The Morphological Observation of the Basal Vessels of the Brain of Human Infants

by

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Abbreviations

a. c.:	anterior cerebral artery.
a. ch.:	anterior choroidal artery.
m. c.:	middle cerebral artery.
p. c.:	posterior cerebral artery.
p. com.:	posterior communicating artery.
i. c.:	internal carotid artery.
m. a.:	medial artery of corpus callosum .
m. s.:	medial striate artery (Heubner's).
s. c.:	superior cerebellar artery.
i. a.:	internal auditory artery.
B.:	basilar artery.
a. i. c.:	anterior inferior cerebellar artery.
p. i. c.:	posterior inferior cerebellar artery.
v.:	vertebral artery.
a. s.:	anterior spinal artery.
a. com.:	anterior communicating artery.
rt.:	right side .
lt.:	left side.

THE MORPHOLOGICAL OBSERVATION OF THE BASAL VESSELS OF THE BRAIN OF HUMAN INFANTS

1. INTRODUCTION

Needless to say, it is imperative for workers in the neurological field to know and understand the circulatory system of the Central Nervous System. The basal vessels of the brain, especially the circle of Willis and basilar artery are of particular interest and importance as they are the main and only source of metabolism to such vital structures as basal ganglia, hypothalamus, midbrain and pons. Many investigators have therefore contributed to the knowledge of the course, tributary area, variations, anomalies etc., from the anatomical, physiological and pathological aspects. However, most of their investigations have been based on adult specimens, and consist mostly of gross observations.

The only systematic study on fetal brains of the circle of Willis was made by De Vriese (1905), who studied the gross variations of the main vessels of the circle on 100 specimens. She discussed the causes of variations and anomalies from the standpoint of embryological evolutionary processes. Regarding the development of the intracranial arterial system of the human brain, Padget (1948) contributed the most conclusive embryological study on which may be based the interpretation of many of the variations and anomalies we see in the basal arteries of the brain.

Histological studies of both normal and abnormal vessels have been numerous, but again have been based on adult specimens. The literature is, however, singularly incomplete regarding minute observation of branches and twigs originating from the circle of Willis and basilar artery, for variation in size, number, origin, etc. The studies of Stopford, Busse, Saphir, Atkinson and several other investigators (see following chapters) are confined to the main branches of the circle of Willis and the studies by Alexander, Abbie etc. concern the ganglionic or central arteries as a group.

In this investigation, 39 infants' brains were studied. Approximately half of them were still-born, after six to nine months gestation. The remainder ranged in age from ten minutes to three years, and the majority of them were less than one month old. (See Graph I). Detailed dissections were made of the circle of Willis, basilar and vertebral arteries and their branches, making every effort to save all branches and twigs. Accurate drawings were made of each specimen.

With the exception of one specimen of marked congenital arterio-venous malformation and aneurysm of the great vein of Galen in the region of the pineal gland, this study was limited to the circle of Willis including the basilar and vertebral arteries. Only the most significant photomicrographs are attached.

II. REVIEW OF THE LITERATURE

1. The circle of Willis:

The circle of Willis, after Thomas Willis of Oxford (1666), lies in the basal subarachnoid cisterns. It crosses the optic apparatus; the anterior cerebral arteries lying above the chiasm and the rest of the circle lying below the brain mass. The common anatomical text-book descriptions of the circle of Willis (Ranson and Clark; 1953, Strong and Elwin; 1953, Gray's Anatomy; 1954, Mettler; 1942) give little fine detail, especially for the variations from the commonly accepted idea of normal. The writings of Windle(1887), De Vriese (1905), Stopford (1916), Fawcett and Blackford (1905-06), Busse (1920-21), Abbie (1937), Alexander (1942) and Padget (1948) are especially helpful in reviewing the anatomy of the circle.

The internal carotid artery, at about the level of the posterior clinoid process, gives rise to the posterior communicating artery. A few millimeters further laterally the anterior choroidal artery arises. A few millimeters beyond the origin of the anterior choroidal artery, the internal carotid artery terminates by dividing into the anterior and middle cerebral arteries. In the embryologic stage, the anterior cerebral artery is a direct continuation of the internal carotid artery Padget, 1948), but it is observed and agreed that after birth, the middle cerebral artery shows the picture of direct continuation of the internal carotid artery, as described in the common anatomical textbooks above.

The anterior cerebral artery extends forward and medially, and crosses the optic chiasm to join its neighbour of the opposite side forming the anterior communicating artery. The anterior communicating artery has been studied extensively by a number of investigators (De Vriese; 1905, Busse; 1920-21, Padget; 1948, Rubinstein; 1944, Critchley; 1930). The vessel is often doubled, plexiform, or replaced by a broad area of fusion between the two anterior cerebral arteries. Rubinstein (1944) in a study of one hundred adult brains noted that branches of the anterior communicating artery were present in forty-seven cases; twenty-five had two branches and twenty-two had one thin twig. After observing the variations, he questioned the idea of Le Blanc (1926) quoted in Rubinstein (1944) that individual hypothalamic nuclei receive a distinct blood supply from specific arteries from the circle of Willis.

Critchley (1930), in an investigation of the anterior cerebral and anterior communicating arteries, found that the anomalies in these vessels consisted of an asymmetry of the caliber of the two anterior cerebrals such that a vessel of one side might supply both hemispheres, sometimes by way of an hypertrophied anterior communicating artery and at other times by means of other communicating vascular channels. Double, triple or even plexiform anterior communicating arteries are not uncommon. In rare cases, when the anterior communicating artery is absent, there usually is communication through temporary fusion of the two anterior communicating arteries to form a large sinus. Busse (1920-21) examined four hundred anterior communicating arteries and found the vessels to be multiple in two hundred and twenty-seven cases (56.7%)but never absent. Howe (1903) reported a case of absence of communication between the anterior cerebral arteries and moreover , with both posterior communicating arteries represented by a mere thread of tissue. Wyrubow (1902) stated that anomalies of the anterior cerebral arteries were found in 22.3% of the insane and in criminals.

The posterior communicating artery commonly leaves the postero-median surface of the internal carotid just behind the posterior clinoid process and above and medial to the oculomotor nerve. The artery runs along the medial surface of the oculomotor nerve, backward, downward and medial to join the posterior cerebral artery and complete the circle of Willis. Hindze and Fedotowa (1931) described seven types of anomalies of the posterior communicating artery as follows:

1) Primitive type; the posterior cerebral artery forms the continuation of the internal carotid artery. The posterior communicating artery is larger than normal.

2) Transitional type; the posterior cerebral arteries are formed about evenly by the posterior communicating and divisional branches of the basilar artery.

3) Recent type; the posterior cerebral artery is formed principally by the branches of the basilar artery.

4) The internal carotid and basilar arteries are united by an embryonal trigeminal artery or 5) hypoglossal artery.

6) Mixed type; on one side the posterior communicating artery is absent and on the other side it is much larger than normal.

7) Complete separation of the circulation of the internal carotid and vertebral arteries.

Carpenter (1954), in his study of the anterior choroidal artery in 60 hemispheres, noted that the vessel originated from the internal carotid in 76.6%, from the middle cerebral artery in 11.7%, from the posterior communicating artery in 6.7%, and from the junction of the anterior and middle cerebral artery in 3.3%. He also examined the course, size, distribution and variation of this artery and found its principal branches are; 1) perforating branch, 2) branches to uncus, 3) branches to cerebral peduncle, 4) branches to optic tract and lateral geniculate body, 5) terminal branches to choroidal plexus of inferior horn of the lateral ventricle. Anomalies and variation of the circle of Willis will be further discussed later.

2. Basilar artery:

The basilar artery is formed by the junction of the two vertebral arteries (De Vriese, 1905; Padget, 1948). Stopford (1916) found it to be larger than either vertebral, but gradually diminishing in size as it approached its termination. Main branches of the basilar artery normally consist of:

1) Pontine; these include both medial and transverse groups.

2) Anterior inferior cerebellar artery; this vessel, according to Stopford's study on one hundred and fifty adult brains, arose from the lower third of the basilar artery in 72% of cases, from middle third in 18%, and from the upper third in about 7%, with irregularities on the two sides. The anterior inferior cerebellar arteries were located ventral to the abducent nerves in 74% of cases, dorsal in 8%, and variable on the

two sides in 18% of the cases. The anterior inferior cerebellar artery gives rise to a) pontine; b) bulbar; c) internal auditory; and d) cerebellar branches. Atkinson (1949), in his study of "anterior inferior cerebellar artery for its variations, pontine distribution and significance in the surgery of cerebello-pontine angle tumors", described seven anomalies of this vessel and stated that the anterior inferior cerebellar artery supplied the lateral tegmental portion of the pons and is quite vulnerable to trauma during the removal of neoplasms of the cerebello-pontine angle.

3) Internal auditory; this vessel is inconstant, according to Stopford, arising more frequently from the anterior inferior cerebellar (63%) than from the basilar artery(27%). Although it sends branches chiefly to the auditory nerve and inner ear, it also has a few bulbar, pontine or cerebellar branches.

4) Superior cerebellar artery; according to Stopford's study, this pair of vessels arises quite constantly from the basilar artery near its point of bifurcation to form the posterior cerebral arteries. They run laterally around the cerebral peduncles to the superior surfaces of the cerebellar hemispheres where they branch and anastomose freely with the other cerebellar arteries. It is also observed by Padget (1948) that the 4th cranial nerve very frequently emerges between the branches of the first major bifurcation of the superior cerebellar artery.

Stopford found the two vessels equal in size in 33% of cases, and where small or absent, were compensated for by enlargement of the vessel of the other side. The superior cerebellar artery frequently was a double twig instead of a single trunk.

5) Posterior cerebral artery; at the upper edge of the pons, the basilar artery terminates by dividing into two posterior cerebral arteries. They extend laterally and join with the posterior communicating arteries and lie above the oculomotor nerve. The third cranial nerve quite constantly emerges between the posterior cerebral and superior cerebellar arteries. The posterior cerebral arteries then run over the edges of the incisura of the tentorium. While anatomically in the adult brain, the posterior cerebral arteries are the terminal branches of the basilar artery, they arise originally as branches of the internal carotid artery in the form of extension of the posterior communicating artery (De Vriese, 1905; Padget, 1948). Their conclusions were based on embryological studies. Williams (1936) made this decision on the evidence of perivascular innervation of nerve plexus, that the basilar sympathetic plexus extended on to the posterior cerebral artery but stopped short of the posterior communicating artery.

In no case did the fibers extend along the posterior cerebral, nor did they continue onto the posterior communicating artery. His study suggests that while the vessels were being innervated, the terminal portion of the posterior cerebral artery was a continuation of the posterior communicating. In fact, a number of case-reports reveals that the posterior cerebral artery is a direct branch of the internal carotid as a form of extension of the posterior communicating in the adult brain.

Shellshear (1920) suggested that the distribution of arteries obeys some definite ontogenic and phylogenic law. The evolution of vessels is dependent on, and proceeds with, the evolution of their field of distribution. As the brain has expanded to meet new and increasing requirements, its arteries have extended to meet the increased functional demands. In the backward growth of the hemispheres over the midbrain, the area of the distribution of the posterior cerebral artery has been progressively separated from the parent trunk, the internal carotid artery. For natural economy, a nearer source of supply has been found in anastomosis with the basilar artery. Saphir (1935), in his classification of the anomalies of the circle of Willis stated that, "One or both posterior communicating arteries may be so large that the posterior cerebral artery appears to be a terminal branch of the posterior communicating artery. The divisional branch of the basilar artery up to the point of union with the posterior communicating artery (most proximal portion of the posterior cerebral artery) may be so small that it appears to be the posterior communicating artery..... The basilar artery may be formed by the fusion of the posterior communicating and the divisional branch of the basilar artery (the posterior communicating artery and divisional branch of the basilar artery are equal in size)."

3. Vertebral artery:

The vertebral artery enters the foramen magnum and lies between the lowest rootlets of the hypoglossal nerve and upper fibers of the first cervical nerve roots at the junction of the medulla and spinal cord. The vessel then turns anteromedially toward the anterior surface of the medulla at the origin of the hypoglossal nerve. The two arteries, usually meeting in the midline at the lower border of the pons, unite at an acute angle to form the basilar artery. Stopford (1916), in the study of one hundred and fifty adult brains, found the caliber of the vertebral arteries unequal in 51% of the cases. In 72% of the latter group the difference in size was marked; in 22% one vessel was at least twice the size of the other. Each vessel varied greatly in size at various levels; in half the cases the artery was constricted immediately after piercing the dura; above the origin of the anterior spinal artery, the lumen of the artery was found smaller than elsewhere; in four cases the vessel was constricted at the origin of the posterior inferior cerebellar artery, which in each case was almost equal to the size of the vertebral artery. The point of junction of the vertebrals to form the basilar artery also was variable. In 73% of cases the junction was at the lower border of the pons; in 19%, below it; and in 8%, above it. Occasionally a vertebral artery was fenestrated, the result of incomplete persistence of the embryonic network from which the vessels are formed. Stopford also found that the left vertebral artery practically formed the basilar artery in some cases with the right vertebral entering it at a right angle. Padget (1944 in Dandy's monograph) referred to several cases in which the vertebrals pursued independent courses and did not join to form a basilar artery.

Several important branches arise from the vertebral arteries:

1) Anterior spinal artery. This vessel, usually formed

by the fusion of branches from each vertebral artery, descends on the anterior surface of the cervical spinal cord. The vessel may arise from either vertebral alone without contribution from the other .

2) Posterior inferior cerebellar artery. Stopford found these vessels to be of equal size in 22% of cases. In the remainder, the larger vessel arose on either side with equal frequency (39%); either (right 15%, left 6%) or both arteries (3%) may be absent. Because of normally rich anastomosis on the surface of the cerebellum, these variations have little functional significance. In all such cases, branches of the anterior inferior cerebellar arteries were found to replace the absent vessels. The posterior inferior cerebellar artery gives off a) bulbar; b) cerebellar; c) clinoidal; and d) posterior spinal branches.

3) Posterior spinal artery. This vessel arises from the posterior inferior cerebellar artery in 73% of cases, and from one or both vertebral arteries in the remainder.

4. The central or ganglionic branches of the circle of Willis:

Strong and Elwyn (1953) summarized well in their textbook of Neuroanatomy the central branches of the circle of Willis, after Abbie (1937), Aitken (1909), Alexander (1942) etc. The following is quoted from their book; "The ganglionic arteries which supply the diencephalon, corpus striatum and internal capsule are arranged in 4 general groups: anteromedial, anterolateral, posteromedial and posterolateral. The anteromedial arise from the domain of the anterior cerebral and anterior communicating artery, some twigs coming directly from the carotid at its place of bifurcation. They enter the most medial portion of the anterior perforated spaces and are distributed to the anterior hypothalamus including the preoptic and suprachiasmatic regions.

The numerous posteromedial arteries which enter the tuber cinereum, mammillary bodies and interpeduncular fossa are derived from the most proximal portion of the posterior cerebral and from the whole extent of the posterior communicating arteries. Some twigs come directly from the carotid artery just before its bifurcation. A rostral and caudal group may be distinguished. The rostral group supplies the hypophysis, infundibulum and tuberal regions of the hypothalamus. A number of vessels known as thalamo-perforating arteries, penetrate more deeply and are distributed to the anterior and medial portions of the thalamus. The caudal group supplies the mammillary region of the hypothalamus, the subthalamic structures, and likewise sends fibers to the medial wall and nuclei of the thalamus including massa intermedia. Other vessels from the caudal group are distributed to the midbrain, supplying the rapheal region of the tegmentum, nucleus ruber and medial portions of the pes pedunculi. The posterolateral or thalamogeniculate arteries arise more laterally from the posterior cerebral arteries. They penetrate the lateral geniculate body and supply the large caudal half of the thalamus including geniculate bodies, pulvinar and most of the lateral nuclear mass. The anterolateral or striate arteries which pierce the anterior perforating substance arise mainly from the basal portion of the middle cerebral artery and to a lesser extent from the anterior cerebral. As a rule, those from the anterior cerebral artery supply the anteroventral portion of the head of the caudate nucleus and adjacent portions of the putamen and internal capsule."

5. The development of the circle of Willis, basilar and vertebral arteries:

The frequent variations from the normal pattern of the circle of Willis, basilar and vertebral arteries and its frequent asymmetry have been commented upon since these vessels first attracted the attention of investigators. Painstaking studies have been made by Windle (1887), Fawcett and Blackford (1905-06), De Vriese (1905), Stopford (1916), Busse (1920-21), Reinhoff (1924), Fetterman and Moran (1941), Critchley (1930), Bremer (1943), Rubinstein (1944), Padget (1944 and 1948) and others. A knowledge of the embryology of the circle of Willis is necessary to understand the anomalies and perhaps the development of aneurysms in this region.

Padget (1948), in her extensive study on the development of the cranial arteries in the human embryo, found that the essential adult pattern of the circle of Willis can be recognized as early as the second month, before the vessels have acquired accessory coats. In the primitive vascular plexus at this stage, the source of all the major arteries is distinct but not their direction nor their size. These are determined by the subsequent growth of the brain, which requires augmentation of certain channels and allows the disappearance of others. A brief summary of Padget's study (1948) follows: "The internal carotid, the basilar, and the vertebral arteries are formed during the first three stages (4 to 5 mms., 5 to 6 mms. and 7 to 12 mms., the length of the embryo). The fourth stage (12 to 14 mms.) is a significant transitional period in reference to both the aortic arches and cranial arteries. The last three "post-branchial" stages (16 to 40 mms.) show the emergence of all the adult arteries, or their permanent adult stems of origin, and the completion of the circle of Willis. Like vascular development elsewhere, that of the head arteries is characterized by a gradual dwindling or elimination of certain vessels, originally prominent, which serve temporary needs, parallel - ed by the elaboration of others.

The primitive internal carotid of the 4-5 mm. stage has two major divisions, a caudal branch which later constitutes the posterior communicating artery after anastomosis with the bilateral neural arteries which precede the basilar artery, and a cranial division, which curves cranioventrally around the base of the optic vesicle. Although this latter division has often been called the "anterior cerebral artery", only a small part of it is represented in the adult vessel. From this primary division of the carotid, several collateral branches arise during later stages; these are, first, the anterior choroidal, secondly the middle cerebral, and finally the major part of the anterior cerebral artery. During the 20 mm. stage, when the anterior cerebral extends up between the cerebral hemispheres, the primitive olfactory artery dwindles and sends an offshoot to the anterior perforating substance as well as to the formation of plexus in the region of the anterior communicating artery. The more constant medial striate (Abbie, 1937), or recurrent artery of Heubner, which arises from the anterior cerebral at the level of the anterior communicating artery, is very conspicuous in the embryo after 20 mm. The posterior communicating artery, which represents the original caudal division of the primitive internal carotid, remains relatively large throughout all the stages in this series. Until the completion of the vertebral artery in the early post-branchial phase (12 to 14 mm.), it is the channel through which the internal carotid supplies all the arteries of the hindbrain. The posterior cerebral artery emerges by means of an elaboration of one of the large diencephalic or mesencephalic branches of the posterior communicating artery, in the stage of 40 mm.

Of the cerebellar arteries, the superior cerebellar artery becomes first identifiable at the 7 to 10 mm. stage. Then the stems for both the inferior cerebellar arteries, anterior and posterior, become recognizable. In embryos between 20 and 40 mm., both arteries are represented by vessels which terminate in the large choroid plexus of the fourth ventricle which these arteries supply via small branches in the adult. Before the 40 mm. stage, these arteries can usually be identified only tentatively as those which are larger and longer than numerous other associated basilar and vertebral branches which arise to supply the hindbrain regions, lying between the 7th and 12th cranial nerve roots massed in this area. Since these transverse branches are so often connected by longitudinal remnants of a prominent lateral channel (the primitive lateral basilo-vertebral anastomosis) paralleling the basilar artery and the cerebral part of the primitive vertebral arrery, the arteries of the embryonic medulla long present a somewhat plexiform appearance. The variable origin in the adult of the anterior and posterior cerebellar arteries, in contrast with the relative constancy of the superior cerebellar artery (Stopford, 1916), is thus readily explained.

The conspicuous temporary artery (which Padget (1948) credits herself for the first description), contributes extensively toward the formation of the bilateral longitudinal neural arteries which join to form the basilar artery, and because of its position has here been named the primitive trigeminal artery. The cranial end of each neural artery is supplied by the trigeminal artery, which, following the involution of the first two aortic arches, is now considered a branch of the primitive internal carotid artery. Development of the diencephalic and mesencephalic regions at this time is accompanied by an extension of the primary caudal division of the internal carotid artery. Not until it has developed a secondary anastomosis with the cranial end of the neural artery, however, does the caudal division of the carotid become the definitive posterior communicating artery. Until this time, the trigeminal branch of the internal carotid is the major source of blood to the longitudinal neural artery of the hindbrain, the caudal connections of which with the transitory hypoglossal artery and the first cervical segmental artery are typically small.

Subsequently, the bilateral neural arteries consolidate to form the basilar artery. Concomitantly or soon thereafter, the posterior communicating artery takes over from trigeminal artery the role of supply to the arteries of the hindbrain during the remainder of the branchial period.

Following the establishment of the posterior communicating artery (an important channel in the embryo in contrast to its subsidiary role in the adult circle of Willis), the trigeminal artery usually dwindles. In certain embryos, however, the primitive trigeminal branch persists for varying periods after formation of the posterior communicating and basilar arteries, producing a prominent carotico-basilar anastomosis. In such cases the posterior communicating artery, in the terminal part connecting it with the basilar artery, was found to be relatively small. The formation of the vertebral arteries relieves the internal carotid of its earlier role of supply to all the arteries in the hindbrain. Interrupted remnants, particularly of the basilar end of the anastomosis, were identified in several embryos up to 40 mm. The occasional persistence of the primitive trigeminal artery in the adult, like that of several other arteries which serve temporary embryonic needs, may result in a significant adult anomaly not infrequently reported in the literature - an anastomotic branch of considerable size between the basilar artery and the intracavernous part of the internal carotid. Fig. 1 is the composite diagram of the arteries around embryonic forebrain, to illustrate differences in terminology employed by various writers (preparation of Padget).

De Vriese (1905) discussing the difference in the relative size of the arteries of the adult and the fetus, stated that, "in the embryo, there is apt to be less relative difference in the size of component arteries than is found in the typical adult's". De Vriese supposes that "the internal carotid artery is primitively divided into two well marked terminal branches, cranial and caudal. The anterior and middle cerebral arteries are derived from the cranial terminal branch. The basilar artery is the primitive continuation of the caudal terminal branch of the internal carotid artery; it is originally doubled and is continued on to the spinal cord with branches from the segmental arteries. During the progress of the development, the basilar artery becomes unpaired, and later- in most mammals - becomes taken over by the vertebral arteries which are secondary formation from the anastomosis of the first segmental arteries. The following anomalies of the posterior communicating arteries were found:

a) The caliber of these vessels may be larger than normal.

b) Variations on the caliber of the right and left arteries.

c) Complete absence of one or both vessels.

d) One or both vessels may be so large that the posterior cerebral artery appears to be a terminal branch of the posterior communicating.

e) The basilar artery may be formed by fusion of the posterior communicating and the divisional branch of the basilar artery (the posterior communicating artery and the divisional branch of the basilar artery are equal in size)."

Fig. 2 is redrawn from the 100 fetal cases of De Vriese (1905) regarding the variations of the posterior communicating arteries and their connection with the basilar artery.

6. Structure of the cerebral arteries:

The morphology of the cerebral blood vessels differs from that of the blood vessels of the visceral organs (see Textbook of Histology by Maximow and Bloom, 1952, or Bailey's Textbook of Histology, 1944, Sheinker, 1951). The intima is separated from the media by a very distinct, elastic membrane which is better developed here than in the blood vessels elsewhere in the body. The media likewise contains a few elastic fibers irregularly scattered and intimately mixed with the circularly-arranged muscle fibers. No external elastic membrane between media and the adventitia is present in cerebral blood vessels. The adventitia consists of loose connective tissue, the nuclei of which are parallel to the axis of the blood vessel. There is a lack of elastic tissue in the poorly developed adventitia.

The elastic tissue of the cerebral vessels is thus segregated into a well developed layer which is relatively rigid, and is surrounded by a smooth muscle layer, probably devoid of elastic tissue. This muscle layer, in turn, is surrounded by a sponge-like perivascular space which, too, is non-rigid. This arrangement is in contrast to the blood vessels in the skeletal muscle, for example, where the elastic tissue is interspersed throughout the blood vessel walls, thus affording comparatively slight shock absorbing quality.

Baker (1937) found that the very small cerebral arteries are composed almost entirely of collagenous tissue. Cortical vessels under 70 mu. and arteries to the basal ganglia measuring about 50 mu. in the diameter have little if any muscular support. He noted that the cerebral arteries differ in structure from similar sized arteries elsewhere, for the media, composed predominantly of collagen fibers, contains less elastic and muscular tissue. Humphreys (1939), using different staining standards, found that the walls of the cerebral arteries are thinner than those elsewhere in the body but have a distinct media of smooth muscle. An outer circular and inner longitudinal coat was recognized on vessels down to 20-25 mu. in diameter.

Forbus (1930) noted that the circular muscular coat of the arteries extends up to the bifurcations, then surrounds each branch vessel. Frequently at the fork of the bifurcation the muscular coat is lacking. Bremer (1943) concluded the muscular layer at the bifurcation appears latest or does not develop because there the opposing walls prevent expansile movement of the vessel. Since the development of the tunica media is predicated by the throbbing of the arterial wall, in the absence of such pulsations, the tunica media does not develop. Tuthill (1933) considered that this defect in the media is due to artefacts produced by the stresses of dehydration and embedding of the vessels for section. She observed in serial sections that the muscular coat was never completely lacking. Bremer (1943), in his study of the embryology of the cerebral blood vessels, noted that with the tremendous differences in the relative growth of various portions of the brain, the angles between some vessels at their divergence might increase from a very acute angle to an obtuse one,as great as 180 degrees in the adult. This suggests that an angle of divergence of a vessel in the embryonic state might actually become the outside of the angle in the adult state.

