-uterine life, when it represents the origin of the posterior cerebral from the internal carotid, than later, when the posterior cerebral is reinforced by anastomosis with the basilar and the posterior communicating is no longer essential for the maintenance of the blood supply of the posterior part of the cerebrum. Consequently, the posterior cerebral normally transfers its origin from the internal carotid to the basilar, with the result that the posterior communicating attains its maximum functional importance very early, but soon loses it, owing to the development of the anastomosis between the posterior cerebral and the basilar; and from that time onward fails to increase in size at the same rate as the other arteries. In cases where the anastomosis between the posterior cerebral and basilar is feeble and insufficient, the posterior communicating does not lose its function but persists as the main channel of supply to the main trunk of the posterior cerebral. Under these circumstances the posterior communicating is frequently larger than the origin of the posterior cerebral from the basilar, and the latter in consequence appears to be a branch of the internal carotid. That is to say, what appears in the adult to be a compensatory enlargement of the posterior communicating, to accommodate for its abnormally small origin from the basilar, is, strictly speaking, a persistence of the embryonic condition. Clinically, one would expect, even momentary, obstruction of the internal carotid in these cases to manifest more widespread and alarming symptoms than cases where the circle of Willis conformed to the more normal arrangement. The seventh instance of an incomplete circle illustrates perfectly the embryonic condition, because it represents complete failure of development of the anastomosis between the basilar and the posterior cerebral, and consequently in this case the latter vessel is a true branch of the internal carotid.

The Posterior Cerebral Artery.

As is to be expected from the above account, the size of the origin of this vessel from the basilar was inversely proportionate to the size of the posterior communicating in all (except one case).

The size of the origin of the arteries of the two sides was equal in 32 per cent., the right was larger in 36 per cent., and the left in 32 per cent. No observer has previously determined the relative sizes of the two at their origin, although clinically this must be the most important point. The artery appeared to arise chiefly from the internal carotid, on both sides in 2 per cent., the right only in 5 per cent., and the left side only in 3 per cent.

In No. 41 the posterior cerebral sprang from the internal carotid alone, owing to the failure of its normal post-fœtal origin from the basilar.

In No. 73 the vessel was double, the supernumerary ramus being a branch of the posterior communicating. Shaw (125) described two examples of duplication of this artery, one on the right side and one on the left; both consisted of a double origin from the basilar, and in both the two branches united immediately after junction with the posterior communicating. Reduplication of this artery is apparently extremely rare, as there are no other records of such an occurrence.

In No. 120, as previously indicated, the left posterior cerebral provided the superior cerebellar of that side. Normally the artery passes anterior to the oculomotor nerve, but it is only in actual contact in about 50 per cent. Windle (157) reports a case in which the oculomotor was divided by a branch of the posterior cerebral. In four instances the basilar was found to bifurcate below the normal position (upper border of pons), in which case the posterior cerebral must inevitably make a more pronounced loop round the IIIrd nerve and consequently endanger the nerve by strangulation, if any force acting in a caudal direction is exerted upon it.

Lautard (86) described very fully the abnormal vessels which compensate for a very small posterior cerebral artery.

The Posterior Communicating Artery.

This branch of the internal carotid was present in 93 per cent. on both sides, and was absent in 4 per cent. on the right and 3 per cent. on the left. The arteries of the two sides were of equal size in 28 per cent., the right was larger in 35 per cent., and the left in 37 per cent. This is in direct contradiction to the opinion of Box and Eccles (26), who maintain that the right posterior communicating is invariably the larger. Both were unusually large in 3 per cent., and the vessel of either side alone was of extreme size in 1 per cent. Both were minute in 3 per cent., and the left alone was particularly small in 2 per cent.

On both sides in 2 per cent. the posterior communicating was larger than the origin of the posterior cerebral from the basilar, and as a result the latter vessel appeared to be a branch of the internal carotid; this occurred on the right alone in 3 per cent., and the left alone in 3 per cent.

The Anterior Cerebral Artery.

No marked abnormality of this vessel was noticed. The relative size is of little clinical importance, owing to the practically constant presence of the anterior communicating.

Barkow (10) described a case in which the anterior cerebral arteries fused to form one common trunk in a similar manner to the junction of the vertebrals to form the basilar, a condition found constantly in the lower mammals.

Beaumonoir (15) quotes a case in which the right middle cerebral gave origin to the anterior cerebral artery of both sides. In No. 123 an accessory middle cerebral was found, arising from the left anterior cerebral at the level of the junction with the anterior communicating.

The presence of a middle anterior cerebral, in addition to the right and left, has been noted frequently since the time of Barbieri (8). It was discovered in 6 per cent.

The Middle Cerebral Artery.

No abnormality in origin or size of this branch of the internal carotid has been noted.

The Anterior Communicating.

A communication between the two anterior cerebral arteries was found constantly. Barbieri (8), Spitzka (131), and Blackburn (twice in 220) have seen examples of its absence, but it is a very rare condition. A normal single channel was found in 85 per cent., a double communication (partial or complete) in 9 per cent., and in 3 per cent. there was lateral fusion for a short distance without the intervention of any communicating branch. In No. 118 the anterior communicating exhibited a "dimpling," which indicated an attempt at duplication. In one case there was a triple communication, and in another a quadruple or what might be more correctly termed an anastomatic network.