The essential peculiarities of the histologic structure of the cerebral blood vessels may be summed up as: absence of an external elastic membrane, and presence of a well developed inner elastic layer; minimal development of elastic fibers in the circular layer of the media, associated with a striking lack of longitudinal elastic fibers. Other peculiarities which were not stated in this chapter are: the Virchow-Robin perivascular space and presence of a distinct adventitial layer in the capillaries.

Carmichael (1945) explained the rarity of the cerebral aneurysms in the common presence of medial defect as due to the elastic tissue, which in these vessels is almost wholly concentrated in the internal elastic membrane and offers an effective barrier to ultimate expansion. In fact, Glynn (1940) found such a defect of muscular layer in 80% of both normal and aneurysmal vessels. Walker (1954) stated that the various anomalous types of the circle of Willis must of necessity modify the hemodynamics and cause abnormal stresses in the circle of Willis. Padget (1944) emphasized the frequency of fetal forms and abnormalities of the circle of Willis in the cases of cerebral aneurysms, the variation in the circle of Willis being almost twice as frequent as in the normal brain. There is higher incidence of a closed circle with communications larger than normal. The extensive observations (1437 cases) of Riggs and Rupp (1943) on the anomalies of the circle of Willis associated with cerebral aneurysm point to the significance of such malformations in the production of changes in the intra-vascular dynamics favoring the development of aneurysms. Walker (1954) also pointed out the high incidence of extra cranial congenital abnormalities and intracranial aneurysms, such as polycystic kidneys, coarctation of aorta associated with hypertension etc. Winternitz et al (1948) state that at the junction of a branch with the parent vessel, one finds not only the greatest number of vasa vasorum, but also the majority of atheromata.

7. The abnormalities and variations of the Circle of Willis, basilar and vertebral arteries:

Although it is more convenient to refer to this subject in Chapter V "Discussion" where details may be compared with those of this study, a brief survey of the literature will be made as follows:

The difference in the relative size of the arteries between adult and fetus was commented on by De Vriese (1905): in the fetus as in the embryo, there is apt to be less relative difference in the size of component arteries than is found in the typical adult's. The interpretation for that was already presented earlier in this chapter. De Vriese summarized the anomalies of the posterior communicating arteries as follows:

a) The caliber of these vessels may be larger than normal.

b) Variations in the caliber of the right and left arteries.

c) Complete absence of one or both vessels.

d) One or both vessels may be so large that the posterior cerebral artery appears to be a terminal branch of the posterior communicating artery. The divisional branch of the basilar artery up to the point of union with the posterior communicating artery (most proximal portion of the posterior cerebral) may be so small that it appears to be the posterior communicating artery.

e) The basilar artery may be formed by fusion of the posterior communicating and the divisional branch of the basilar artery (the posterior communicating and the divional branch of the basilar artery are equal in size).

Padget in Dandy's monograph (1944) stated that in the presence of aneurysm of the circle of Willis, in 67% the circle resembled the fetal form while the remaining 33% possessed one or more small or impervious vessels. Fawcett and Blackford (1905-06), in 700 examinations of the circle of Willis, discovered the circle to be complete in 96.1% and incomplete in 3.8%. The incomplete circles were due to absence of a right posterior communicating artery in 1.8% (4.5% in Windle's,1887), absence of the left posterior communicating in 1.4% (Windle, 6.5%) and absence of both posterior communicating in 0.4% (Windle, 1.5%). The anterior communicating artery was absent in one case only. The circle was asymmetric, due to enlargement of the right posterior communicating artery in 12.4% and enlargement of the left in 9.1%. They found it difficult to account for the great difference between their figures and those of Windle, unless it was due either to the fact that Windle's cases were from insane patients, or the greater number of cases in their own series (700 to 200).

Stopford (1916) stated that in 105 adult brains (94.6%) out of 111, there was a complete anastomosis of the circle of Willis. In 6 of the remaining brains, the circle of Willis was incomplete because of the absence of the posterior communicating artery on one or both sides. Blackburn (1907) stated that enlargement of one or both posterior communicating arteries was a common anomaly. In almost every specimen, the enlargement of the posterior communicating arteries coincided with the small trunk of posterior cerebral artery at their point of origin from the basilar or at their proximal portions. Berger (1923) described the transformation of the left posterior communicating artery into a fibrous cord. The right posterior communicating artery was very large. The right posterior cerebral artery seemed to be a continuation of the right posterior communicating artery. Hindze and Fedotowa (1931) described a case of absence of the posterior communicating artery on one side. This vessel on the other side was very large and seemed to be the origin of the posterior cerebral artery. These authors described 7 types of anomalies. (See Page 7).

The anterior half of the circle of Willis is much more dependable than the posterior half as a source of collateral circulation. Critchley (1930), in an investigation of the anterior cerebral and anterior communicating arteries, found that the anomalies in these vessels consisted of asymmetry of caliber of the two anterior cerebrals and that a vessel of one side might supply both hemispheres, sometimes by way of an hypertrophied anterior communicating artery and at other times by means of other communicating vascular channels. Double, triple or even plexiform anterior communicating arteries are not uncommon. In rare cases when the anterior communicating artery is absent there is usually communication through temporary fusion of the two anterior communicating arteries to form a large sinus. Busse (1920-21) examined 400 anterior communicating arteries and found the vessels to be multiple in 227 cases (56.7%) but never absent. Howe (1903) reported a case of absence of communication between the anterior cerebral arteries and,moreover, with both posterior communicating arteries represented by mere threads of tissue. Berry and Anderson (1910) also reported a case in which one vertebral artery did not communicate to form a basilar artery. Wyrubow (1902) stated that anomalies of the anterior cerebral arteries were found in 22.3% of the insane and in criminals. The anterior cerebral artery was apparently within normal limits in over 90% of 553 cases (Adachi-Hasebe,83, quoted from Dandy's,1944; Blackburn 220, De Vriese 50, and Windle 200 cases) and was absent in 2 cases. No statement regarding the size of the anterior cerebrals was made by Fawcett and Blackford (1906) in their 700 cases.

Padget's study (1944) of the adult, from the literature, reveals that "though no statement as to size or length of the anterior communicating artery was made by any author, it was apparently considered normal in 68% of 1803 adult brains (Adachi-Hasebe, 83; Blackburn, 220; Busse, 400; De Vriese, 50; Fawcett and Blackford, 700; Stopford, 150; Windle, 200), while various forms of duplication were described in the remainder." The normal form of this artery is probably best described in Cunningham's "Textbook of Anatomy" as "wide but short". The most common abnormality of the anterior communicating artery is one of the various forms of duplication; 57% of 100 consecutive fetal (De Vriese), and 32% of 1803 adult specimens (Adachi-Hasebe, Blackburn, Busse, De Vriese, Fawcett and Blackford, Stopford, Windle). The absence of the anterior communicating was reported in only three cases out of a total of 1803 cases. Rubinstein (1944), in his series of 100 adult brains, noted that 47 showed branches coming off from the anterior communicating artery. Of these 47, 25 had two branches and 22 had one thin twig. Regarding the posterior communicating artery, Padget (1944) reviewed the literature and stated that the incidence of normal posterior communicating connections in 4 series of adults (1033 cases) was less than 50% (De Vriese, 50; Fetterman and Moran, 200; Adachi-Hasebe, 83; Fawcett and Blackford, 700). The "transitional" and "primitive" types, so named by Saphir (1935), are characteristic of many animals (De Vriese) and also, as Padget herself observed, of the human embryo. Combinations of the transitional and primitive and normal types give a potential collateral circulation greater than the normal, and therefore labelled "large". They occurred in 75% of 100 fetal specimens of De Vriese (1905). In Fetterman and Moran's study (1941), small collateral was most frequent in cases well past middle age;

thread-like posterior communicating arteries in 20% of 200 cases averaging 59 years of age and all over thirty-eight. If the cases of Stopford (1916), Windle (1888), and Blackburn (1907) are added to the 1033 cases above, making a total of 1603, the posterior communicating artery was reported absent on one side in 3%, absent on both sides in 3%, and small (i.e. probably often imperforate) on one or both sides in 12%. The highest incidence of such deficient collateral circulation reported by any one author was 23% in 200 specimens (Fetterman and Moran).

Regarding the posterior cerebral artery, De Vriese, Padget, Shellshear, Williams etc. concluded that the posterior cerebral artery is originally a branch of the internal carotid artery, while in the adult it appears as a branch of the basilar artery. Williams' (1936) conclusion was based on the nerve plexus distribution on the posterior communicating and the posterior cerebral. Stopford (1916) noted that the posterior communicating artery has its greatest importance in intra-uterine life when it forms the proximal portion of the posterior cerebral artery. Saphir (1935), in his classification of the anomalies of the circle of Willis stated that... "One or both posterior communicating arteries may be so large that the posterior cerebral artery appears to be a terminal branch of the posterior communicating. The divisional branch of the basilar artery up to the point of union with the posterior communicating artery (most proximal portion of the posterior cerebral) may be so small that it appears to be the posterior communicating artery... The basilar artery may be formed by the fusion of the posterior communicating and the divisional branch of the basilar artery (the posterior communicating artery and divisional branch of the basilar artery are equal in size)." Regarding the statistical study of the variations of the posterior inferior, anterior inferior, superior cerebellar arteries and vertebral arteries and anterior spinal arteries, these are already referred to in earlier descriptions of this chapter, based mostly on Stopford and Atkinson.

8. Associated congenital anomalies:

The literature cites higher percentages of association of intracranial aneurysms and associated congenital anomalies in other organs, although all the incidences are found on the adult brains, or in a few cases, in early childhood.

Parker's (1926) case no. 2 which had two aneurysms on the circle of Willis, had a congenital atresia of the isthmus of the aorta; the right internal carotid artery was larger than the left. Case Number four had bilateral internal carotid aneurysms, fusiform dilations of the basilar and "other evidence of congenital malformation". Mitchell and Angrist (1943) found one case of association of large, polycystic kidneys and multiple cysts of liver in thirty-six cases of intracranial aneurysms. Forster and Alpers (1943) reported the case of a thirteen week old boy with an aneurysm on the basilar artery associated with bilateral polycystic kidneys. Suter (1949), in his 5,960 autopsies, found twenty-seven congenital, four arterio-sclerotic and one syphilitic aneurysm of the basal cerebral arteries. In the same series were five patients who had polycystic kidneys. Suter estimated that this frequence of association is 100 times the predictable chance coincidence of these lesions in the series. He concluded there is some relationship between congenital cerebral aneurysms and polycystic kidneys.

Sahs (1950) found four cases of associated congenital polycystic kidneys in sixty cases of autopsy-verified intracranial aneurysms. Hypertension was present in each case. Hamby's report (1952) of Buffalo General Hospital's record reveals that three cases had polycystic kidneys in 86 verified intracranial aneurysms.

Ask-Upmark and Ingvar (1949) report nine cases (19%) of malformation of the kidneys were found among 47 autopsies on patients who died of subarachnoid hemorrhage. Eppinger (1888) reports that intracranial aneurysms are commonly associated with coarctation of the aorta. Dandy (1944) reported that his case Number 12, Table C, was diagnosed as intracranial aneurysm because the patient was known to have coarctation of the aorta with long - standing hypertension.

Baker and Shelden (1936) reported the coexistence of cerebral aneurysms and coarctation of the aorta.

Abbott (1928) found that 12% of deaths of patients with coarctation were due to intracranial hemorrhage, 20% died of rupture of heart or aorta, and 30% of cardiac insufficiency.

Walker (1954) postulated that those who have congenital anomalies involving kidneys and heart may develop, with some other precipitating factors such as atherosclerosis or heart diseases (endocarditis, congenital or syphilitic etc.), into aneurysms, saccular, fusiform or mycotic types.

9. Regarding arteriovenous malformation in the region of the pineal gland and congenital aneurysm of the great Vein of Galen:

One cause of arteriovenous aneurysm is the failure in the development of the capillary bed which normally is interposed between the arterial and venous systems. Differing from the traumatic and inflammatory types, the congenital arteriovenous aneurysm has many large anastomosing channels between arterial trees and venous return. It is this characteristic, when found, that identifies it as congenital. Several openings between the artery and the vein are sometimes seen in traumatic and inflammatory communications, but never in such numbers as in the congenital type (Jaeger and Forbus, 1946).

The observation made by Streeter (1918) on the development of the venous system of the brain, and that of Padget (1948) on the arterial system, leads us to see that during the very early stages of the fetal development of the circulatory system of the cranial cavity the vascular apparatus is represented by an irregular system of channels which in no way represents the permanent arteries, veins and capillaries. From the walls of these primordial vessels sprout endothelial buds which connect with the already established channels to form arteries, veins and capillaries which gradually take adult form, long before these vessels have even acquired their fully developed histologic structures.

Jaeger and Forbus (1946) presenting a case of bilateral arteriovenous communications of the posterior and middle cerebral arteries observed from birth to the patient's death, at four and a half years of age, discussed the arteriovenous malformation from the embryological standpoint. Their case was typical of the usual multiple end-on connections between arteries and veins found with congenital arteriovenous aneurysms and, furthermore, adds evidence in support of the commonly held opinion that they are unquestionably congenital, in that in this case they were found bilaterally in the cerebral hemispheres, arising from both halves of the arterial trees of the circle of Willis. They also stated that,"Strange to say, as nearly as could be determined by gross dissection, the abnormal anastomosis were largely on the branches of the posterior cerebral artery and its venous return, although anomalous arterial communications were seen to come off the internal artery at the site of the anterior choroidal artery. In addition to the direct arteriovenous communication through large branches, there was over-development of tiny vascular loops into nests of coiled vessels, which undoubtedly represent anomalous attempts to form a capillary bed between artery and vein. They thought that the whole vascular deformity was due to the lack of resistance of a capillary network between arteries and veins, but as yet there is insufficient evidence on which to base any conclusive hypotheses as to what actually determines the malformation".

French and Peyton (1954), presenting 5 cases of arteriovenous malformations in the region of the pineal gland, all of which were of congenital origin, stated that they are arteriovenous shunts with venous drainage into the great vein of Galen. They also discussed the origin of the malformation of their cases from the embryological aspects as follows; a small anterior cerebral artery arises from the anterior communicating artery. This vessel persists normally in many vertebrates and anomalously in man as a single anterior cerebral artery (median artery of corpus callosum). When it does there is often an associated lack of normal development of the paired anterior cerebral arteries. Arteriovenous abnormalities may arise between terminal branches of the normal anterior cerebral arteries or anomalous median artery of the corpus callosum or middle cerebral artery and venous branches draining into the great vein of Galen...... many of the vessels extending into the mesencephalon and diencephalon anastomose across the midline with their counterparts on the opposite side. Vestiges of these anastomosis between the primitive vascular channels crossing the midline may result in the formation of the arteriovenous aneurysms. Persistent and enlarged communications with the venous outflow via the great vein of Galen may produce malformations comparable to those presented in their reports.

Raskin (1949), presented a case of congenital malformation, arteriovenous angioma racemosum,which was located at the base of the brain in the formation of an inextricable tangle. This angioma was fed by both arteries and veins and was drained by an enormously distended great vein of Galen. It was undoubtedly of congenital origin, its numerous tangled vessels were separated by glial tissue, and its enormous size and extent testified to this.

III. MATERIAL AND METHOD

Thirty-nine infant's brains were obtained from the Pathological Institute, McGill University, during the course of their routine autopsies, in the period from September 1954 to May 1955. Seventeen cases were stillborn; eight cases after nine months gestation, seven cases after eight months gestation, and two cases after seven months gestation. Among those 22 live born cases, fifteen were after nine months gestation, five cases after eight months gestation, one case with seven and a half months gestation, and one case with five and a half months gestation.

Although the brains were obtained at random, the male specimens far exceeded the female (24 to 15).

All the brains were of children belonging to the white race.

Method:

In the earlier course the brain was suspended in ten percent Formalin solution immediately after the removal of the brain and was fixed for more than ten days before separation of blood vessels from other brain substances was made with a blunt instrument in a specially designed sink, under a magnifying glass.

It was, however, soon realized that the separation of the vessels from the brain substances could be accomplished more easily and intactly before the fixation, in the soft, fragile original state. Therefore the following procedures were routinely applied; immediately after the removal of the brain, it was put in the specially designed sink, in which the soft, fragile infant brain parenchyma was easily washed away under constantly running tap-water and with minimal manipulation the relatively hard vessels and pia-arachnoid membrane were left intact, as a rule. After general inspection of the whole vascular system normal, abnormal or anomalies etc., arterial trees were separated from veins and pia-arachnoid under the magnifying glass and dissecting microscope with meticulous care. The specimen was then fixed in the ten percent Formalin solution for ten days. See the photographs showing the process of the trimming of the vessels into the basal area from the general. Photographs 1, 2, and 3. The specimen was then trimmed into the circle of Willis, basilar and vertebral arteries and their branches and twigs. Since photography seldom reveals the detail of a tridimensional structure of varying caliber and configuration, detailed drawings were made under a dissecting microscope. The drawing was generally done on the brain side (dorsal aspect, facing the brain surface) of the specimen, since most of the branches and twigs originate from the brain side and are distributed on and into the brain. The small branches and twigs which originate directly from the main trunk of the circle of Willis and basilar artery were marked as a small hatched circle, on 32 cases out of a total of 39 cases, partially and completely depending on the intactness of the specimen (see the detail in the following chapter). The relative length, position, caliber etc. was carefully considered on the drawing of the specimen.

After the drawing, the specimen was then sectioned randomly, mostly the bifurcations, and middle third of basilar artery and on few cases on the selected places where it showed a somewhat abnormal appearance. The staining was invariably of Verhoff's elastic-fiber staining method.

IV. RESULTS

1. The length of gestation period, age, sex and race (see Graph 1).

Twenty-two liveborn cases:

a) with nine months gestation - 15 cases; ages were 10 minutes, 1 hour, 19 hours, 2 days, 2 days, 3 days, 4 days, 5 days, 1 month, 38 days, 6 weeks, 3 months, 3 months, 18 months, 3 years old.

b) with eight months gestation - 5 cases; ages were 12 hours, 14 hours, 22 hours, 25 1/2 hours, 2 months old.

c) with seven and a half months gestation - one case; age was 19 hours old.

d) with five and a half months gestation - one case; age was 3 days old.

Seventeen stillborn cases:

a) with nine months gestation - 8 cases.

b) with eight months gestation - 7 cases.

c) with seven months gestation - 2 cases.

Sex; male, 24 cases; female, 15 cases.

Race; all white race.

2. Associated congenital anomalies (see Table 1).

Congenital anomalies in general systems other than brain were found in thirteen cases from a total of thirty-nine. This is based on the report of the general pathology department. They are subclassified for C-V (cardiovascular system), G-I (gastrointestinal), G-U (genitourinary), Resp. (respiratory) and Others. Among thirteen cases, two cases revealed the involvement of more than two systems classified above.

TABLE I

Serial No.	C-V	G-U	G-I	Resp.	Others
2	yes				
4			yes		
5					yes
6	yes		yes		
7	yes				
15					yes
22	yes				
29		yes			
30	yes	yes		yes	yes
31		yes			
32	yes				
33	yes				
39	yes				
Total	8	3	2	1	3
%	47.0%	17.6%	11.8%	5.8%	17.6%

The classification of the congenital anomalies found in 13 cases among 39 total cases (33.3%).

Note: "yes" signifies presence of anomalies.

A. Among the anomalies of C-V (cardiovascular) system, the following were found: complete transposition of the aorta and pulmonary arteries with a complete flap valve covering foramen ovale and patent ductus arteriosus, interventricular septal defect, truncus arteriosus, atresia of pulmonary valve, common ventricle, patent foramen ovale, hyperplasia of pulmonary artery, tetralogy of Fallot, dextroposition and overriding of aorta, double right renal artery, arteriovenous malformation with congenital aneurysm of the great vein of Galen, hypertrophy of heart, accessory superior vena cava (oblique vein of Marshall).

B. Among the anomalies of G-U (genitourinary) system, the following were found: polycystic kidneys, hypoplastic kidney, uterus Didelphys and dicoelous with double vagina, double ureter on the right, double pelvis of right kidney,

C. Among the anomalies of G-I (gastrointestinal) system, the following were found: Hirschsprung's disease (short segment, rectosigmoid), congenital anomaly of stomach (postpyloric pouch), congenital anomaly of large intestine (colon fully intraperitoneal).

D. In the Resp. (respiratory) system, the following was found; hypoplasia of lungs (bilateral).

E. Others: congenital defect of diaphragm; diaphragmatic hernia with herniation of stomach, small bowel, ascending and transverse colon, spleen and part of left lobe of liver into left pleural cavity, tracheo-esophageal fistula (absence of atresia; middle third of esophagus to trachea above carina), harelip, cleft palate, microophthalmia.

3. General configuration of the circle of Willis, basilar and vertebral arteries.

Among 33 specimens (6 specimens; Nos. 30,32, 34, 35, 36, 38, out of 39 total were excluded because they were taken only partially for the convenience of the Pathological Institute for their routine serial section examination), 31 cases (93.9%) had complete circles and 2 cases were incomplete. (6.1%)

Among 31 cases with complete circles:

a) thirteen cases (41.9%) had no fenestella in any part of the circle (Nos. 4, 6, 13, 14, 17, 18, 19, 20, 22, 23, 26, 29, 31).

b) eight cases (25.8%) had one fenestella on the anterior communicating artery (Nos. 1, 3, 5, 8, 10, 12, 21, 27).

c) eight cases (25.8%) had two fenestellae; on the anterior communicating artery in 7 cases (Nos. 7, 16, 24, 28, 33, 37 and 39), one case on the anterior communicating and on the junction of basilar and right vertebral arteries

(No. 25).

d) two cases (6.1%) had 3 fenestellae on the anterior communicating artery (Nos 2, 15). Among group a), No. 4 showed the left anterior cerebral artery divided in two main trunks at the level of anterior communicating artery, as if there were three main stems of anterior cerebral arteries, instead of the usual two, although the middle one was the medial artery of corpus callosum. In Case No. 20, the connection of one side of posterior communicating artery and the proximal portion of posterior cerebral artery was thread-like.

Among those 31 complete circle cases, 2 cases (Nos 1, 8) were incomplete from the practical aspect (i.e. probably impervious). Case No. 1 showed right posterior communicating derived from the anterior choroidal artery and its connection with the ipsilateral posterior cerebral artery was tiny, thread-like, plexiform twigs. Case No. 8 showed right anterior cerebral artery and both posterior communicating arteries thread-like.

Of the two incomplete circles (Nos 9, 11), Case No. 9 showed the left posterior cerebral artery derived from the ipsilateral anterior choroidal artery and there was no communication with the basilar artery. The right posterior communicating artery was thread-like.

Case No. 11 showed the right posterior communicating artery had no communication with the basilar artery.

When these two incomplete circles were added to by two practically incomplete circle cases (Nos 1, 8), the proportion went up to 12.9% from 6.1%. See detail of individual circle of Willis in the hand drawings.

<u>4. Caliber of the anterior cerebral arteries - 38 cases:</u>

In thirty-two cases the size of caliber was approximately equal on right and left. The left anterior cerebral was larger than the right in 5 cases, (Nos. 3, 4, 8, 10, 11,). The right anterior cerebral artery was larger than the left in one case, (No. 6). One case, No. 39, showed small calibered, multibranched anterior cerebral arteries bilaterally on the proximal portion before the anterior communicating artery, and therefore was excluded from this series.

<u>5. The total number of branches and twigs originating from the anterior communicating artery in 32 specimens</u> (randomly selected according to the intactness of the artery, and counted and marked under the dissecting microscope).

The counting takes in all the branches and twigs including the median artery of corpus callosum, originating from the anterior communicating artery in the area delineated by lines drawn on the medial wall of the anterior cerebral arteries between pre- and post-anterior communicating arteries.

As Graph Two shows, the number ranged from none to 10. Two to five were the most frequent numbers encountered and the average was 3.9.

SERIAL No.	1	2	3	4	5	6	7	8	9	10	11	12	14	16	17	19	20	21	23	24	25
No. OF BRANCHES & TWIGS	3	10	6	6	4	3	6	3	2	0	2	1	1	7	2	2	2	5	1	3	3

SERIAL No.	26	27	28	30	31	33	34	35	36	38	39
No. OF BRANCHES & TWIGS	5	5	7	3	5	2	9	8	2	5	3

TOTAL = 32 CASES

See detail in Graph 2 and Drawings; general and special (Figs. 3 & 4). In photograph 4 the subbranchings from those branches and twigs originating directly from the anterior communicating artery are quite numerous and give the impression of a larger number of branches. In this study, however, only those branches and twigs originating directly from the anterior communicating artery alone are counted and marked.

6. The number of fenestellae in the anterior communicating artery in 39 cases.

SERIAL No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
No. OF FENEST.	1	3	1	0	1*	0	2	1	1	1	1	1	0	0	3**	2	0

SERIAL No.	18	19	20	21	22	23	24	25	26	27	28	29	30	31
No. OF FENEST.	0	0	0	1	0	0	2	1	0	1	2	0	2	0

SERIAL No.	32	33	34	35	36	37	38	39
No. OF FENEST.	0	2	1	2	0	2	0	2

Thus:

0 fenestella in 16 cases,
1 fenestella in 12 cases,
2 fenestellae in 9 cases,
3 fenestellae in 2 cases,
Total......39 cases.

Note: * In addition, two more fenestellae in anterior cerebrals lateral to anterior communicating artery.

** In addition, two more fenestellae in the anterior cerebrals lateral to the anterior communicating artery.

7. Posterior communicating artery:

a) Relative size of caliber on right and left side in 39 cases:-

Approximately equal in 22 cases.

The right larger than the left in 12 cases.

The left larger than the right in 5 cases.

b) Comparative size with the ipsilateral posterior cerebral artery, of its distal portion from the junction with the posterior communicating artery.

The right posterior communicating artery (37 cases out of 39).

Approximately equal with the posterior cerebral in 17 cases (45.9%).

Posterior cerebral slightly larger than the posterior communicating in 4 cases (1.0%).

Posterior communicating smaller than the posterior cerebral in 15 cases (43.2%).

The left posterior communicating artery (36 cases out of 39).

Approximately equal with posterior cerebral in 14 cases (38.8%).

Posterior cerebral slightly larger than posterior communicating in 2 cases (5.5%).

Posterior communicating smaller than posterior cerebral in 20 cases (55.5%).

c) The origin: except for one case (No. 1) in which the right posterior communicating artery was derived from the anterior choroidal artery, all the rest originated from the internal carotid artery.

d) Subclassification of the posterior communicating artery by the method of De Vriese (1905), Hindze and Fedotowa (1931) and Saphir (1935). This classification was done in consideration of the relative size between posterior communicating artery and posterior cerebral (proximal and distal portion), besides the size of the posterior communicating proper.

i) Primitive type: the size of caliber of the posterior communicating and distal portion of the posterior cerebral arteries is approximately equal, but the posterior communicating is definitely larger than the proximal portion of the posterior cerebral artery. On the right side, 22 cases (56.4%); on the left, 15 cases (38.4%).

ii) Transitory type: the posterior cerebral artery is slightly larger than the posterior communicating, but the proximal portion of the posterior cerebral artery is approximately equal with the posterior communicating artery. On the right side, 11 cases (28.2%); on the left, 11 cases (28.2%).

iii) Recent or adult type: a) posterior communicating is much smaller than posterior cerebral in either its proximal or distal portion. On the right side, 3 cases (7.4%); on the left, 10 cases (25.6%).

b) Posterior communicating is tiny, thread-like. On the right, 3 cases (7.4%); on the left, 3 cases (7.4%). See detail in Graph 3 and Hand-drawings, general and specific (Figs. 5 & 6).

8. Anterior choroidal artery:

a) The relative size of the caliber on the right and left:

Approximately equal on the right and left	in 29 cases
The right larger than the left	in 5 cases
The right slightly larger than the left in	1 case
The right smaller than the left in	4 cases
Total......	39 cases

b) The comparative size with the ipsilateral posterior communicating artery; the right anterior choroidal artery:

Approximately equal with posterior communicating in	2 cases (5.1%).
Anterior choroidal larger than the p. com. in	6 cases (15.3%).
Anterior choroidal smaller than the p. com. in	30 cases (76.9%).
Anterior choroidal slightly smaller than p. com. in	1 case (2.6%).
Total..........	39 cases

The left anterior choroidal artery:

Approximately equal with posterior communicating in	3 cases (7.7%).
Anterior choroidal larger than p. com. in	9 cases (23.0%).
Anterior choroidal smaller than p. com. in	26 cases (66.6%).
Anterior choroidal slightly smaller than p. com. in	1 case (2.6%).
Total..........	39 cases

See detail in Hand-drawings, general and special (Figs. 5 & 6).

9. Posterior cerebral artery:

a) The relative caliber of the proximal portion of the posterior cerebral artery (from the basilar artery to the junction with the posterior communicating artery).

Approximately equal on the right and left in	20 cases (60.6%).
The right larger than the left in	4 cases (12.1 %).
The right smaller than the left in	8 cases (24.2%).
The right slightly smaller than the left in	1 case (3.0%).
Total....	33 cases

b) The comparative size with the ipsilateral posterior communicating artery.

i) The proximal portion (from the basilar to the junction with posterior communicating).

The right side;

p.c. approximately equal with the p. com. in 4 cases (11.4%)

p.c. larger than the p. com. in 14 cases (40.0%)

p.c. slightly larger than the p. com. in 1 case (2.8%)

p.c. smaller than the p. com. in 15 cases (42.8%)

absence of p.c. in the proximal portion in 1 case (2.8%)

Total............................35 cases

The left side;

p.c. approximately equal with the p. com. in 3 cases (8.6%)

p.c. larger than the p. com. in 19 cases (52.4%)

p.c. smaller than the p. com. in 12 cases (34.2%)

absence of proximal portion of p.c. in 1 case (2.8%)

Total..35 cases

ii) The distal portion of the posterior cerebral artery from the junction with the posterior communicating.

The right side;

p.c. approximately equal with p. com. in 19 cases (51.4%)

p.c. larger than the p. com. in 14 cases (37.8%)

p.c. slightly larger than p. com. in 4 cases (10.7%)

Total....37 cases

The left side;

p.c. approximately equal with p. com. in 14 cases (37.8%)

p.c. larger than the p. com. in 21 cases (56.7%)

p.c. slightly larger than the p. com. in 2 cases (5.4%)

Total............................ 37 cases

See detail in Hand-drawings, both for general and special (Figs. 5, 6).

10. Superior cerebellar artery:

a) Origin;

	Right side,	left.
1) From basilar artery on its rostral extreme	30	30
2) From the proximal portion of p.c.	1	2
3) From both basilar and proximal portion of p.c.	3	2
Total	34	34

b) The number of superior cerebellar arteries;

The right side;	The left side;
one.....in 28 cases	one.....in 26 cases
two.....in 6 cases	two.....in 8 cases
34 cases	34 cases

Note:

The number of superior cerebellar arteries was determined not only by gross distribution of the artery over the cerebellum but by its relationship to the course of the trochlear nerve which, according to Padget's observation, emerges from between the first major bifurcation of the superior cerebellar artery.

See the detail in the Hand-drawings, general and special (Figs. 5, 6).

11. Posterior inferior cerebellar artery:

a) Origin;

	Right	Left
1) From the vertebral artery (caudal to the origin of a.s.)	18	18

	Right	Left
2) From the vertebral artery (same level with the origin of a.s.)	1	0
3) From the vertebral artery (rostral to the origin of a.s.)	1	0
4) From the basilar artery (derived from a.i.c.)	0	2
Total.............	20 cases	20 cases

See the detail in Hand-drawings, general and special (Figs. 7 & 8).

12. Vertebral artery:

a) The relative size of caliber of right and left;

Approximately equal on right and left in	21 cases
The right larger than the left in	4 cases
The right smaller than the left in	4 cases
Total.........	29 cases

b) The comparative size with the basilar artery;

i) The right side;

The basilar artery larger than the vertebral in	28 cases
The basilar artery approximately equal with the vertebral artery in	1 case
Total..............	29 cases

ii) The left side;

The basilar artery larger than the vertebral in	27 cases
The basilar approximately equal with the vertebral artery in	2 cases
Total..............	29 cases

See the detail in Hand-drawings, general and special (Figs. 7 & 8).

13. Anterior spinal artery:

The number;

one.....in 12 cases

two.....in 9 cases (at least on its origin)
Total......21 cases

The origin, the mode of fusion and the number of anterior spinal arteries are well demonstrated in the drawings.

See the detail in Hand-drawings, general and special (Figs. 7 & 8).

14. The number of branches and twigs originating from the circle of Willis and basilar artery:

Thirty-two cases were selected randomly for this purpose, out of a total 39 cases. The area was limited to the circle of Willis and basilar artery, and the counting was done partially and completely on the divided area described below, depending on the intactness of the specimen.

The rostral limit was made on the parallel line drawn through the rostral wall of the anterior communicating artery extending laterally to the anterior cerebral arteries. The medial limit was made on the line drawn through the point of the upper medial wall of the posterior communicating artery to the internal carotid artery with a right angle.

The rostral lateral limit was made on the bifurcation of middle and anterior cerebral arteries, delineated from the point of the upper lateral wall of the bifurcation down to the middle cerebral artery with a right angle. The caudal lateral limit was made on the junction of the posterior communicating and posterior cerebral arteries delineated from the point of the lateral wall of the caudal extreme of the junction, down to the posterior cerebral artery with a right angle.

The caudal extreme was drawn from the medial point of junction of two vertebrals with basilar artery to the vertebrals with a right angle. It was again subdivided into R 1, R 2, L 1, L 2, P and B; R 1 for the part of right anterior communicating artery and anterior cerebral, and part of internal carotid artery delineated from the middle of anterior communicating to medial extreme and the rostral-lateral extreme as described above and excluding posterior communicating artery and the rest on the right side. R 2 is for the right posterior communicating artery. L 1 is for the counterpart of R 1 on the left side. L 2 is for the left posterior communicating artery. P is for proximal portion of the posterior cerebral arteries, bilateral, delineated from the rostral extreme of basilar artery line drawn above superior cerebellar artery and caudal-lateral extremes described above. B is for the basilar artery delineated from the rostral extreme of basilar, as above, and caudal extreme of basilar artery described as above.

TABLE II

NUMBER OF BRANCHES AND TWIGS ORIGINATING FROM THE CIRCLE OF WILLIS AND BASILAR ARTERY

SERIAL NO.	LENGTH OF TERM.	AGE	SEX	RIGHT 1	LEFT 1	RIGHT 2	LEFT 2	P	SUB-TOTAL	B	TOTAL
5	8 MONTHS	S.B.	M	19	20	7	6	11	63	29	92
12	9 MONTHS	19 HRS	F	13	12	5	4	7	41	23	64
14	9 MONTHS	S:B:	M.	15	14	4	5	10	48	24	72
16	9 MONTHS	1 ½ YRS	F	15	15	8	3	6	47	22	69
20	8 MONTHS	S.B.	M	17	9	11	5	10	52	22	74
21	9 MONTHS	S.B.	M	18	11	4	2	14	59	19	78
24	8 MONTHS	S.B.	M	20	13	9	7	10	59	17	76
25	9 MONTHS	S.B.	M	22	23	6	9	5	65	23	88
26	8 MONTHS	14 HRS	M	22	19	7	11	9	68	25	93
27	8 MONTHS	S.B.	M	16	22	12	6	8	64	18	82
28	8 MONTHS	S.B.	M	25	21	10	7	15	78	26	104
10	9 MONTHS	3 MOS	F	14	16	7	5	6	48		
23	9 MONTHS	S.B.	F	19	11	9	2	10	51		
11	7 ½ MONTHS	19 HRS	M	14	10	4	3				
36	8 MONTHS	22 HRS	F	10	13	6	5				
38	8 MONTHS	12 HRS	M	15	12	9				25	
39	8 MONTHS	2 MOS	M			7	8			31	
8	8 MONTHS	S.B.	F	15	15					18	
4	9 MONTHS	5 DAYS	M			6	8				
3	5 ½ MONTHS	3 DAYS	M					8			
6	9 MONTHS	3 MOS	M							15	
1	9 MONTHS	S.B.	F					10			
17	9 MONTHS	S.B.	M							24	
19	7 MONTHS	S.B.	M			3	5	7		16	
TOTAL:	24 CASES			17	17	19	18	16		17	

The numbers on each designated area as above were counted, some for a single division, some for whole divisions, depending on the condition of the intactness of the specimen and tabulated on Table II and marked on the Hand-drawings of the specimen. As Table II shows, in 11 specimens the branches and twigs of the circle of Willis and basilar artery were counted completely. The remaining 21 specimens were counted partially of which there were 17 cases for the R 1 area, 19 cases for the R 2 area, 17 cases for the L 1 area, 18 cases for the L 2 area, 16 cases for the P area and 17 cases for the B area.

Those figures were also made in Graphs 4, 5, 6 and 7. The significance of the figures on each division and divisions will be discussed in the next chapter "Discussion".

Note: Although the utmost care was exercised in counting and marking in the drawing the branches and twigs originating from the circle of Willis and basilar artery, it must be admitted that there are probably a few errors as some twigs may have been accidentally pulled out during the preparation. A careful search for any evidence of such pulling errors was made under the dissecting microscope and when any minute holes or cavity-like hollows were found, it was generally counted as "twig present" and included in the drawings.

15. Histological examination:

Eighteen specimens were submitted to histological examination. They were selected at random. The staining was invariably by Verhoff's elastic fiber staining method, and sections were cut serially at 10-15 (mostly 15) micron thickness. The cutting was generally horizontal to its longitudinal axis.

SERIAL No=	THE LOCATION FOR THE SERIAL SECTIONS.	MICRON
1	A) ANTERIOR COMMUNICATING INCLUDING THE NEIGHBOURHOOD OF ANTERIOR CEREBRALS	15
	B) THE JUNCTION OF THE MIDDLE AND ANTERIOR CEREBRALS INCLUDING INTERNAL CAROTID UP TO THE POINT OF THE POSTERIOR COMMUNICATING, LEFT.	15
	C) THE COUNTERPART OF B) ON THE RIGHT SIDE	15
	D) THE UPPER THIRD OF THE BASILAR ARTERY INCLUDING THE PART OF PROXIMAL PORTION OF THE POSTERIOR CEREBRALS.	15
2	A) THE ANTERIOR COMMUNICATING INCLUDING THE NEIGHBOURHOOD OF THE ANTERIOR CEREBRALS.	10
	B) THE JUNCTION OF THE MIDDLE AND ANTERIOR CEREBRALS INCLUDING INTERNAL CAROTID UP TO THE POINT OF THE POSTERIOR COMMUNICATING, RIGHT.	10
	C) THE COUNTERPART OF B) ON THE LEFT SIDE.	10
	D) THE UPPER EXTREME OF THE BASILAR ARTERY INCLUDING THE PROXIMAL PORTION OF THE POSTERIOR CEREBRALS.	10
	E) THE LOWER EXTREME OF THE BASILAR ARTERY INCLUDING THE NEIGHBOURHOOD OF THE VERTEBRALS.	15
3	A) THE ANTERIOR COMMUNICATING INCLUDING ANTERIOR CEREBRALS NEAR BY.	15
	B) THE JUNCTION OF THE MIDDLE AND ANTERIOR CEREBRALS INCLUDING INTERNAL CAROTID NEARBY, ON THE LEFT SIDE.	15
	C) THE COUNTERPART OF B) ON THE RIGHT SIDE.	15
	D) THE UPPER PORTION OF THE BASILAR ARTERY INCLUDINGS POSTERIOR CEREBRALS NEARBY.	15
4	A) THE ANTERIOR COMMUNICATING INCLUDING THE ANTERIOR CEREBRALS NEARBY.	15
	B) THE JUNCTION OF THE MIDDLE AND ANTERIOR CEREBRALS INCLUDING INTERNAL CAROTID NEARBY, ON THE RIGHT SIDE.	15
	C) THE COUNTERPART OF B) ON THE LEFT SIDE.	15
	D) THE UPPER PORTION OF THE BASILAR INCLUDING POSTERIOR CEREBRALS NEARBY.	15
	E) THE LOWER PORTION OF THE BASILAR INCLUDING VERTEBRALS NEARBY.	15

Serial No.		The location for the serial sections	Micron
6.	a)	The anterior communicating and nearby anterior cerebrals.	15
	b)	The bifurcation of middle and anterior cerebrals and nearby internal carotid on the left side.	15
	c)	The counterpart of b) on the right side.	15
	d)	The upper basilar artery and nearby posterior cerebrals.	15
	e)	The lower basilar and nearby vertebrals.	15
7.	a)	The anterior communicating and nearby anterior cerebrals.	15
	b)	The bifurcation of middle and anterior cerebrals and nearby internal carotid, on the left side.	15
	c)	The counterpart of b) on the right side.	15
	d)	The upper basilar and nearby posterior cerebrals.	15
	e)	The middle third of the basilar artery.	15
14.	a)	The anterior communicating and nearby anterior cerebrals.	15
	b)	The bifurcation of middle and anterior cerebrals and nearby internal carotid on the left side.	15
	c)	The counterpart of b) on the right side.	15
	d)	The upper basilar and nearby posterior cerebrals.	15
	e)	The first major bifurcation of the left middle cerebral artery.	15
	f)	The first major bifurcation of the right posterior cerebral.	15
15.	a)	The anterior communicating and nearby anterior cerebrals.	15
	b)	The bifurcation of the middle and anterior cerebrals and nearby internal carotid on the right side.	15
	c)	The counterpart of b) on the left side.	15
	d)	The bifurcation of the posterior communicating and posterior cerebral on the right side.	15
	e)	The counterpart of d) on the left side.	15
	f)	The upper portion of the basilar artery.	15
	g)	The lower portion of the basilar and nearby vertebrals.	15
16.	a)	The anterior communicating and nearby anterior cerebrals.	15
	b)	The bifurcation of the middle and anterior cerebrals and nearby internal carotid on the right side.	15
	c)	The counterpart of b) on the left side.	15
	d)	The upper basilar and nearby posterior cerebrals.	15
	e)	The lower basilar and nearby vertebrals.	15
17.	a)	The anterior communicating and nearby anterior cerebrals.	15
	b)	The bifurcation of the middle and anterior cerebrals and nearby internal carotid on the left side.	15
	c)	The counterpart of b) on the right side.	15
	d)	The upper basilar and nearby posterior cerebrals.	15
	e)	The lower basilar and nearby vertebrals.	15
22.	a)	The anterior communicating and nearby anterior cerebrals.	15
	b)	The bifurcation of the middle and anterior cerebrals and nearby internal carotid on the right side.	15
	c)	The counterpart of b) on the left side.	15
	d)	The upper basilar and nearby posterior cerebrals, and all other neighbouring arteriovenous coils, up to the aneurysms of the great vein of Galen.	15

SERIAL NO.		THE LOCATION FOR THE SERIAL SECTION	MICRON
29.	A)	THE ANTERIOR COMMUNICATING AND NEARBY ANTERIOR CEREBRALS.	15
	B)	THE BIFURCATION OF THE ANTERIOR AND MIDDLE CEREBRALS AND NEARBY INTERNAL CAROTID ON THE LEFT SIDE.	15
	C)	THE FIRST BIFURCATION OF THE LEFT MIDDLE CEREBRAL.	15
	D)	THE UPPER BASILAR.	15
	E)	THE COUNTERPART OF B) ON THE RIGHT SIDE.	15
	F)	THE FIRST MAJOR BIFURCATION OF THE MIDDLE CEREBRAL ON THE RIGHT SIDE.	15
	G)	THE MIDDLE THIRD OF THE BASILAR ARTERY.	15
30.	A)	THE ANTERIOR COMMUNICATING AND NEARBY ANTERIOR CEREBRALS.	15
	B)	THE BIFURCATION OF THE MIDDLE AND ANTERIOR CEREBRALS AND NEARBY INTERNAL CAROTID ON THE LEFT SIDE.	15
	C)	THE COUNTERPART OF THE B) ON THE RIGHT SIDE.	15
	D)	THE CHOROIDAL PLEXUS FROM THE LEFT ANTERIOR CHOROIDAL ARTERY.	15
	E)	THE CHOROIDAL PLEXUS FROM THE RIGHT ANTERIOR CHOROIDAL ARTERY.	15
	F)	THE BRANCHES OF THE ANTERIOR CEREBRAL, ONE EACH ON RIGHT AND LEFT.	15
	G)	THE BRANCHES OF MIDDLE CEREBRAL ON FIRST MAJOR BIFURCATION AND REMOTE BRANCH ON THE LEFT SIDE.	15
	H)	THE COUNTERPART OF G) ON THE RIGHT SIDE.	15
31.	A)	THE ANTERIOR COMMUNICATING AND NEARBY ANTERIOR CEREBRALS.	15
	B)	THE BIFURCATION OF THE MIDDLE AND ANTERIOR CEREBRALS AND NEARBY INTERNAL CAROTID ON THE RIGHT SIDE.	15
	C)	THE COUNTERPART OF B) ON THE LEFT SIDE.	15
	D)	THE UPPER BASILAR AND NEARBY POSTERIOR CEREBRALS.	15
32.	A)	THE ANTERIOR COMMUNICATING AND NEARBY ANTERIOR CEREBRALS.	15
	B)	THE BIFURCATION OF THE MIDDLE AND ANTERIOR CEREBRALS AND NEARBY INTERNAL CAROTID ON THE LEFT SIDE.	15
	C)	THE COUNTERPART OF B) ON THE RIGHT SIDE.	15
34.	A)	THE ANTERIOR COMMUNICATING AND NEARBY ANTERIOR CEREBRALS.	15
	B)	THE BIFURCATION OF THE MIDDLE AND ANTERIOR CEREBRALS AND NEARBY INTERNAL CAROTID ON THE RIGHT SIDE.	15
	C)	THE COUNTERPART OF B) ON THE LEFT SIDE.	15
	D)	THE LOWER BASILAR AND NEARBY VERTEBRALS.	15
35.	A)	THE ANTERIOR COMMUNICATING AND NEARBY ANTERIOR CEREBRALS.	15
	B)	THE BIFURCATION OF THE MIDDLE AND ANTERIOR CEREBRALS AND NEARBY INTERNAL CAROTID ON HE RIGHT SIDE.	15
	C)	THE COUNTERPART OF B) ON THE LEFT SIDE.	15

The histological study was mainly limited to the examination of the defects of certain layers of the artery, such as the tunica media or elastica interna. No statistical study of the microscopic defects was attempted. However, the defect in the tunica media and the reinforcement of the elastica interna at the bifurcation was frequently demonstrated. See photos 5, 6, & 7.

The following findings of other investigators on adult specimens were also confirmed; 1) the absence of an external elastic membrane, 2) the presence of a well developed inner elastic layer, 3) the minimal development of elastic fibers in the circular layer of the media, associated with a striking lack of the longitudinal elastic fibers.

The absence or very poor development of the tunica media at the fork of the bifurcation was frequently found in this series, and also in some cases in the ordinary main trunk. See photos 8, 9, & 10. Even considering the artefacts produced by the stresses of dehydration and embedding of the vessels for section, the very poor development of the muscle coat at the bifurcation, and sometimes on the non-bifurcating trunk, presents a striking picture.

V. DISCUSSION

1. The length of gestation, age, sex and race:

Reviewing the literature regarding similar work of this kind, the study of De Vriese (1905) is the only one which covered only fetuses in any substantial number; 100 human fetal brains (3 months to term). Otherwise, all other works were on adult specimens including only an occasional child's brain (Fetterman and Moran, 37 to 84 years; Dandy, 15 to 70 years; Adachi-Hasebe, 9 to 85 years - quoted from Dandy's monograph, 1944 - ; De Vriese, 50 adult brains, 13 to 89 years). De Vriese's study (1905), however, again differs somewhat from my work. She covered fetuses of the age group 3 months to 9 months, while this study covers mostly infants either at the terminal stage of fetal life or early stage of infant's life (see Graph 1). Although, the brains were obtained over a nine months period, randomly, male brains were almost one and a half times as numerous as those of the female specimens and all the specimens were of the white race.

2. Associated congenital anomalies.

Although the literature cites higher percentages of association between intracranial saccular aneurysms and congenital anomalies in other organs, and although all the incidences are found on the adult brains, or in few cases in early childhood, my limited number of specimens of infants did not disclose any intracranial saccular aneurysms.

Among my 39 cases, 13 cases (33.3%) had congenital anomalies (see Table I). 47% of these anomalies were in the cardiovascular system; most of them involving the heart (see detail in Chapter IV). The anomalies involving the genito-urinary system totalled 17.6% and most of them were related to the kidneys, such as polycystic kidneys, double pelvis of kidney, etc.. The gastro-intestinal system was involved in 11.8% and the rest of 4 cases had various anomalies such as harelip, congenital defect of the diaphragm, thoraco-oesophageal fistula, etc.. Besides the above anomalies, incomplete circles of Willis were counted in 2 cases (4 cases, including 2 cases of probable impervious ones), among 33 completely obtained specimens, making 6.1% (12.9% if 2 cases of 'practically incomplete circles' are included).

Considering the high percentage of associated anomalies other than the brain in this infant series, and the records of previous investigators, Parker ('26), Mitchell & Angrist ('43), Forster & Alpers ('43), Suter ('49), Sahs ('50), Hamby ('52), Ingvar ('49), etc. and no single intracranial berry aneurysms in my series, it may be conjectured that those infants who have such congenital anomalies especially involving kidneys and heart may develop, with some other precipitating factors such as atherosclerosis or heart disease, as postulated by Walker (1954), into so-called congenital saccular aneurysms at a later age. It is also quite conceivable that the anomalies of the circle of Willis may also be one of the precipitating factors in the formation of so-called congenital saccular aneurysms in later life, and in this study, anomalous incomplete circles alone showed 12.9%.

3. The general configuration of the circle of Willis:

In my 33 cases, 31 specimens had complete circles of Willis and 2 cases (No. 9 and 11) were incomplete (6.1%), all involving the posterior half of the circle and another two cases (No. 1 and 8) were practically incomplete (i.e. probably impervious); one of the latter two cases showed a tiny thread-like right anterior cerebral artery and thread-like posterior communicating arteries on both sides, and the other case revealed the right posterior communicating artery derived from the anterior choroidal artery and its connection with the ipsilateral posterior cerebral artery was thread-like. One case (No. 39) which was not included in this category had small calibered, multi-branched anterior cerebral arteries on both sides, associated with anomalous triple anterior communicating arteries. Even among those 31 complete circle series, only 13 cases showed single anterior communicating artery and otherwise, all others had more than double communications (see Graph II).