Reference to fig. 5 will make the arrangement of this vessel clearer. Ehrman (56) found the anterior communicating single in 89 per cent., double in 3 per cent., triple in 2 per cent., Y-shaped in 3 per cent., and fusion of the two anterior cerebral arteries in 3 per cent. Mori (99) noted reduplication of the anterior communicating in 14 per cent.

Parsons (107) found this artery absent in many mammals, including Platyrrhine monkeys, the two anterior cerebrals forming a single azygos vessel, which supplies the medial surfaces of both cerebral hemispheres.

Grünbaum and Sherrington (65) found the human type more constant in the chimpanzee and orang, but not invariably present. De Vriese

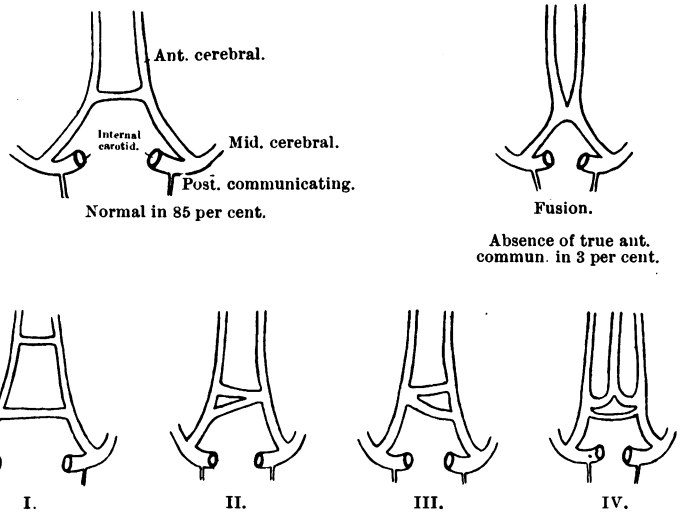


FIG. 5.—Variations of anterior communicating artery.

(47) and Beddard (16, 17, and 18), as in the case of the other cerebral arteries, describe in great detail the morphology and comparative anatomy of this vessel.

The Internal Carotid.

The only thing in connexion with this artery which has been specially noticed is its close approximation to the optic nerve. This will be considered fully in Part III.

Mitchell and Dercum (98) describe a most interesting case of aneurysm

of an abnormal communication between the terminal parts of the two internal carotid arteries. A similar abnormal communication is mentioned by Incoranto.

TABLE II.

	Stopford.	Blackburn.	Windle.	Fawcett and Blackford.	De Vriese (Fœtal).	De Vriese (Adult).
	Percentages.					
Number examined	*150*	*220*	*200*	*700*	...	*25*
Complete circle of Willis	93	...	59	96	...	96
I. *Posterior Cerebral.*						
1. Size at origin:						
(*a*) Equal	32	...	...	...	...	...
(*b*) Right larger	36	...	...	...	...	...
(*c*) Left larger	32	...	...	...	...	...
2. Appeared to arise chiefly from internal carotid:						
(*a*) Both sides	2	10	2	...	30	...
(*b*) Right side only	5	7	5	1	...	20
(*c*) Left side only	3	5	4	1	...	8
II. *Posterior Communicating.*						
Both present	93	...	87	...	...	...
1. Absence:						
(*a*) Both	0	...	1	4	...	4
(*b*) Right only	4	one case	4	2	...	...
(*c*) Left only	3	...	6	1	...	...
2. Size:						
(*a*) Equal	28	...	...	89	38	40
(*b*) Right larger	35	...	...	12	30	32
(*c*) Left larger	37	...	...	9	32	28
Very large:						
(*a*) Both	3	...	...	...	...	...
(*b*) Right only	1	...	...	...	...	12
(*c*) Left only	1	...	...	...	...	...
Minute:						
(*a*) Both	3	2	3	...	...	...
(*b*) Right only	0	1	...	..	...	...
(*c*) Left only	2	3	...	...	...	...
II. *Anterior Communicating*						
Absence	0	1	1	one case	...	...
1. Single	85	90	79	92	48	80
2. Double	9	6	10	7	14	4
3. Triple	1	...	one case	one case	...	...
4. Quadruple or retiform	1	one case	...	...	28	12
5. Fusion of anterior cerebrals	3	3	3	...	10	4
Presence of arteria media cerebralis anterior	6	1	4	3	12	8

The Frequency of Anomalies in Criminals and the Insane.

In the preface reference has been made to the conclusion that anomalies in the basal arterial trunks occur more frequently in the insane. This conclusion is supported by the results in this series, which is composed of 117 brains from sane individuals and 33 from insane; anomalies were found in 61 per cent. of the former and 79 per cent. of the latter. Considerable emphasis has been placed upon this point by many previous writers, and for comparison the various results will be found tabulated in Table III. Unfortunately, this table loses a good deal of its value, because the various recorders have failed clearly to define what they consider as anomalies, and the greatest reliance can therefore be placed upon the results where the percentages are obtained by the same observer both for the insane and healthy. In this series, absence, irregular origin, reduplication, or a considerable discrepancy in size of any artery has constituted an anomaly.

TABLE III.

Observer.	Number Examined, etc.	Percentage of Anomalies.
Blackburn (25).	220 insane.	70
Barbieri (8).	145 idiots.	15
Frigerio (61).	37 insane.	57
Lombroso (89).	71 criminals.	37
Mori (99).	35 insane.	91
	35 sane.	*37*
Parnisetti (106).	65 criminals.	51
Windle (157).	*200 sane.*	*40*
STOPFORD.	*118 sane.*	*61*
	32 insane.	79

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