In one of those complete circles, the connection of one side of the posterior communicating and proximal portion of the posterior cerebral artery was thread-like. Thus, my series of the incomplete circle has a somewhat higher percentage (6.1%) than those of Fawcett and Blackford (3.8%) and Stopford (5.4%). Windle's 12.5% is much higher than my proportion, although his specimens were mostly from insane patients and his series amounted to 200. Regarding the area of incompleteness, the involvement of the posterior half of the circle corresponds with my series and those of Fawcett and Blackford, Windle, Stopford and others.

The anterior cerebral artery was apparently within normal limits in over 90% of 553 cases (Adachi-Hasebe, 83 - quoted from Dandy, '44;- Blackburn, 220; De Vriese, 50; and Windle, 200) and was absent in 2 cases.

The literature, however, does not reveal any statistical data regarding the anterior cerebral arteries and therefore no comparison can be made but my series show 32 specimens approximately equal in size of caliber on the right and left out of 38 totals examined; in 5 cases the left was larger than the right (13.1%) and in one case the right was larger (2.6%).

The fact that the left is larger than the right in a much higher proportion may be due to anatomicohemodyamic factors, since the position of the heart, and the relatively more direct blood flow into the cranium through the carotid artery is on the left side, as a rule.

One of those two incomplete circles of Willis, case No. 9 showed the very large anterior choroidal artery on the left side, the branch of which leads not only into the choroidal fissure (thus following the regular course of the anterior choroidal arterial course) but also far back to the occipital lobe (main trunk) and there was no posterior cerebral artery deriving from the basilar or posterior communicating arteries on that side. In my review of the literature, I could not find in any series this kind of anomaly.

The anomaly in which the posterior communicating artery was derived from the anterior choroidal artery, as was found in case No. 11, was reported in the literature and cited already. The interpretation of this kind of anomaly, according to De Vriese and Padget and others is that it is due to anomalous processes in the embryological stage, although their explanation does not fit for the anomalies cited above; "from the cranial branch of the internal carotid derives middle and anterior cerebral and anterior choroidal arteries and from the caudal branch, posterior communicating artery derives------"; therefore, according to their studies and thinking, it is unlikely that the posterior communicating artery or the posterior cerebral derives from the anterior choroidal artery. However, it is a fact that the anterior choroidal derives, in some cases, from the posterior communicating artery as already cited (Carpenter), and the posterior cerebral from the posterior communicating in a high proportion, especially in the fetus. (De Vriese, Padget etc..).

4. Anterior communicating artery:

Padget's study (1944) in cases of adults from the literature (from Dandy's monograph in 1944) reveals that "though no statement as to size or length of the anterior communicating artery was made by any author, it was apparently considered normal in 68% of 1803 adult. brains (Adachi-Hasebe, 83; Blackburn, 220; Busse, 400; De Vriese, 50; Fawcett and blackford, 700; Stopford, 150; Windle, 200), while various forms of duplication were described in the remainder.

As shown in my drawings, general and special (Fig.3 and 4), there are 27 varieties of anterior communicating artery in 39 specimens; the number, position, shape and size of the fenestellae, number of median arteries of corpus callosum, total number of branches and twigs originating from the anterior communicating, the length, the relationship with the neighbouring anterior cerebrals etc. were considered in the drawings.

These great variations in the anterior communicating artery should be explained from the embryological evolutionary processes as works of De Vriese, Bremer, Padget and others. Busse (1920) examined 400 anterior communicating arteries and found the vessel to be multiple in 227 cases and 39 cases of aneurysms, and displayed 24 hand-drawings of variations of the anterior communicating artery, mainly from the standpoint of the number of fenestellae and gross malformation, omitting any branches or twigs originating from the vessel or other minor details as demonstrated in my drawings.

A number of authors fail to mention any branches as coming from this anterior communicating artery and only one investigator, Rubinstein ('44) so far, has dealt with this subject. Recently published anatomical text-books (Brash, 1952 in Cunningham's textbook; Strong and Elwyn, 1953; Ranson and Clark, 1953; Gray's textbook, 1954) describe the median artery of the corpus callosum as a rather constant branch from the anterior communicating artery but never described a specific number of this artery, or other branches originating from this vessel.

In my 32 specimens out of the total 39, I have painstakingly traced the origin of the branches and twigs and marked them on the drawings as small hatched circles. The number ranged from 0-10, and 2 to 5 were the most frequent numbers encountered. See Graph 2 and Hand-drawings, Figs. 3, 4. This, of course, included the median artery of the corpus callosum which was, in most of the cases, one in number as is shown in the graph and drawings, while in 8 cases there were none. Thus, we see not only multi-anterior communicating arteries, but also the branches and twigs are relatively numerous, compared with Rubin-stein's (1944), of which twenty-five cases had two branches and 22 had one in 100 anterior communicating arteries. The study of De Vriese shows that only mammals and some amphibia have well developed anterior communicating arteries, but fish, amphibians, reptiles and birds have none. The intricacy and physiological delicacy of the metabolism of the human brain and the multiplicity and variety of the anterior communicating artery may have some direct relationship to the development of intracranial aneurysms in this region in later age, as in the form of frequently described congenital berry aneurysms; since no investigators ever before found such a berry aneurysm in the anterior communicating artery or in any other part of the circle in the fetus or in infants.

5. Re posterior communicating artery:

In this series of 39 cases, so called primitive type of posterior communicating artery described by Saphir (1935), Hindze and Fedotowa (1931), De Vriese (1905) was found in 22 cases on the right side and 15 cases on the left (56.4% and 38.4%).

Combining the primitive and transitional types, for comparison with De Vriese's "large" posterior communicating artery which occurred in 75% of 100 fetal specimens, my series showed 84.6% on the right side and 66.6% on the left side. An abnormally small thread-like posterior communicating artery occurred in three cases each on the right and left, making 7.7% which is somewhat lower than Stopford, Blackburn and Windle's series of adult specimens. Although, there were no cases of absent posterior communicating arteries, one posterior communicating derived from the anterior choroidal artery and the other case had no connection,whatsoever, with the ipsilateral posterior cerebral artery (in this case, the posterior cerebral artery was derived from the anterior choroidal artery).

Seventeen variations of the posterior communicating arteries, including the variations of the proximal portion of posterior cerebral arteries were drawn (see Drawings general and special,fig. 5 and6). The size, caliber, origin and relationship with the posterior cerebral arteries was carefully considered in the drawings for the differentiation. When the posterior communicating artery alone is considered, 22 specimens were approximately equal in size on the right and left and in 12 cases, the right was larger than the left, and in 5 cases, the left was larger than the right.

The fact that such a high proportion of large posterior communicating arteries is found in infant stage, as well as in the fetal specimens by De Vriese, and a high proportion of thread-like small posterior communicating in adult life over middle age (Fetterman and Moran, 1941), is presumably due to relatively less physiological significance and, therefore, less growth with age, because the posterior cerebrals become more dependent on the basilar artery for the blood flow, not as in fetal life, when the posterior communicating artery was the main source of blood flow for the posterior cerebral. The above fact may have some contributory factor in the development of the aneurysms in this vessel in adult life.

Again, no mention regarding the number of branches and twigs originating from the posterior communicating artery was found in the literature; in this series, 19 posterior communicating arteries on the right side and 18 specimens on the left were selected at random and carefully counted and marked. (see Table II). The number varied from 2 to 12 on one side and 5 to 7 were the most frequent numbers encountered and the average was 6. As you see in Table II, regarding the overall number of branches and twigs originating from the circle of Willis and basilar artery, the variation of the number in each case is such that the description by Atkins (1909) or Abbie (1937) and others that "each branch of the circle of Willis has a precise area for the distribution" is hardly convincing, although their study was based on the branches which penetrate the perforating substance. Even if Abbie's hypothesis is right, it is certainly not true that the same branch originating from the same side of the stem of the circle supplies the same area.

6. Anterior choroidal artery:

The study of the anterior choroidal artery was limited to its origin, comparative size on the right and left and also size in comparison with the ipsilateral posterior communicating artery. All cases were derived from the internal carotid artery, none from the posterior communicating , and 29 cases among 39 total were approximately equal in caliber on the right and left. Curiously, as in the cases of the posterior communicating arteries, the right side had a higher proportion of larger anterior choroidals than the left(6 to 3).

The reason for its comparison with the ipsilateral posterior communicating artery was to see if either the anterior choroidal or the posterior communicating has any compensatory function, at least in the fetal and infantile stage, as would be the case if one is abnormally smaller than the other in supplying the region of the hypothalamus, optic tracts and the neighbouring area. Eight cases showed the anterior choroidal approximately equal or larger than the posterior communicating among 39 total cases on the right side and on the left side, 12 cases were approximately equal or larger. That is, in over 70% of cases, the posterior communicating arteries were larger than the anterior choroidal arteries in the infant stage, which apparently reverses the proportion in adult life, postulating from the work re the posterior communicating in the fetus and the adult as already discussed above.

7. Posterior cerebral artery:

Shellshear (1920), Padget (1948), De Vriese (1905) concluded that the posterior cerebral artery is originally a branch of the internal carotid artery, while in the adult it appears to be a branch of the basilar artery. Williams' conclusion (1936) was based on the nerve plexus distributing on the posterior communicating and posterior cerebral arteries. Saphir (1935), in his classfication of the anomalies of the circle of Willis stated that, "One of both posterior communicating arteries may be so large that posterior cerebral artery appears to be a terminal branch of the posterior communicating. The divisional branch of the basilar artery up to the point of union with posterior communicating artery (most proximal portion of the posterior cerebral) may be so small that it appears to be the posterior communicating artery...."

In my 35 cases where the arteries could be compared, the proximal portion of the posterior cerebral artery was equal in size to the ipsilateral posterior communicating artery in 4 cases on the right side, and 3 cases on the left side. It was smaller than the posterior communicating artery in 14 cases on the right side (37.1% of total) and 19 cases on the left side (51.4% of total).

These seem rather high percentages, when compared with the adult where the posterior communicating artery is usually smaller than the posterior cerebral artery (Fetterman and Moran). One would therefore conclude that as the brain grows, the proximal portion of the posterior cerebral artery increases in size and carries a greater hemodynamic burden than in early life. The mechanism of this relative increase in size is not clear.

8. Posterior inferior cerebellar, anterior inferior cerebellar, vertebral, superior cerebellar, anterior spinal and basilar arteries:

Of these groups, Stopford's investigation (1916) is most helpful; in his study of 150 adult brains, he found the caliber of the vertebral arteries unequal in 92%, the left being larger in 51% of the cases.

This is a striking variation comparing with my 27.6% unequality of the right and left vertebral arteries, although my cases comprise only 29 and these are exclusively infants or fetuses near term. The number of cases with one vertebral artery larger than the other was divided equally between right and left (4 cases on each side in 29 cases).

The anomalies described in Berry and Anderson (1910), Cavatorti (1907, quoted from Padget, 1944), Stopford and others, such as missing of one vertebral or no basilar but two separate vertebrals for the function of basilar, or fenestellae in the vertebral..., were not observed in this series except for one which had one fenestella in basilar artery on its lower extreme (Case No. 25). Stopford also made a statisical study with diagrams regarding anterior spinal artery from the standpoint of origin, level of fusion or communication and anomalies (see Fig. 9). The normal origin deriving from both vertebral arteries comprised

85% and so-called normal fusion occurred in 63%. In my 21 cases, all anterior spinal arteries were derived from both vertebral arteries and all fused. However, 12 cases out of 21 showed definitely single anterior spinal arteries (57.1%) and in 9 cases, it showed double, at least in its origin from the vertebrals and after the fusion at least for a short distance. Fig. 6 and 7 were prepared to illustrate the variation, number and origin of the anterior spinal arteries as well as vertebrals, posterior and anterior inferior cerebellar arteries, which will be discussed shortly.

Stopford stated that the posterior inferior cerebellar arteries were found to be of equal size in 22% of cases. In the remainder, the larger vessel arose on either side with equal frequency (39%); either (right 15%, left 6%) or both arteries (3%) may be absent. Although, he did not mention where these vessels originate in cases of absence of the vertebrals, Atkinson's study (1949) clearly indicates that the basilar artery is also the origin of the posterior inferior cerebellar artery in some cases, mostly from anterior inferior cerebellar artery (see Fig. 10).

In my 19 specimens, all the posterior inferior cerebellars originated from the vertebrals on the right side, but on the left side 2 specimens showed the artery taking origin from the basilar artery; deriving from the anterior inferior cerebellar artery. It is generally observed and so described in most anatomical text-books that when it originates from the vertebral, it arises caudal to the origin of the anterior spinal artery. However, in this series, one case showed its origin rostral to the anterior spinal artery and the other case from the same level of the anterior spinal artery; this is apparently due to the unusually caudal position of origin of the anterior spinal artery as you see in the drawings(Case No.15 and 16).

Regarding the superior cerebellar artery, Stopford found the vessels equal in size in 33% of the cases and where small or absent were compensated for by enlargement of the other side, and they were frequently double twigs. No mention was made regarding the origin of the artery, apparently assuming all the superior cerebellar arteries originate from the basilar artery on its upper extreme.

In this series, I have observed the origin and number of the superior cerebellar artery; a single artery was observed in 28 cases and double in 6 cases among 34 totals on the right side, and 26 single and 8 double cases on the left side.

Although 30 cases of mine originated from the rostral extreme of the basilar, among the 34 cases on the right and left, the origin from the proximal portion of the posterior cerebral arteries was counted once on the right and twice on the left, and when it was double, one branch each from the basilar and posterior cerebral on its proximal portion (see Drawings;General and Special, fig. 5 and 6).

9. The number of branches and twigs originating from the circle of Willis and basilar artery:

It is strange to say that no study of this subject has ever been done by any investigator for the fetal, infant or adult brain; only main branches,such as superior cerebellar, anterior inferior or posterior inferior cerebellar or median striate artery of Heubner and others,were investigated for the substantial number (Stopford, Atkinson, Abbie and others). Otherwise, the branches were investigated as a group as "antero-median, antero-lateral, postero-median, poster-lateral ganglionic arteries (Abbie, Alexander, Strong and Elwyn and others)". Regarding the branches of anterior communicating artery, only one investigator, Rubinstein, was found, as already quoted previously.

My investigations on this subject were carried out without any injection method because of the following reasons:the smallness and fragility of the specimen causes easy tearing and breaking of tiny branches and twigs by injection, which also may lead to poor visualization of the microscopical study,and most of all, the main object of this study was to see the minute morphology, not the supply area of the arteries and their branches and twigs.

The meticulous counting and marking under dissecting microscope was summarized in Table II and demonstrated in Drawings; small branches and twigs as hatched small circles. As Table II shows , the branches and twigs originating from the circle of Willis and the basilar artery of 11 specimens were counted completely (see individual cases on the drawings) and those of the remaining 21 specimens were counted divisionally as designated in the previous chapter as R-1, R-2, L-1, L-2, P,B, depending on the intactness of the specimen examined.

This covers, therefore, so-called antero-median and postero-median central or ganglionic arterial branches of the circle of Willis by Strong and Elwyn (1953).

Since every millimeter in the brain stem, hypothalamus and its vicinity contains many important and vital structures, such an abundant blood supply judged by the number of branches and twigs, is not surprising. However, great variation in the number and origin of branches and twigs originating from each separate division of the circle of Willis does not support the idea that each branch has the precise area of supply as advocated by Abbie, Aitken, Shellshear and others.

The number of branches and twigs from anterior cerebral and anterior communicating arteries roughly corresponds to the number of anterior perforating spots which was counted as 18 to 20 by Shellshear.

The discrepancy should be accounted for either by subdivision of branches after leaving the stem of the circle of Willis or by twigs which may supply the surface of the base of the brain.

The relatively small number of branches and twigs originating from the posterior communicating artery, although more than 70% (84.6% on the right and 66.6% on the left) of the specimens show 'large' (primitive and transitory types), indicate its relatively poor blood flow with age.

The number of branches and twigs originating from the proximal portion of the posterior cerebrals and basilar arteryes is relatively very abundant and less variable in number, as you see in Table II. It probably signifies the great importance of their supply area, namely midbrain and pons.

It is also noteworthy that the branches and twigs on anterior communicating and its immediate vicinty, the bifurcation area of anterior cerebral and middle cerebral arteries, the bifurcation area of the internal carotid and posterior communicating, and the proximal portion of the posterior cerebral and the basilar area are most densely located and those places above are one of those favorite spots for the development of berry aneurysms in adult life, as reported so often in the literature.

10. Histology:

The histological investigation, for this time, was limited to a study of the defect of certain layers of the artery and no statistical study of the microscopical defects of the specimen was attempted; however, the defect of the tunica media and the reinforcement of the elastica interna at the bifurcation were very frequently demonstrated, as already investigated and demonstrated by Forbus (1930), Bremer (1943), Tuthill (1933), Glynn (1940) and others. The defect of the tunica media was not only found at the bifurcation, but also, at random, selected parts of the main trunk of the circle and basilar artery which was also demonstrated by the above investigators.

Carmichael (1945) stated that "if the mere existence of a minute developmental gap in the muscular coat of an artery were enough to determine the formation of an aneurysm, almost every circle of Willis would bear a generous crop of tiny aneurysmal sacs and most of us would die from meningeal hemorrage in childhood or early youth. But while media defects are extremely common, cerebral aneurysms are relatively rare, presumably because the elastic membrane offers an effective barrier to unlimited expansion", the significance of those microscopical defects demonstrated in my study may have little value. However, it certainly proved that even in the early infantile stage as well as in the fetal stage (its terminal period) such defects have already been demonstrated, a fact I cannot refer to any investigator, because no microscopic study of cerebral blood vessels for this age group has ever been done before.

VI. SUMMARY AND CONCLUSION

Thirty-nine infants' brains were studied for the basal vessels, mostly for the circle of Willis, basilar and vertebral arteries and their branches and twigs. The examinations were directed for the morphological (both micro- and macroscopical) and the statistical aspects; the variation of the size, origin, comparative size on one divisional stem to the other, the number of branches and twigs originating from the above mentioned vessels, totally and divisionally, and microscopic study for the characteristic features of the intracranial arteries.

The extensive review of the literature concerned above was made.

Among thirty-nine cases investigated for the associated congenital anomalies, thirteen cases had anomalies. Those involving the cardiovascular system were 47%; the genitourinary system, 17.6%; gastrointestinal system, 11.8%; and miscellaneous involvement, 23.6%.

Among thirty-three specimens examined for their general contour, two cases were found with an incomplete circle, both involving the posterior half of the circle.

For the investigation of the fenestellae in the thirty-nine anterior communicating arteries, it was found that there was no fenestella in sixteen cases, one in twelve cases, two in nine cases, and three in two cases. Thirty-two anterior communicating arteries were examined for the numerical study of the branches and twigs originating from them; the number ranged from none to ten, with two to five the most frequent numbers encountered and the average was 3.9.

The size of the anterior cerebral arteries was examined in thirty-eight cases and found about equal in size on the right and left in thirty-two cases. In five cases the left was larger than the right side. In one case the right side was larger than the left.

For thirty-nine examined posterior communicating arteries, the primitive type was found in twenty-two cases on the right (56.4%), and fifteen cases on the left (38.4%). For the transitory type, eleven cases on the right (28.2%), and eleven cases on the left (28.2%) and for the recent (or adult) type, six cases on the right (14.8%), and thirteen cases on the left (33.0%). Besides the origin, comparative size between right and left, and comparative size between posterior cerebral (proximal and distal) and posterior communicating were made.

Among thirty-nine investigated anterior choroidal arteries, twenty-nine were found about equal in size on right and left and in six cases, the right was larger and in four cases, the left was larger. When this artery was compared with the posterior communicating, thirty cases were found smaller than the posterior communicating (76.9%) on the right and twenty-six cases on the left (66.6%).

For the posterior cerebral artery the proximal and distal portions were separately studied; for the thirt-three proximal portions examined, twenty cases were found about equal in size on right and left (60.6%), and in four cases the right was larger than the left (12.1%), and in nine cases, the left was larger (27.2%). When the posterior cerebral arteries (proximal portion) were compared with posterior communicating arteries, it was found about equal in four cases (11.4%), posterior cerebral larger in fifteen cases (42.8%), posterior cerebral smaller in fifteen cases (42.8%), on the right side. On the left side, about equal in three cases (8.6%), posterior cerebral larger in nineteen cases (52.4%), posterior cerebral smaller in twelve cases (34.2%). The distal portions from the junction with posterior communicating were also compared with the posterior communicating arteries and percentaged.

For the superior cerebellar artery, the origin and the number were studied, and the number was found one in twenty-eight cases and two in six cases on the right side, and for the left side one in 26 cases, two in 8 cases (total of 34 cases).

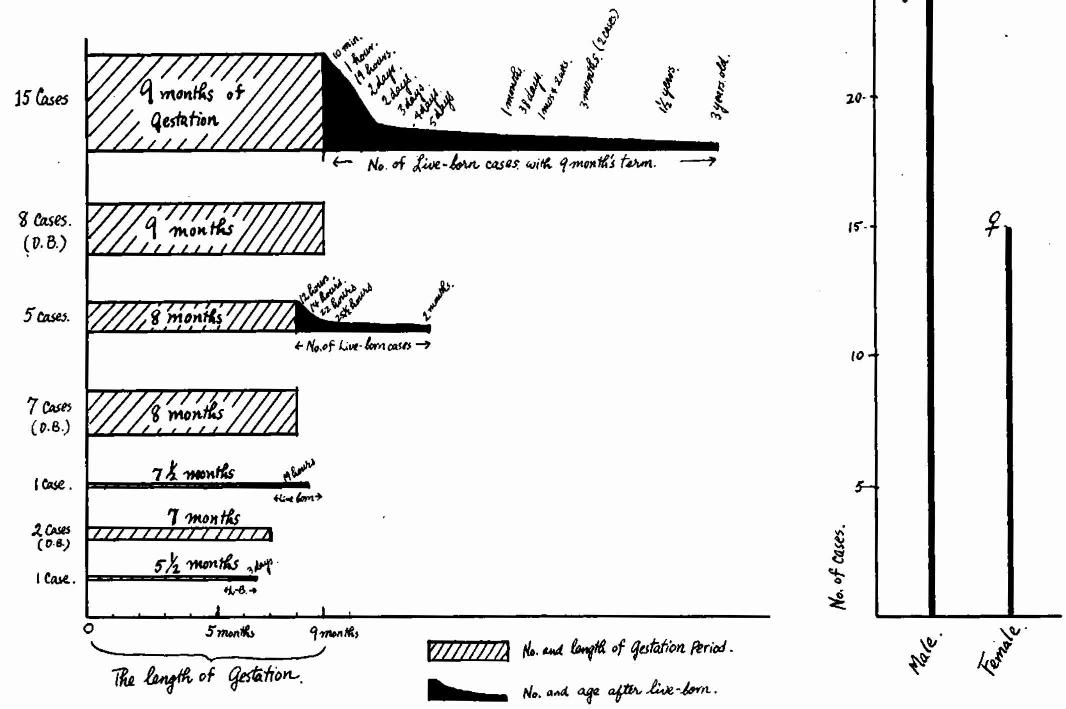
Among twenty examined posterior inferior cerebellar arteries, twenty cases originated from the vertebral artery on the right side. For the left side 18 originated from the vertebrals and 2 from the basilar artery via anterior inferior cerebellar.

Among 21 examined anterior spinal arteries, the number was found one in twelve cases and two in nine cases.

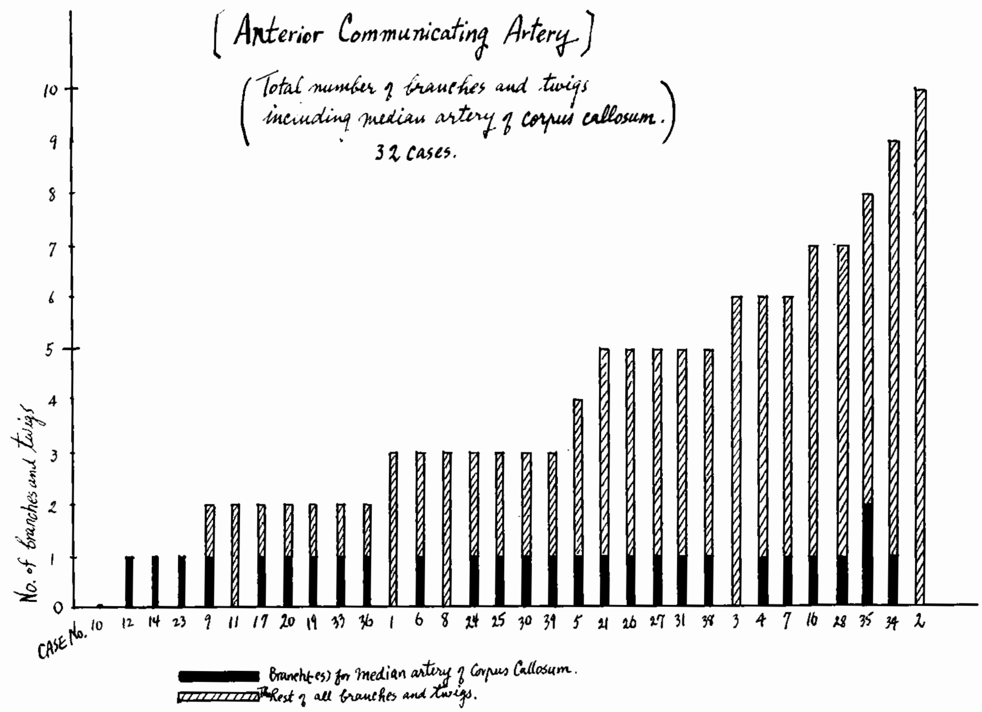
For the vertebral artery , twenty-one cases in twenty-nine examined were found about equal on the right and left, and in 4 cases the right was larger, and in the other 4 cases the left was larger. The comparison with the basilar artery was also made.

For the numerical study of the branches and twigs, eleven specimens of the branches and twigs originating directly from the circle of Willis, and basilar artery were counted and marked completely. Thirteen cases of the circle of Willis, and the remaining 13 were studied divisionally as outlined in Chapter IV, and charted in Table II. The grouping of the relatively large number of twigs and small branches was noted in the area of bifurcation. The relatively great number of branches and twigs were also observed in the basilar artery and proximal portion of the posterior cerebral artery. It was also noted that there was a relatively small number on the posterior communicating artery.

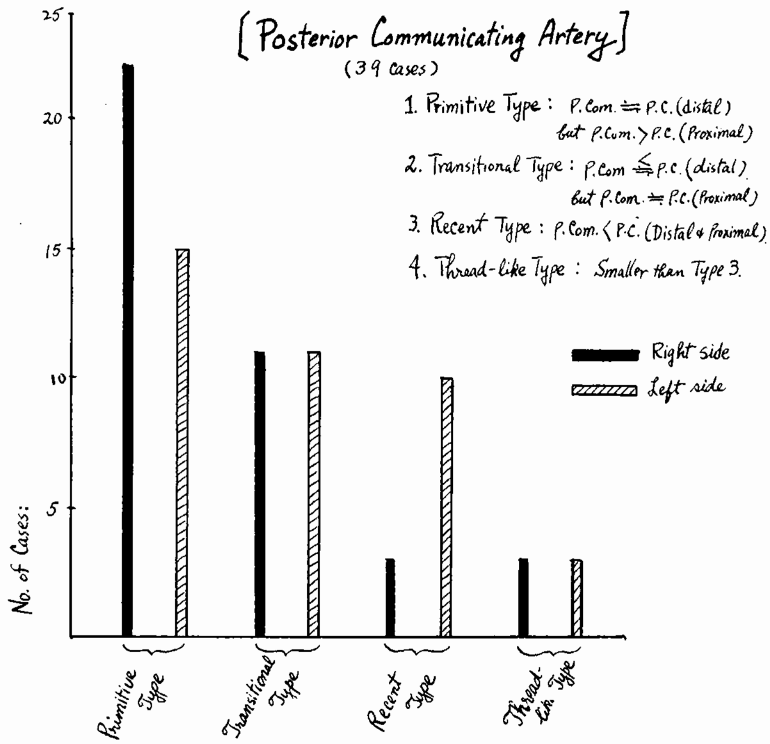
[The Length of Term, Age and Sex Distribution.]



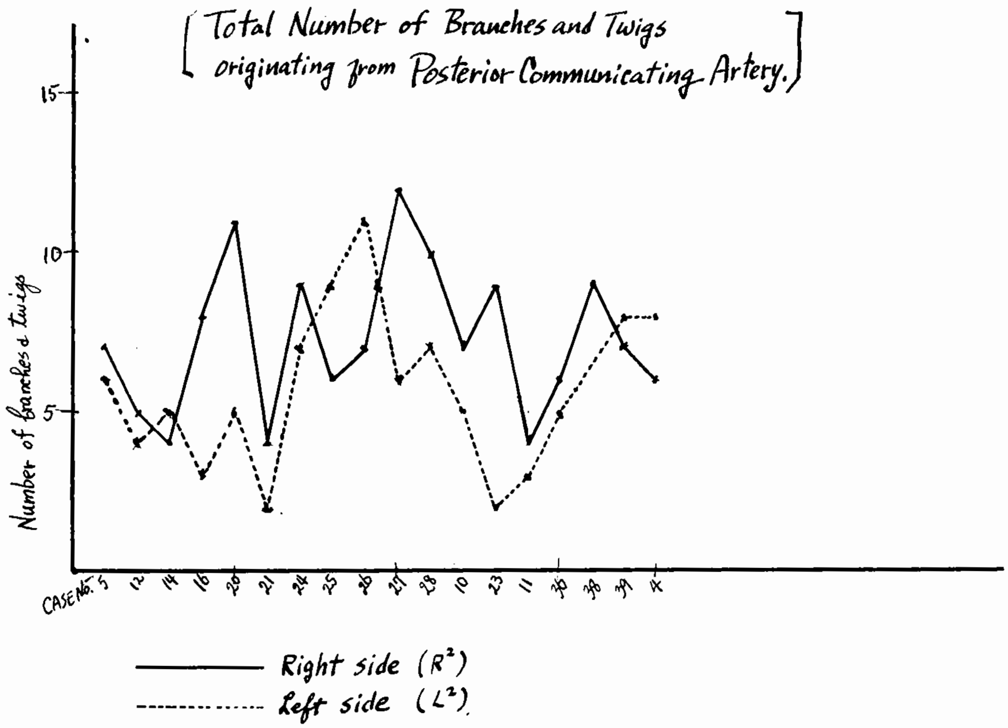
[GRAPH 1]


[Anterior Communicating Artery]
(Total number of branches and twigs including median artery of corpus callosum.)
32 cases.
No. of branches and twigs
CASE No.
10 12 14 23 9 11 17 20 19 33 36 1 6 8 24 25 30 39 5 21 26 27 31 38 3 4 7 16 28 35 34 2
Branch(es) for median artery of Corpus Callosum.
The Rest of all branches and twigs.

[GRAPH 2]


[Posterior Communicating Artery]
(39 cases)
1. Primitive Type : P.Com. ≒ P.C. (distal)
but P.Com. > P.C. (Proximal)
2. Transitional Type : P.Com ≦ P.C. (distal)
but P.Com. ≒ P.C. (Proximal)
3. Recent Type : P.Com. < P.C. (Distal & Proximal)
4. Thread-like Type : Smaller than Type 3.
Right side
Left side
No. of Cases:
25
20
15
10
5
Primitive Type
Transitional Type
Recent Type
Thread-like Type

[GRAPH 3]

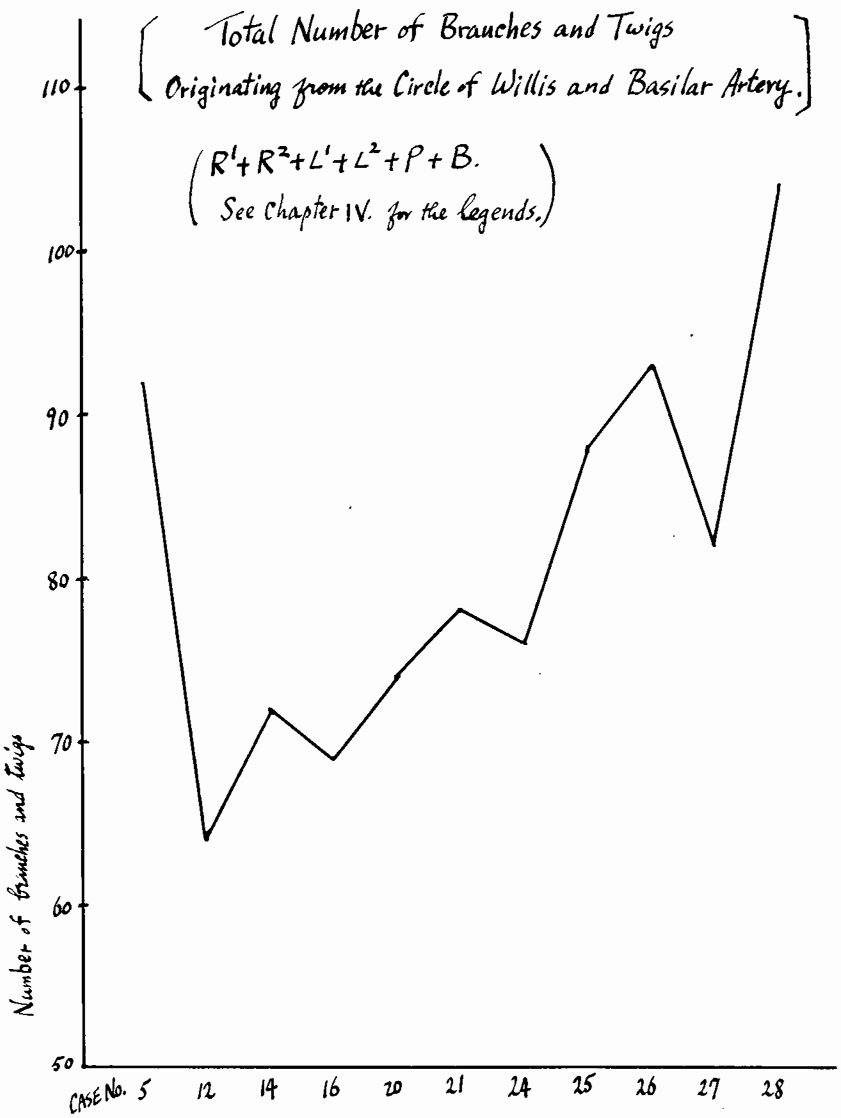


Total Number of Branches and Twigs originating from Posterior Communicating Artery.
15
10
5
Number of Branches & twigs
CASE No. 5
12
14
16
20
21
24
25
26
27
28
10
23
11
30
38
39
4
Right side (R^2)
Left side (L^2)

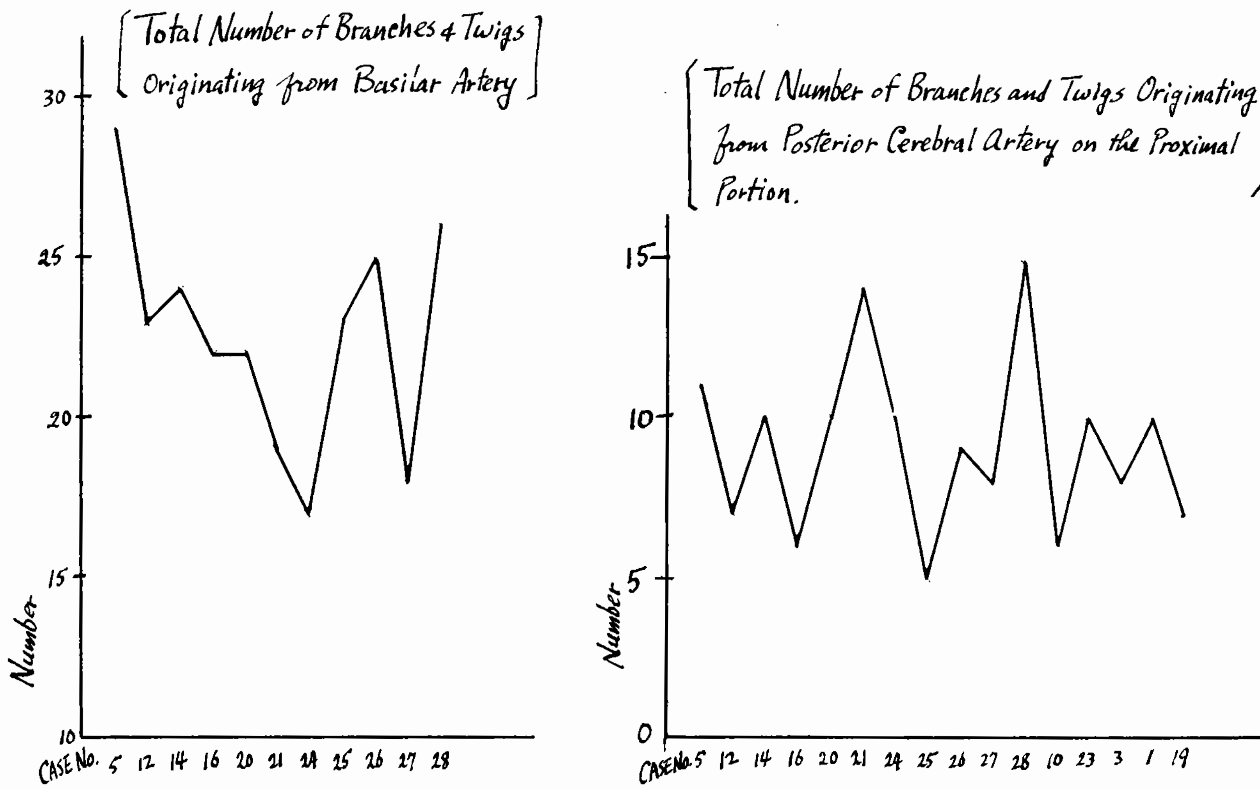
(GRAPH 4)


[Total Number of Branches and Twigs Originating from the Circle of Willis.]
(R' + R² + L' + L² + P.)
(See Chapter IV. for the Legends)
80
70
60
50
40
30
Number.
CASE No.
5
12
14
16
20
21
24
25
26
27
28
10
23

[GRAPH 5]


Total Number of Branches and Twigs
Originating from the Circle of Willis and Basilar Artery.
($R^1 + R^2 + L^1 + L^2 + P + B$.
See Chapter IV. for the legends.)
Number of Branches and Twigs
110
100
90
80
70
60
50
CASE No. 5
12
14
16
20
21
24
25
26
27
28

[GRAPH 6]


[Total Number of Branches & Twigs Originating from Basilar Artery]
30
25
20
15
10
Number
CASE No. 5 12 14 16 20 21 24 25 26 27 28
[Total Number of Branches and Twigs Originating from Posterior Cerebral Artery on the Proximal Portion.]
15
10
5
0
Number
CASE No. 5 12 14 16 20 21 24 25 26 27 28 10 23 3 1 19

[GRAPH 7]

Photo 1.

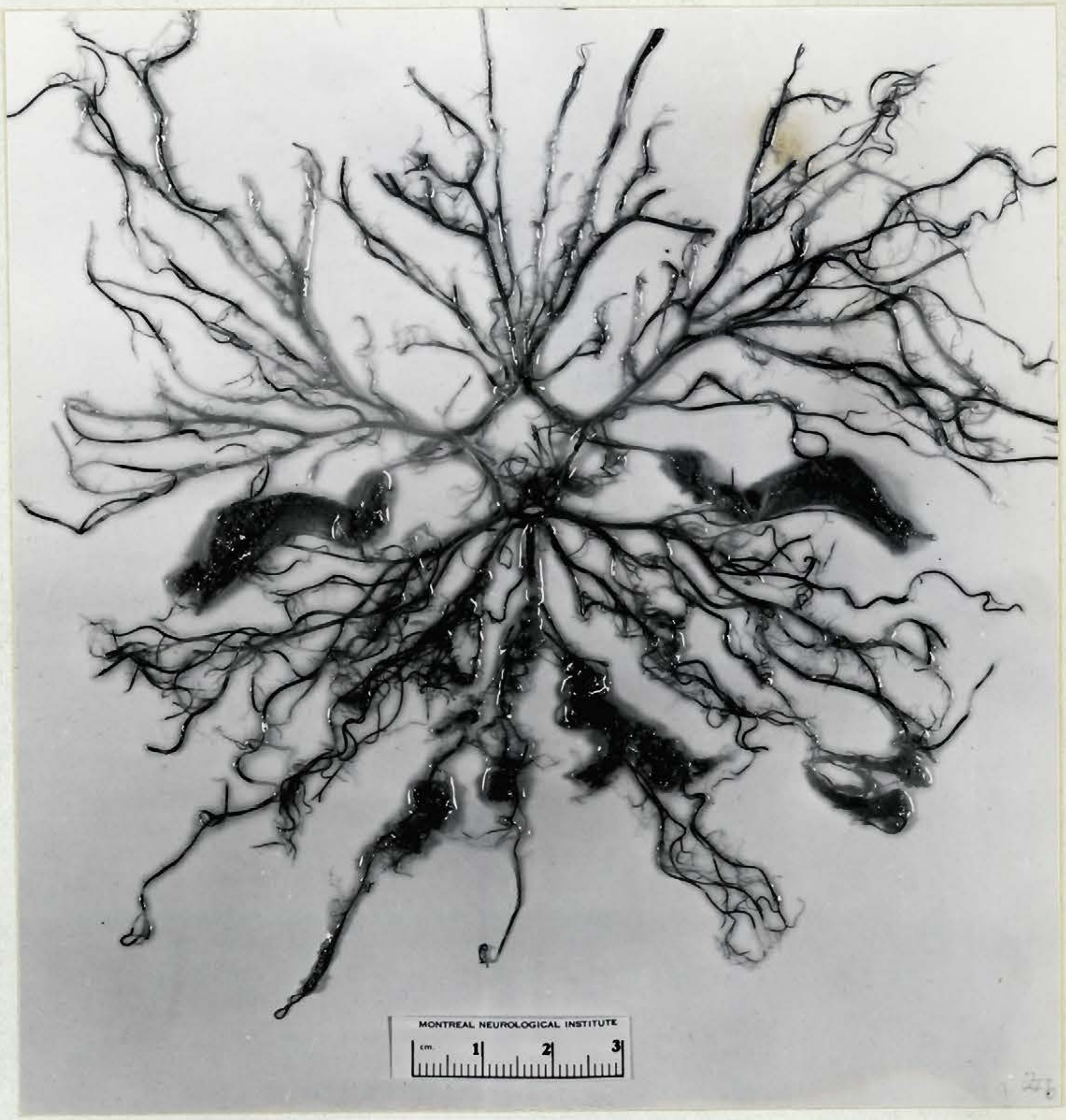


Photo 2.

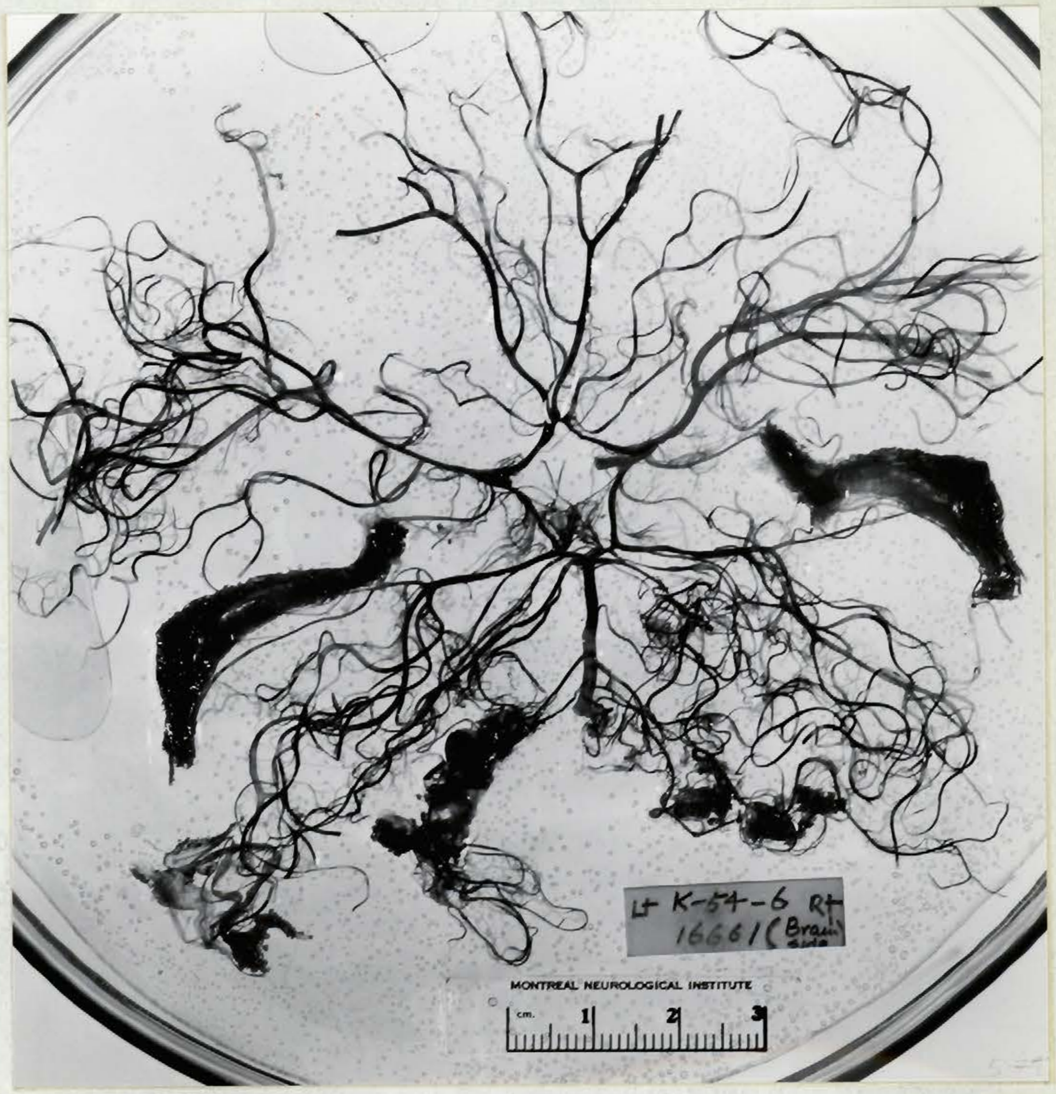

Lt K-54-6 Rt
16661 (Brain side)
MONTREAL NEUROLOGICAL INSTITUTE
cm. 1 2 3

Photo 3.

Photo 4.

Photo. 4. Anterior communicating artery of Case Number 35 (brain side) 13.5X

Photo 5.

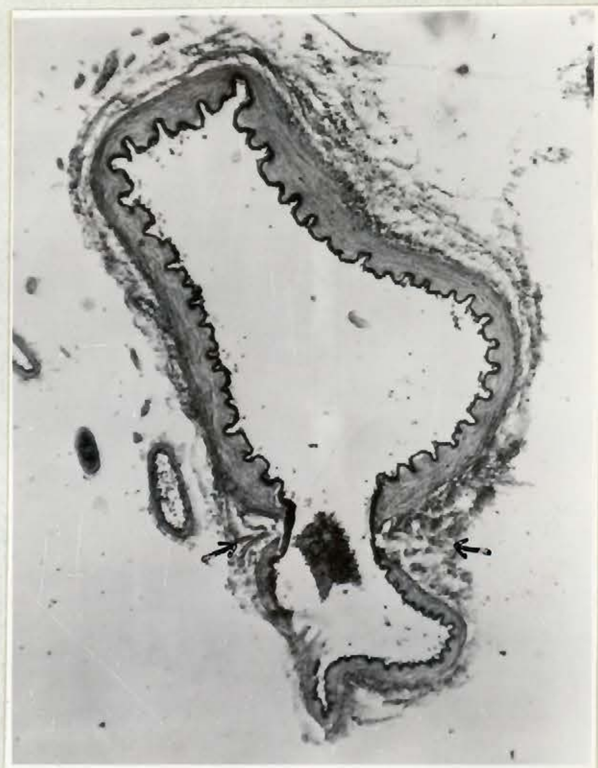


Photo 6.

Photo 7.

Photo. 5. At anterior communicating artery (from Case Number 7) 79X Verhoff's staining

Photo. 6. At the bifurcation of anterior communicating and anterior cerebral arteries (from Case Number 31) 76X Verhoff's staining

Photo. 7. At anterior communicating artery (Case Number 34) 79X Verhoff's staining

Note marked defect (or absence) of tunica media and reinforcement of elastica interna at the bifurcation.

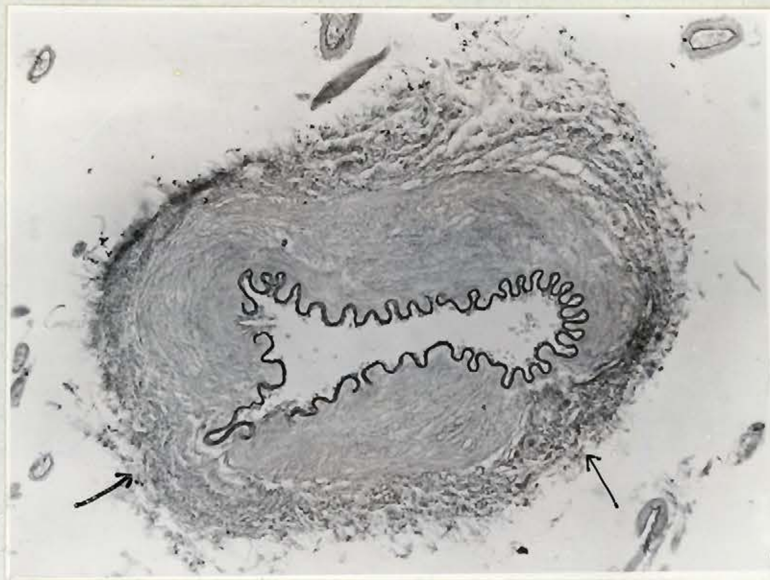
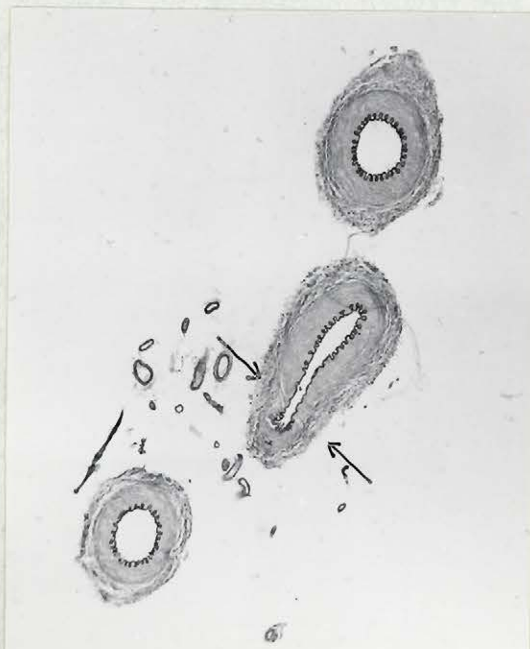


Photo 8.



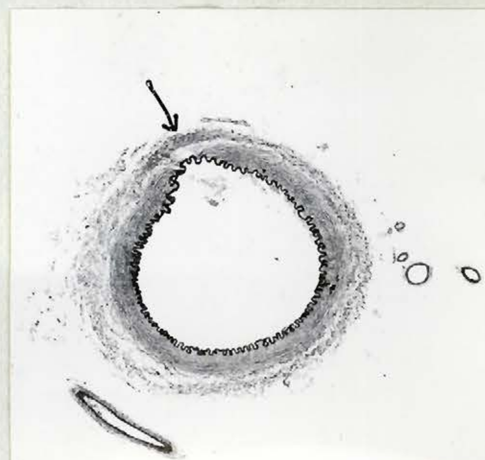


Photo 10.

Photo 9.

Photo. 8. Anterior cerebral artery (from Case Number 30) 110X Verhoff's staining

Photo. 9. Anterior cerebral arteries distal from anterior communicating arteries (Case Number 30) 35X Verhoff's staining

Photo. 10. Internal carotid artery before the bifurcation of the middle and anterior cerebral arteries (Case Number 2) 35X Verhoff's staining

Note the defect of tunica media in main trunk of the circle of Willis.

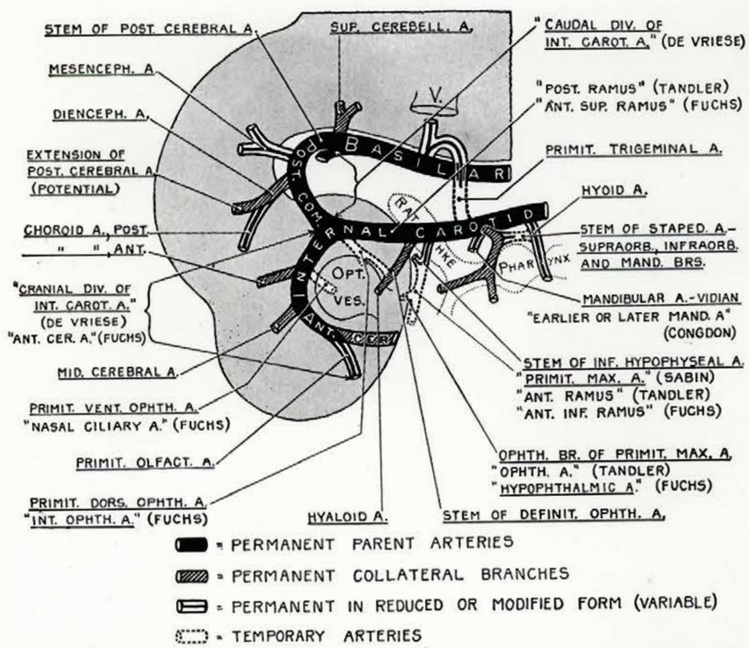
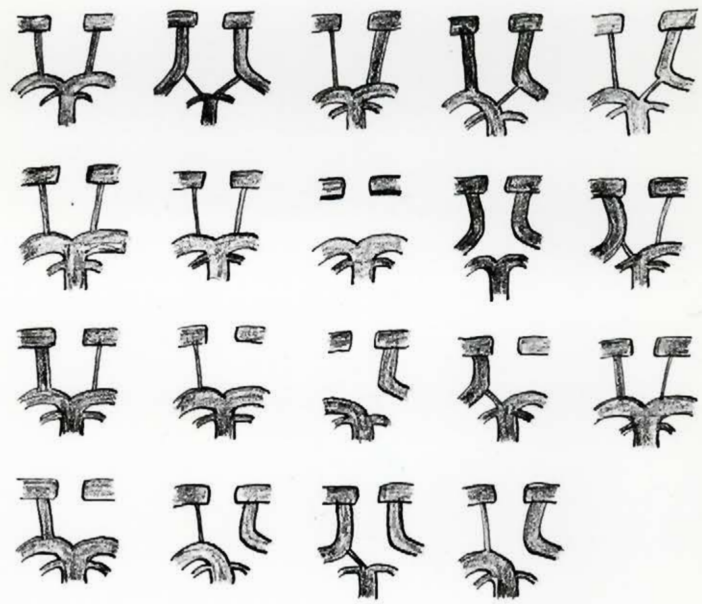


FIG. 12. Composite diagram of the arteries around the embryonic forebrain to illustrate differences in terminology employed by various writers. Their names are in parentheses, their designations are in quotation marks, and those adopted or orginated for this study are underlined. This variation in terminology must be noted in reference to any correlation of the development of the human stapedial and ophthalmic arteries with that described for other species.

Fig. 1.

Fig. 1. from Padget (1948)



19 Variations of the posterior Communicating arteries and their connections with the Basilar artery. (Drawn from the 100 foetal cases of De Vriese)
Age 3 mos – Term (Average age = 9 mos). white

The duplicated types of anterior communicating artery predominantly observed in the 100 foetal cases of De Vriese.

Fig. 2.

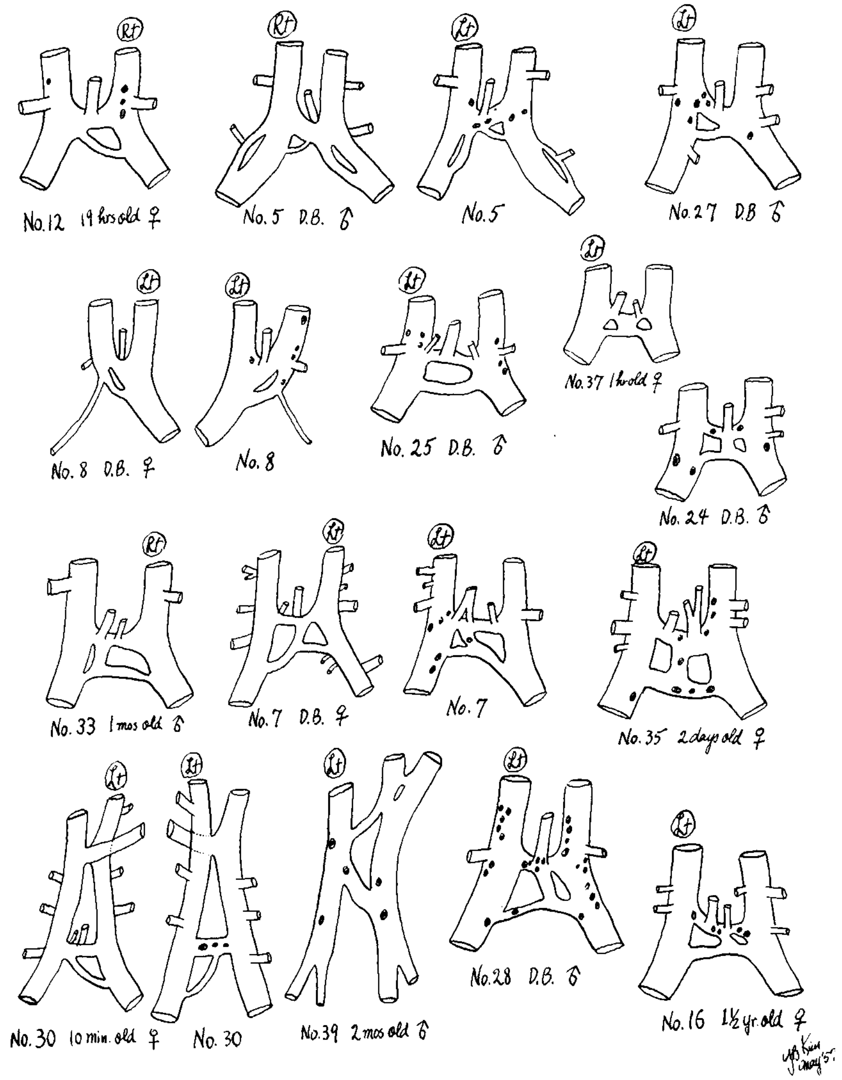

Rt
No.12 19 hrs old ♀
Rt
No. 5 D.B. ♂
Lt
No. 5
Lt
No. 27 D.B ♂
Lt
No. 8 D.B. ♀
Lt
No. 8
Lt
No. 25 D.B. ♂
Lt
No. 37 1 hr old ♀
No. 24 D.B. ♂
Rt
No. 33 1 mos old ♂
Lt
No. 7 D.B. ♀
Lt
No. 7
Lt
No. 35 2 days old ♀
Lt
No. 30 10 min. old ♀
Lt
No. 30
Lt
No. 39 2 mos old ♂
Lt
No. 28 D.B. ♂
Lt
No. 16 1½ yr. old ♀

Fig. 3.

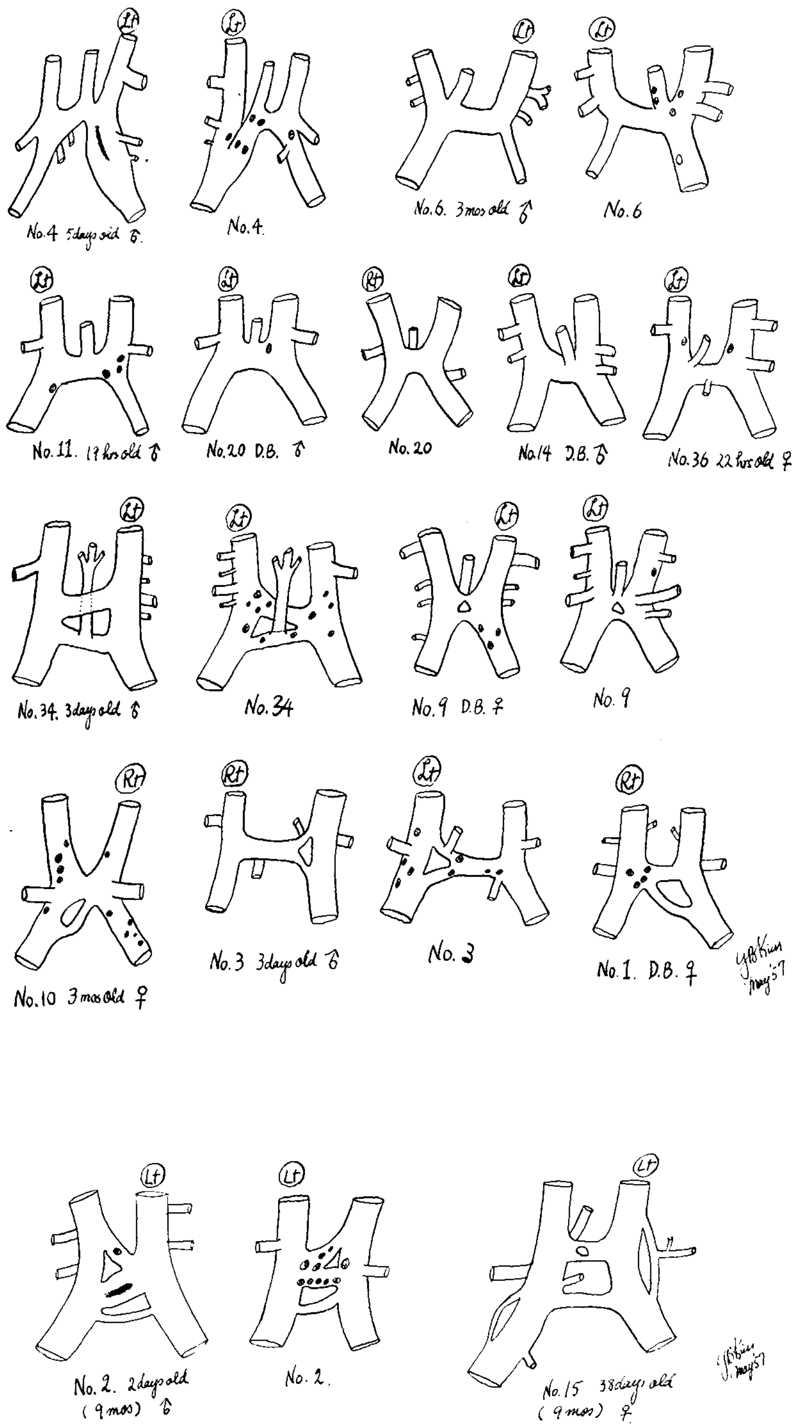

No.4 5days old ♂
No.4.
No.6. 3mos old ♂
No.6
No.11. 17hrs old ♂
No.20 D.B. ♂
No.20
No.14 D.B. ♂
No.36 22hrs old ♀
No.34. 3days old ♂
No.34
No.9 D.B. ♀
No.9
No.10 3mos old ♀
No.3 3days old ♂
No.3
No.1. D.B. ♀
No.2. 2days old
(9mos) ♂
No.2.
No.15 38days old
(9mos) ♀

Fig. 4.

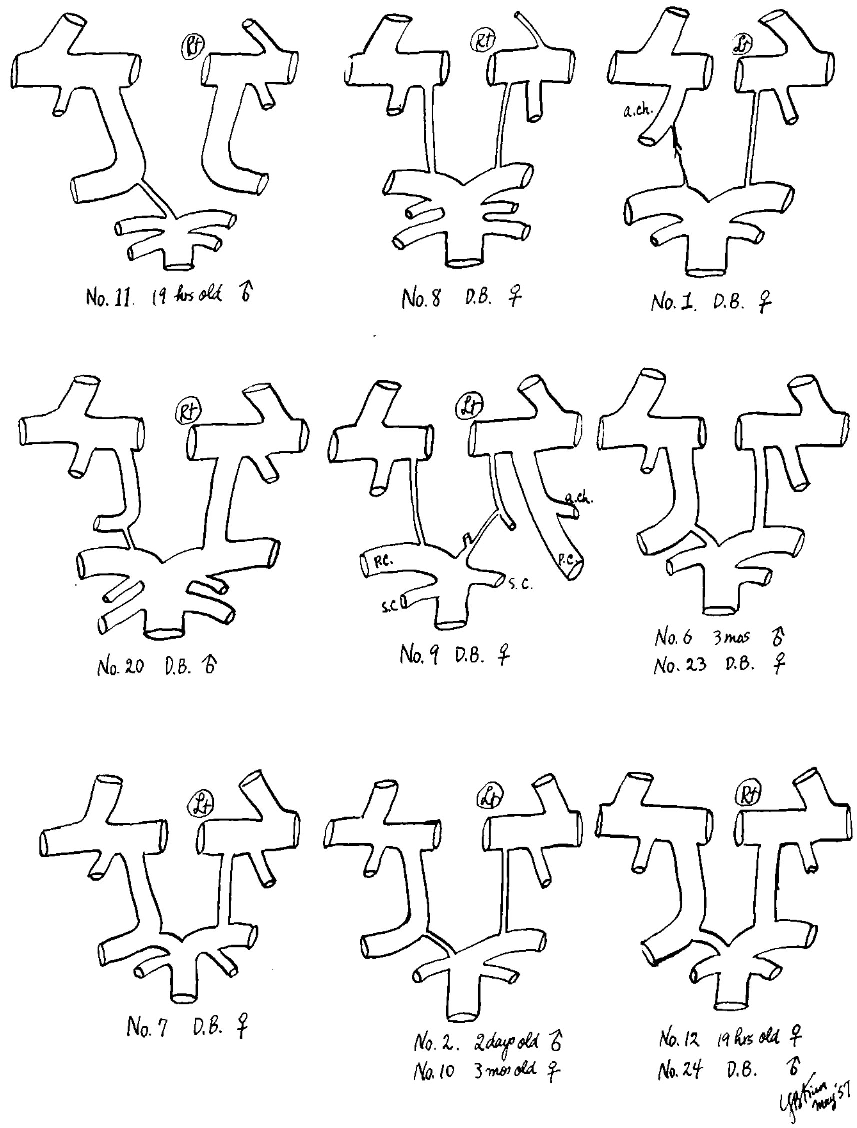

Rt
a.ch.
Lt
No. 11. 19 hrs old ♂
No. 8 D.B. ♀
No. 1. D.B. ♀
P.C.
S.C.
No. 20 D.B. ♂
No. 9 D.B. ♀
No. 6 3 mos ♂
No. 23 D.B. ♀
No. 7 D.B. ♀
No. 2. 2 days old ♂
No. 10 3 mos old ♀
No. 12 19 hrs old ♀
No. 24 D.B. ♂

Fig. 5.

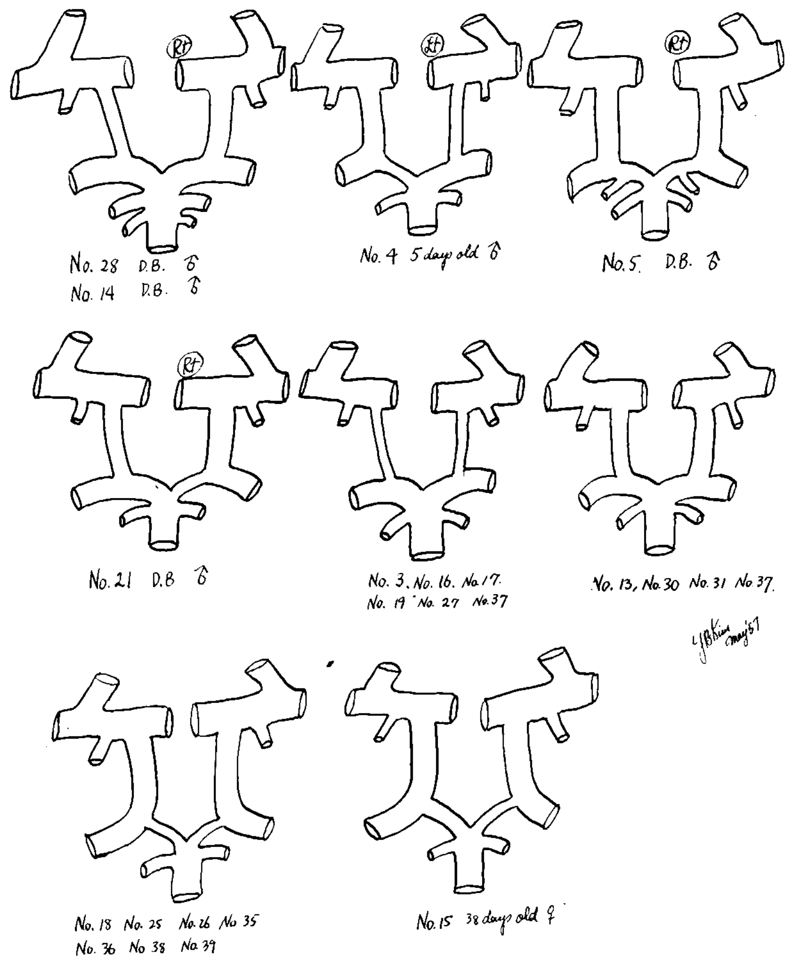

Rt
Lt
Rt
No. 28 D.B. ♂
No. 14 D.B. ♂
No. 4 5 days old ♂
No. 5. D.B. ♂
Rt
No. 21 D.B ♂
No. 3. No. 16. No. 17.
No. 19 No. 27 No. 37
No. 13, No. 30 No. 31 No. 37.
YBKim May '57
No. 18 No. 25 No. 26 No 35
No. 36 No 38 No 39
No. 15 38 days old ♀

Fig. 6.

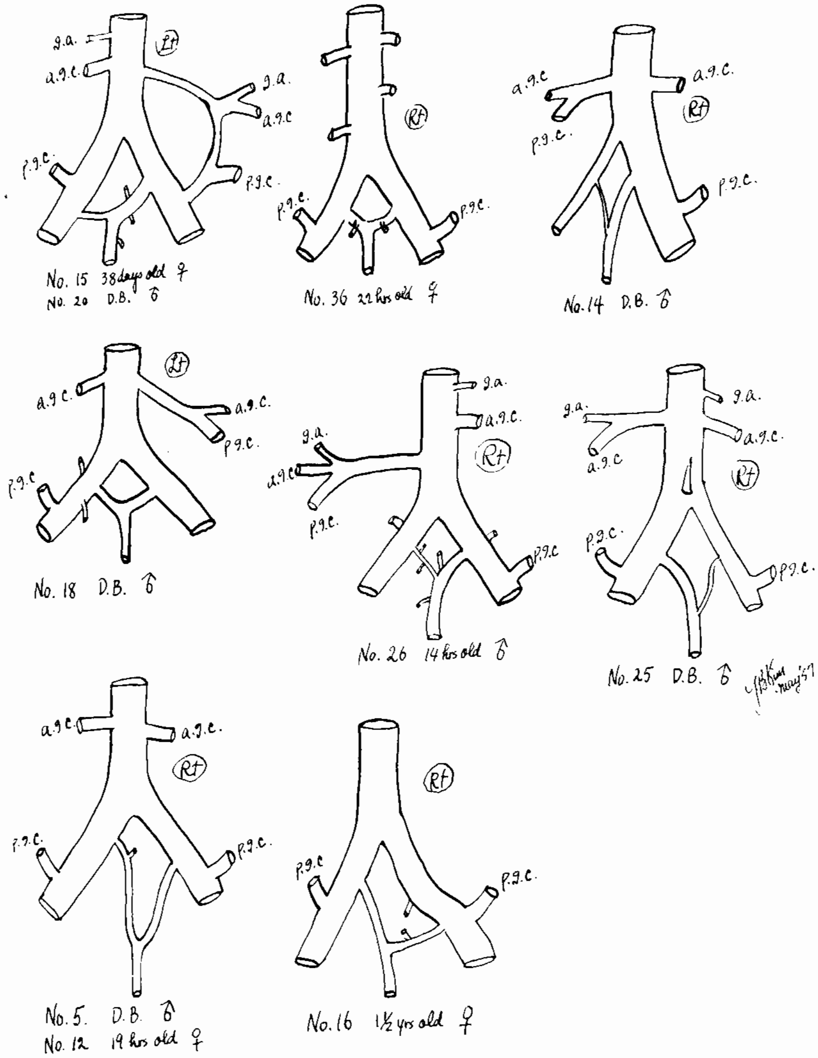

g.a.
a.g.c.
Lt
g.a.
a.g.c
p.g.c.
p.g.c.
No. 15 38 days old ♀
No. 20 D.B. ♂
Rt
p.g.c.
p.g.c.
No. 36 22 hrs old ♀
a.g.c
a.g.c.
Rt
p.g.c.
p.g.c.
No. 14 D.B. ♂
Lt
a.g.c.
a.g.c.
p.g.c.
p.g.c
No. 18 D.B. ♂
g.a.
a.g.c.
Rt
g.a.
a.g.c
p.g.c.
p.g.c
No. 26 14 hrs old ♂
g.a.
g.a.
a.g.c.
a.g.c
Rt
p.g.c.
p.g.c.
No. 25 D.B. ♂
a.g.c
a.g.c.
Rt
p.g.c.
p.g.c.
No. 5. D.B. ♂
No. 12 19 hrs old ♀
Rt
p.g.c
p.g.c.
No. 16 1½ yrs old ♀

Fig. 7.

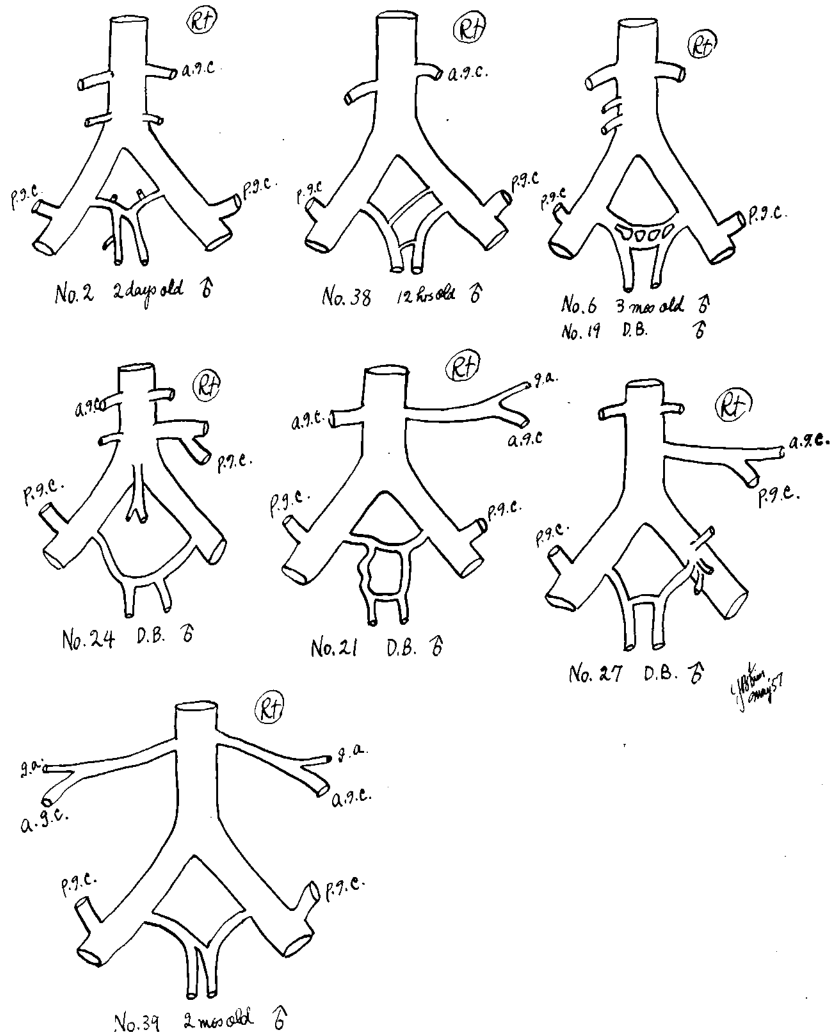
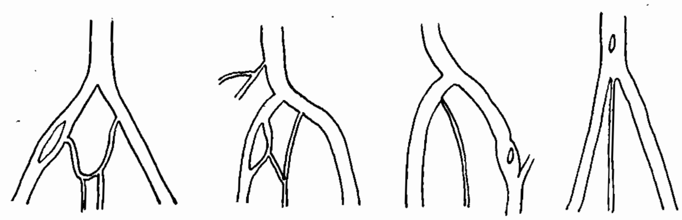
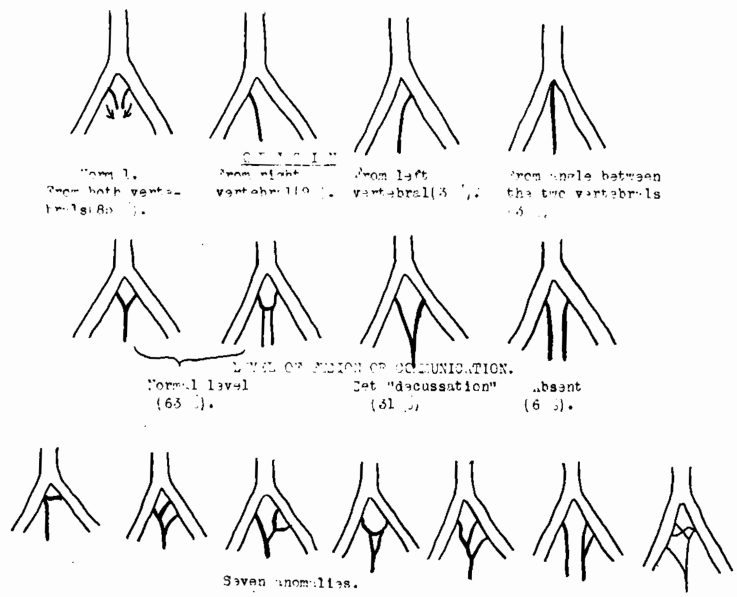

Rt
a.g.c.
p.g.c.
No. 2 2 days old ♂
No. 38 12 hrs old ♂
No. 6 3 mos old ♂
No. 19 D.B. ♂
g.a.
No. 24 D.B. ♂
No. 21 D.B. ♂
No. 27 D.B. ♂
No. 39 2 mos old ♂

Fig. 8.

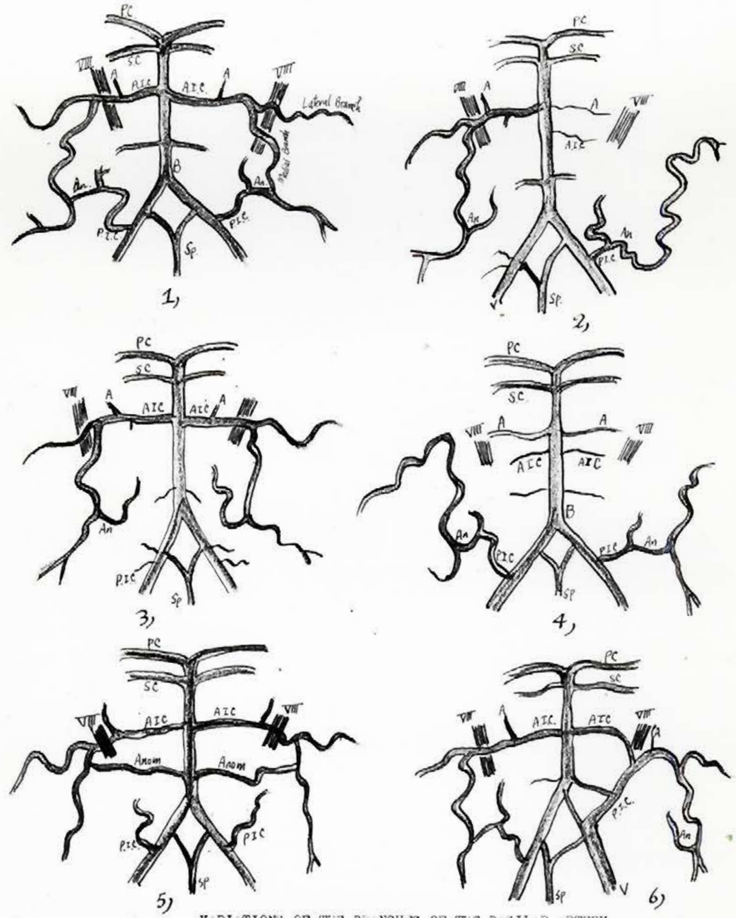


Anomalies of vertebral and basilar arteries.(Redrawn from Stopford)



VARIATIONS OF ANTERIOR SPINAL ARTERY(redrawn from Stopford)

Fig. 9.



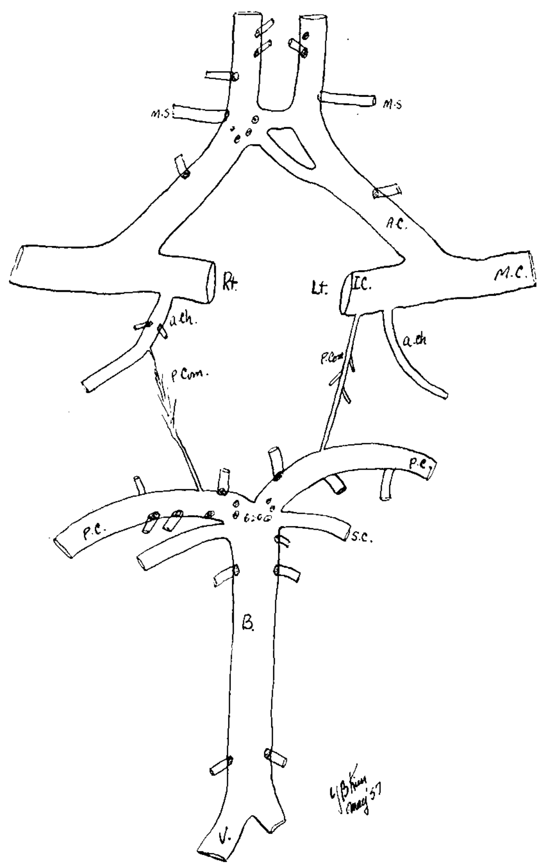
VARIATIONS OF THE BRANCHES OF THE BASILAR ARTERY

1) A fairly common arrangement. **2)** The anterior varying inversely with the posterior inferior(common). **3)** Both posterior vessels small, their areas of supply being chiefly fed by the anterior vessels(uncommon). **4)** Both anterior vessels small, their areas of supply being chiefly from posterior vessels(uncommon). **5)**. Anomalous importance of vessel from the junction of vertebral arteries. **6)**. Rare--posterior vessel being continuation of vertebral artery. (Redrawn from W.J.Atkinson)

Pc.-Posterior cerebral artery: Sc.-Superior cerebellar artery: A.I.C.-Anterior inferior cerebellar artery: B.-Basilar artery: V.-Vertebral artery: Sp.-Spinal artery: A.-Internal auditory artery: VIII.-Acoustic nerve: An.-Anastomotic vessel: Anom.-Anomalous vessel.

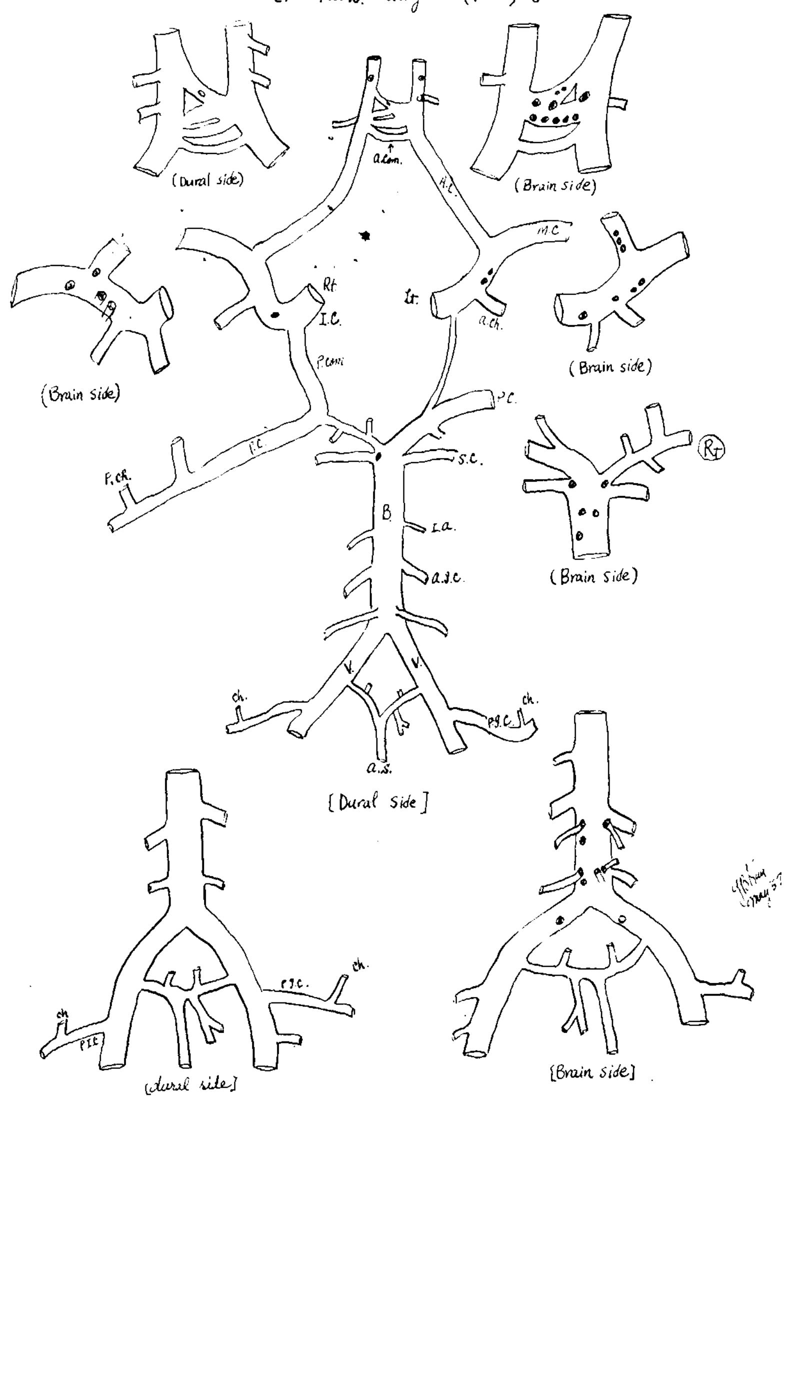
Fig. 10.

Case No. 1. D.B. (9 mos). ♀

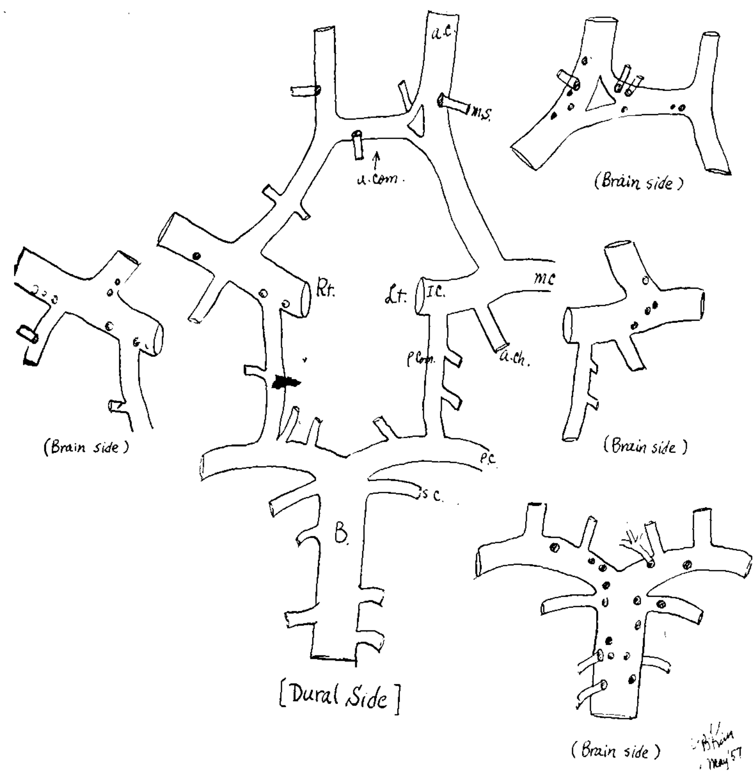


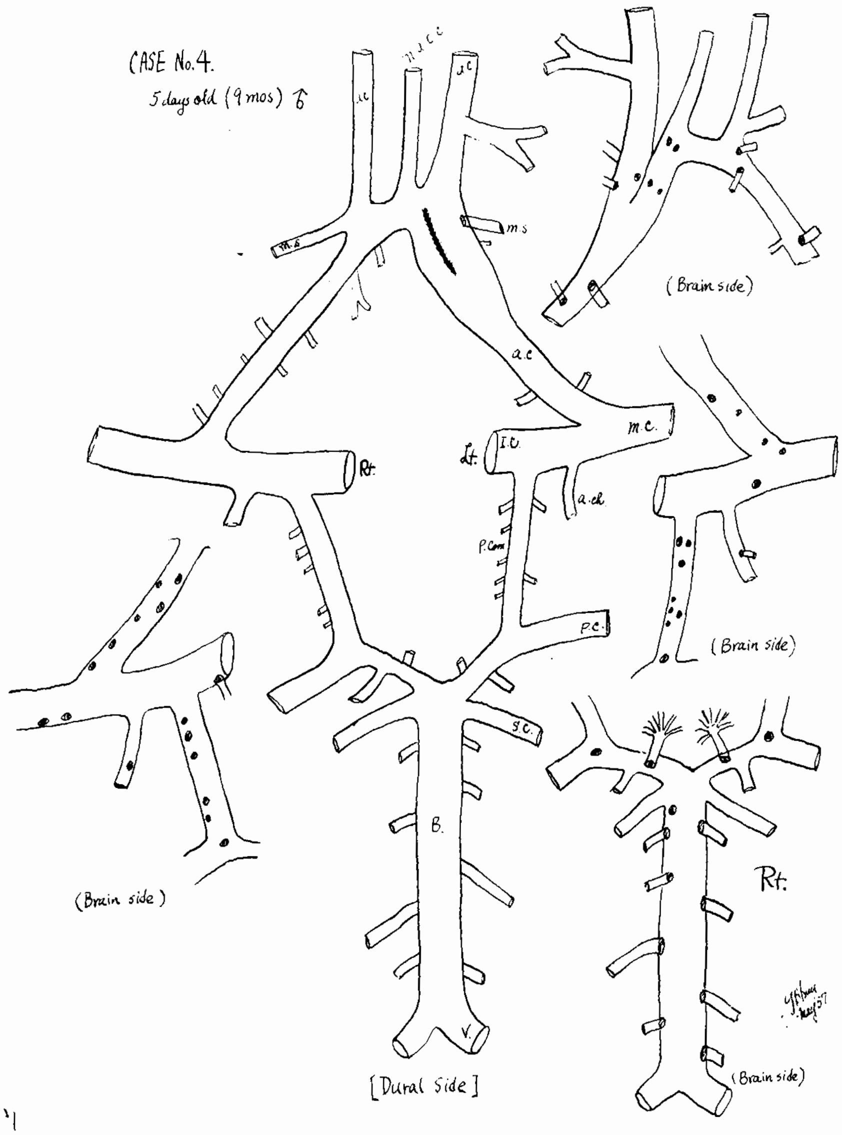
(DURAL SIDE)

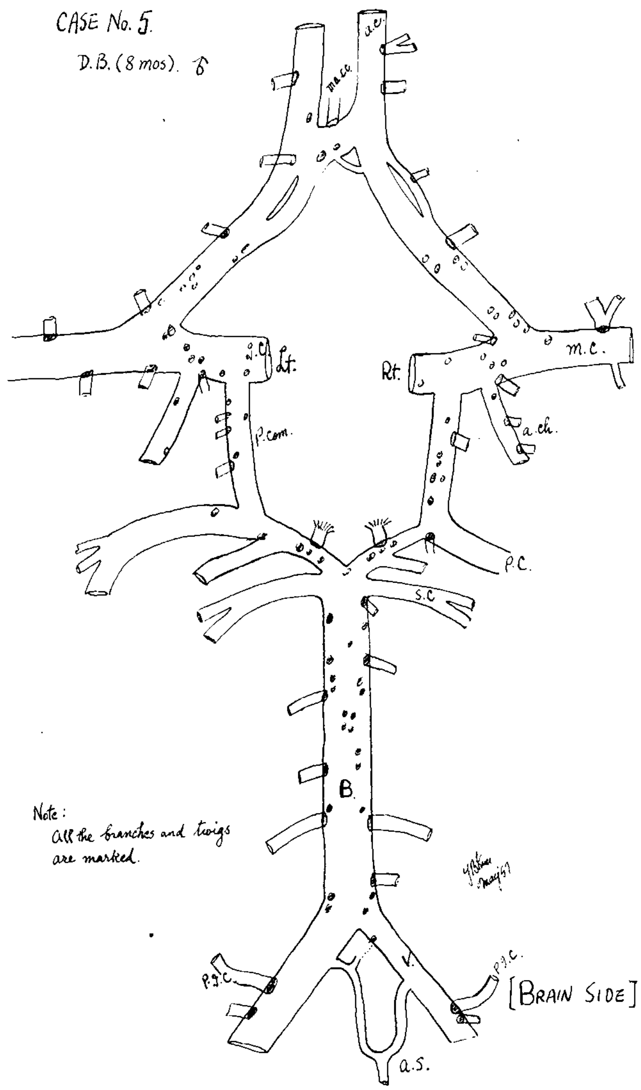
CASE No. 2. 2 days old (9 mos) ♂



CASE No. 3. 3 days old (5½ mos) ♂.

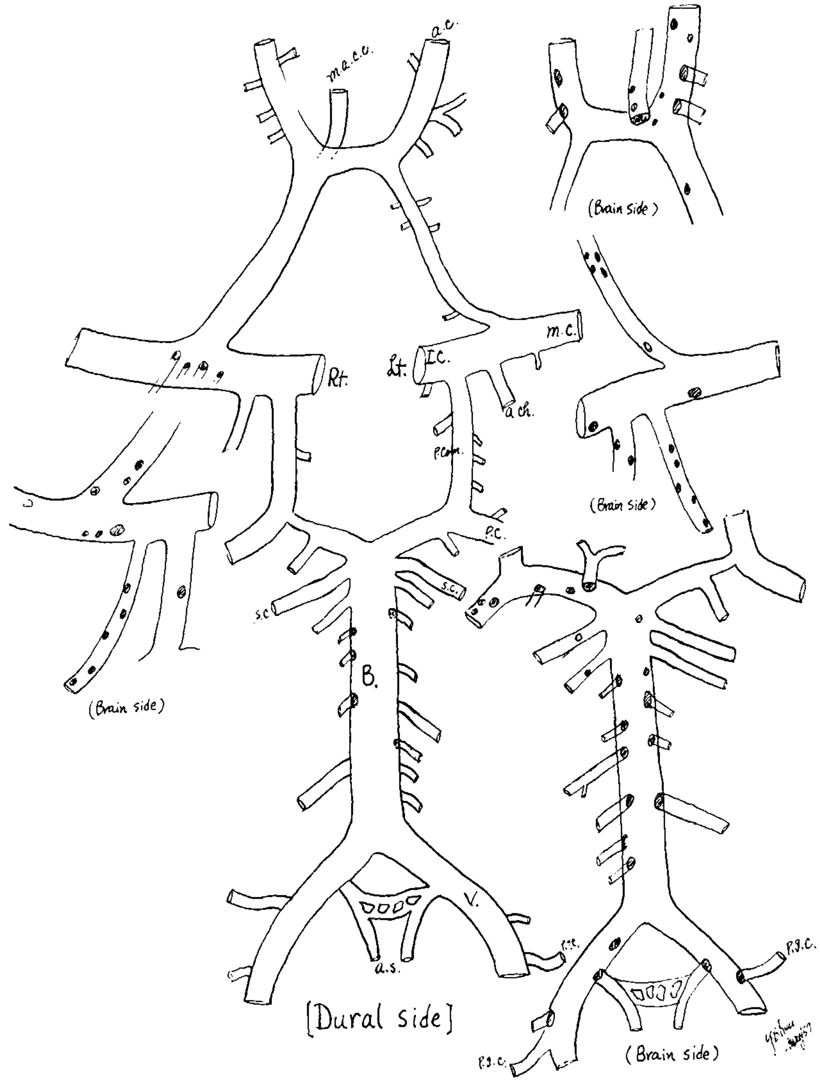



CASE No.4.
5 days old (9 mos) ♂
m.s
m.s
a.c
Rt.
Lt.
I.C.
m.c.
a.ch
P.Com
P.C.
g.c.
B.
V.
[Dural Side]
(Brain side)
(Brain side)
(Brain side)
Rt.
(Brain side)

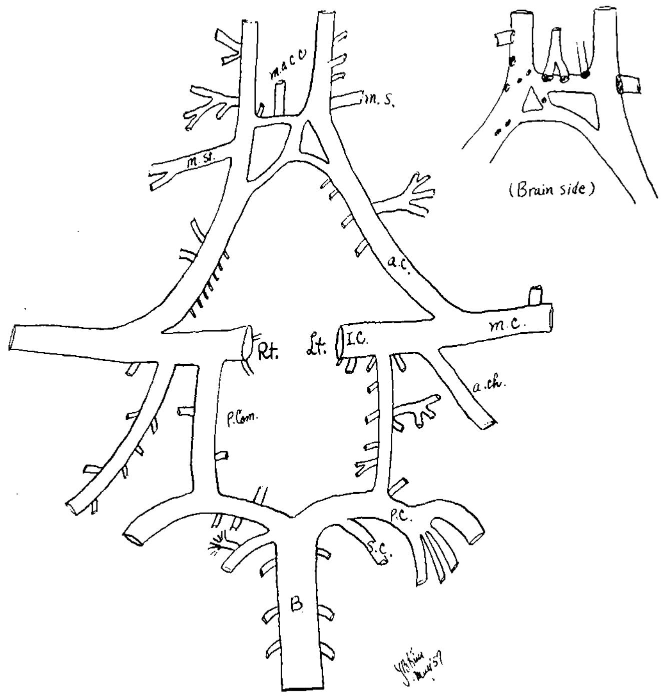


CASE No. 5.
D.B. (8 mos). ♂
a.c.
m.a.c.
m.c.
Lt.
Rt.
P.com.
a.ch.
P.C.
S.C
B.
V.
P.g.C.
P.g.c.
a.s.
[BRAIN SIDE]
Note:
All the branches and twigs
are marked.

CASE No. 6. 3 mos old (9 mos) ♂

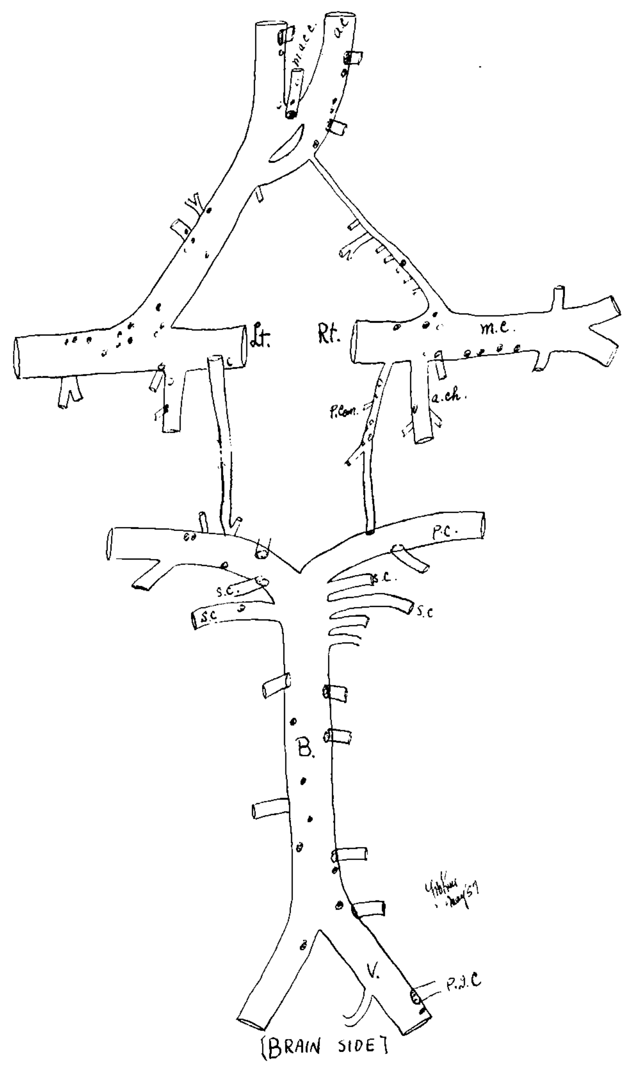


CASE No. 7. D.B. (9 mos) ♀

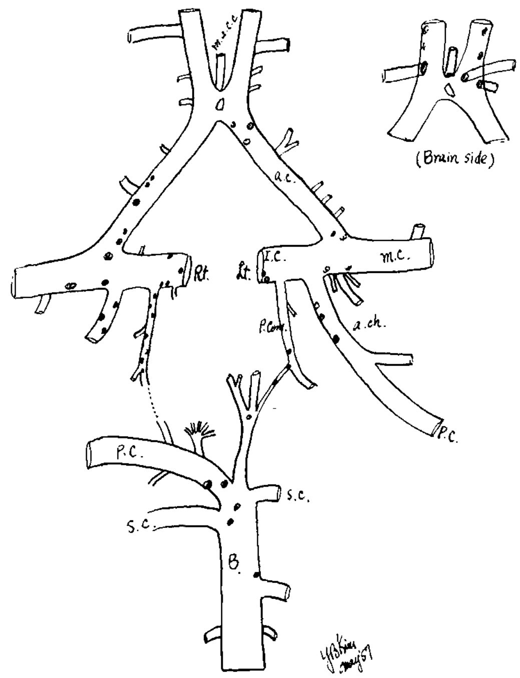


[Dural Side]

CASE No. 8 D.B. (8 mos) ♀

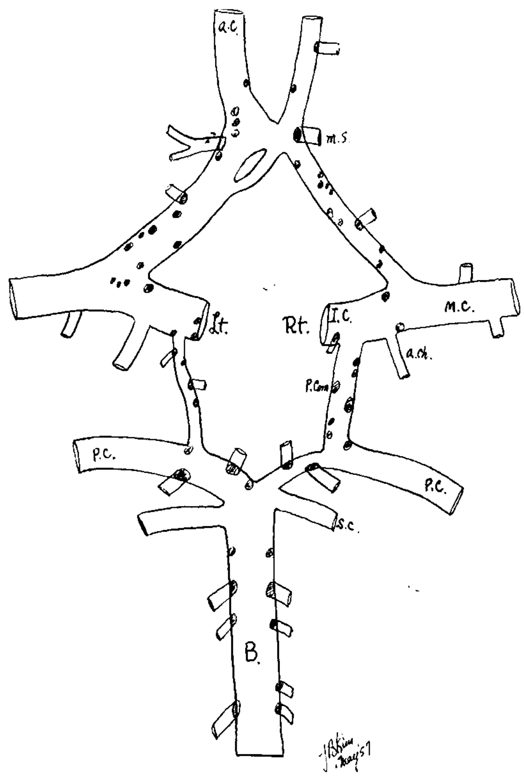


CASE No. 9 D.B. (8 mos) ♀



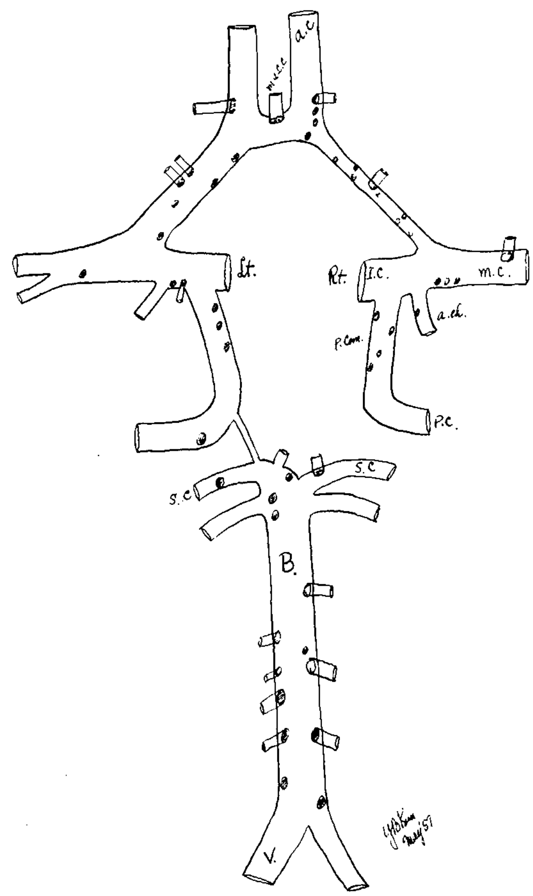
[Dural side]

CASE. No. 10 3 mos old (9 mos) ♀



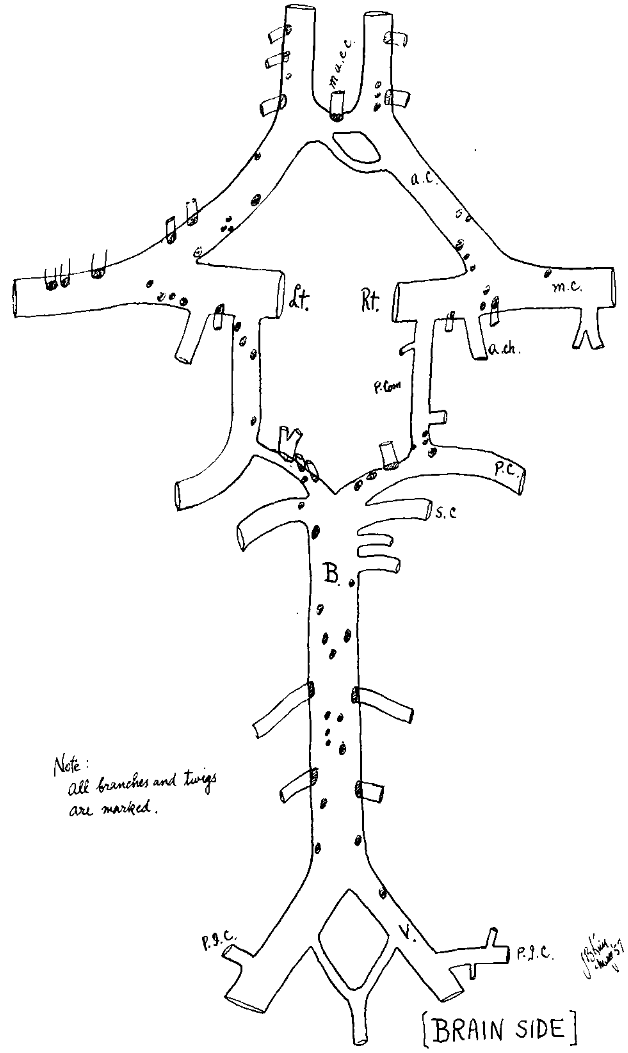
[Brain side]

CASE No. 11 19 hrs old (7½ mos) ♂



[Brain Side]

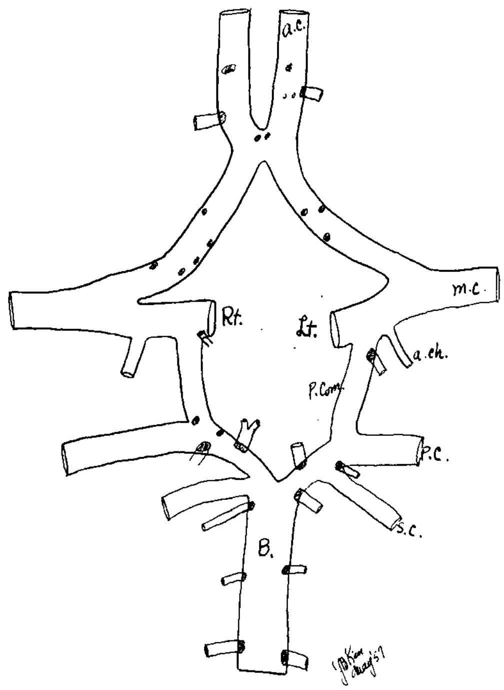
CASE. No. 12 19 hrs old (9 mos) ♀



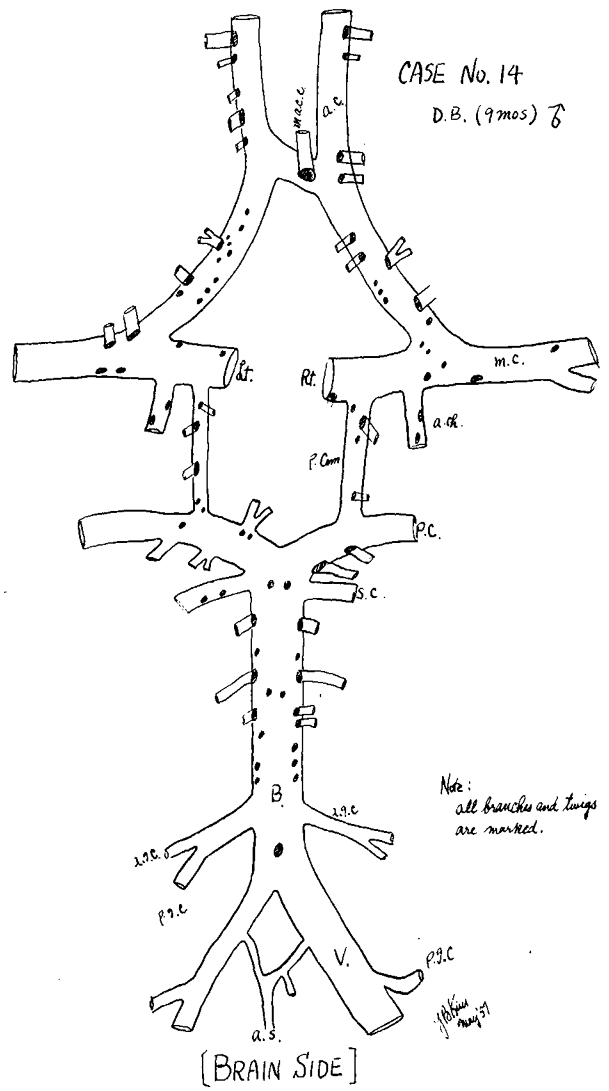
Note:
all branches and twigs
are marked.

[BRAIN SIDE]

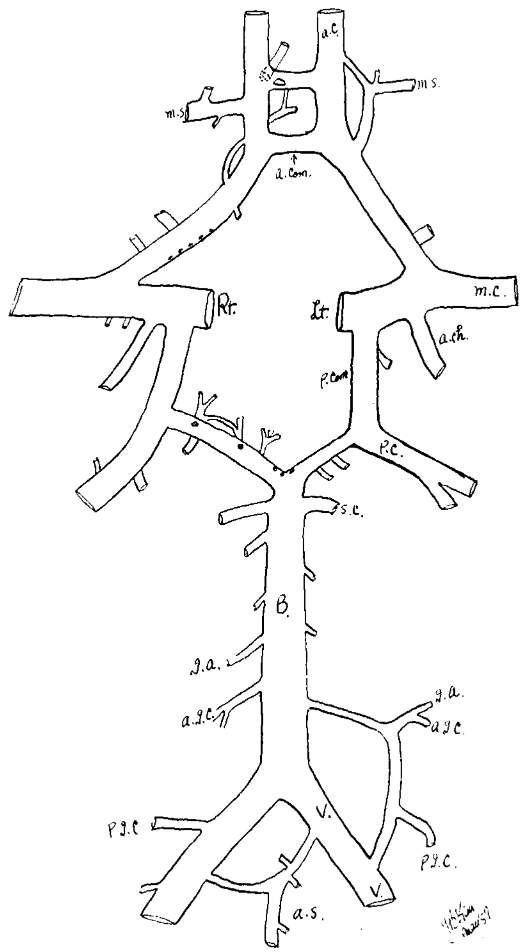
CASE No. 13 3 Yrs Old ♀



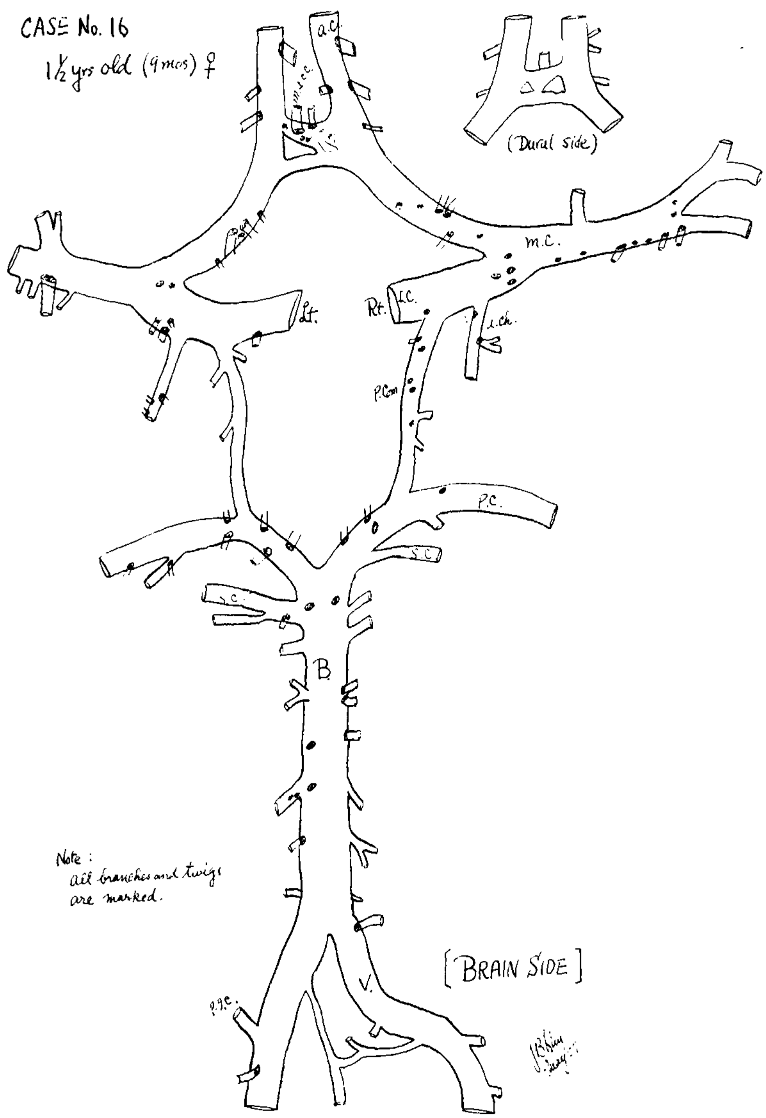
[Dural side]


CASE No. 14
D.B. (9 mos) ♂
m.a.c.c
a.c.
Lt.
Rt.
m.c.
a.ch.
P. Com
P.C.
S.C.
B.
a.i.c.
a.i.c.
P.i.c
P.i.c
V.
a.s.
Note:
all branches and twigs
are marked.
[BRAIN SIDE]

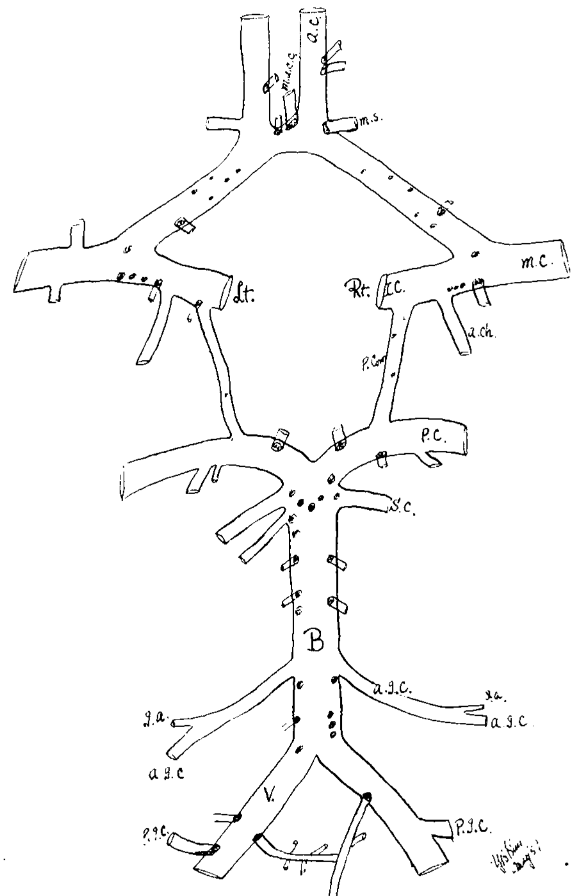
CASE No. 15 38 days old (9 mos) ♀



[DURAL SIDE]

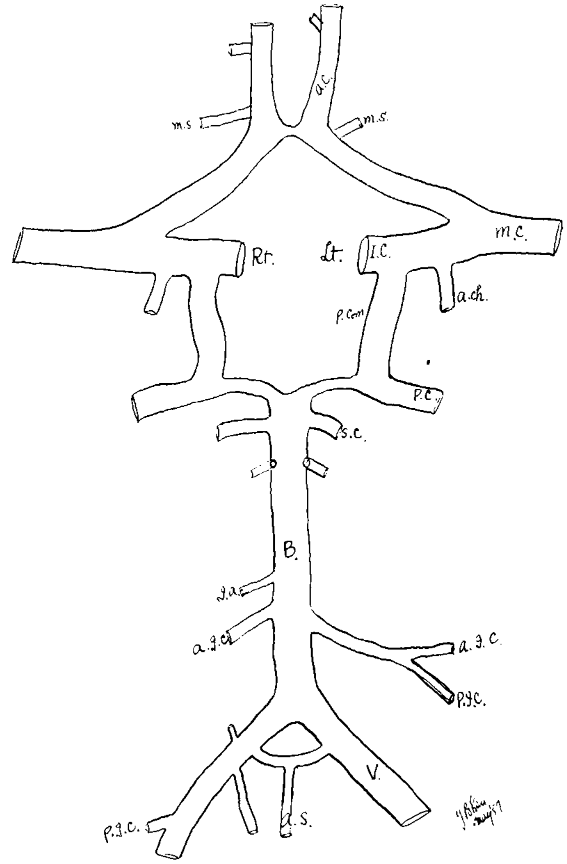

CASE No. 16
1½ yrs old (9 mos) ♀
a.c.
(Dural side)
m.c.
Lt.
Rt.
i.c.
P.Com
p.c.
s.c.
s.c.
B
Note :
all branches and twigs
are marked.
[BRAIN SIDE]
V.
p.i.c.

CASE No. 17 D.B. (9 mos) ♂



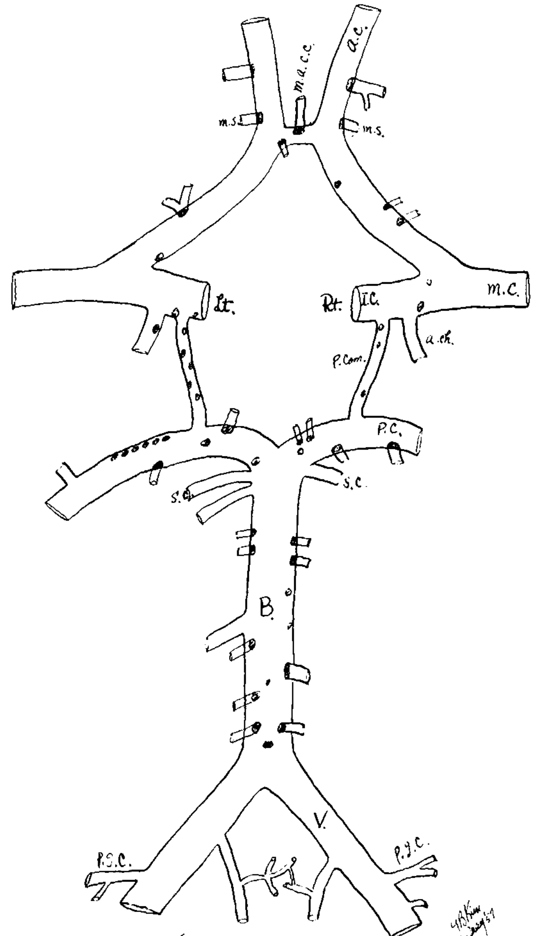
[BRAIN SIDE]

CASE No. 18 D.B. (7 mos) ♂



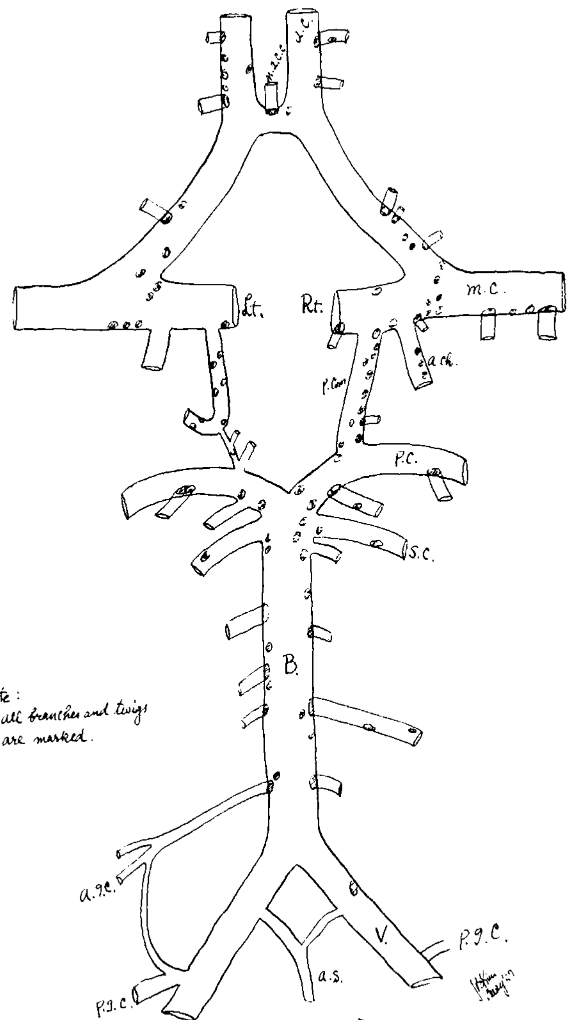
[DURAL SIDE]

CASE No. 19 DB (7 mos) ♂



[BRAIN SIDE]

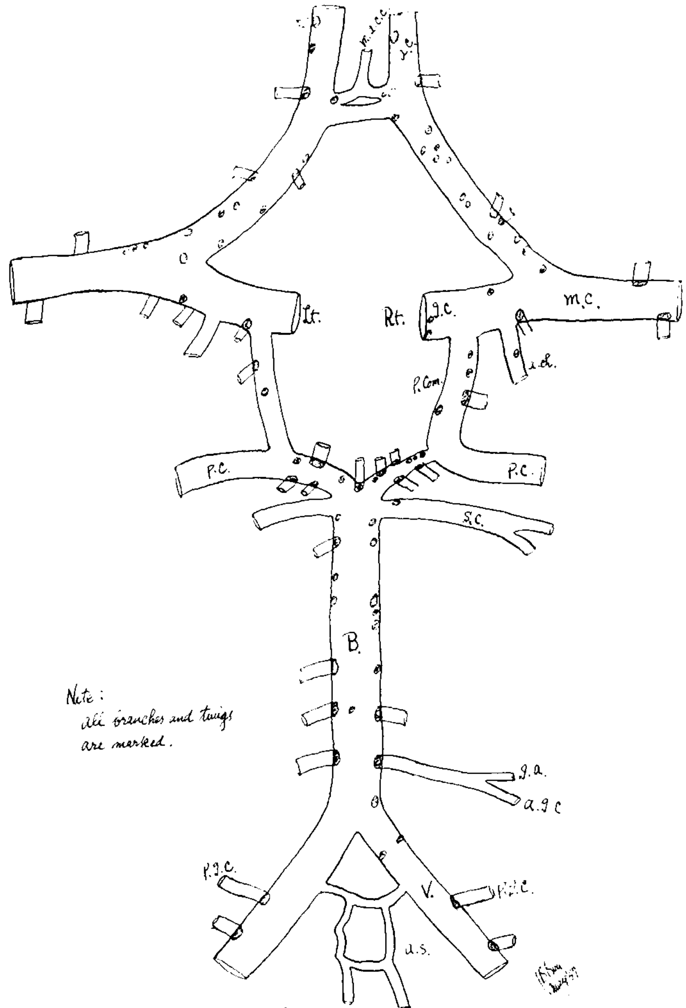
CASE No. 20 D.B. (8 mos) ♂



Note: all branches and twigs are marked.

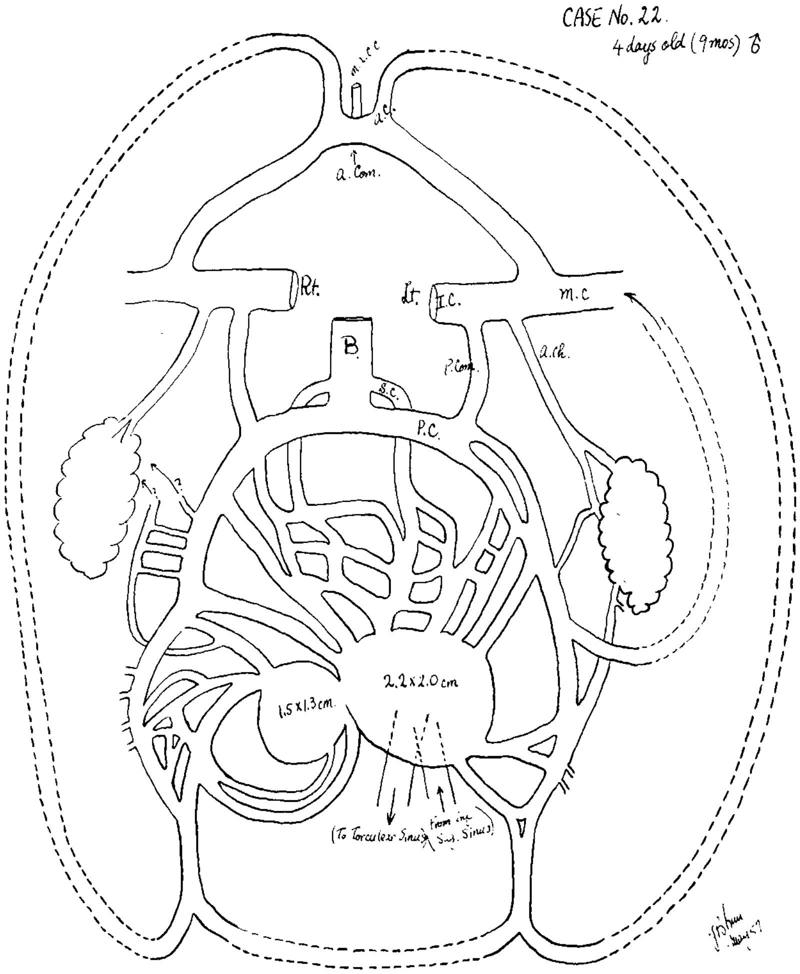
[BRAIN SIDE]

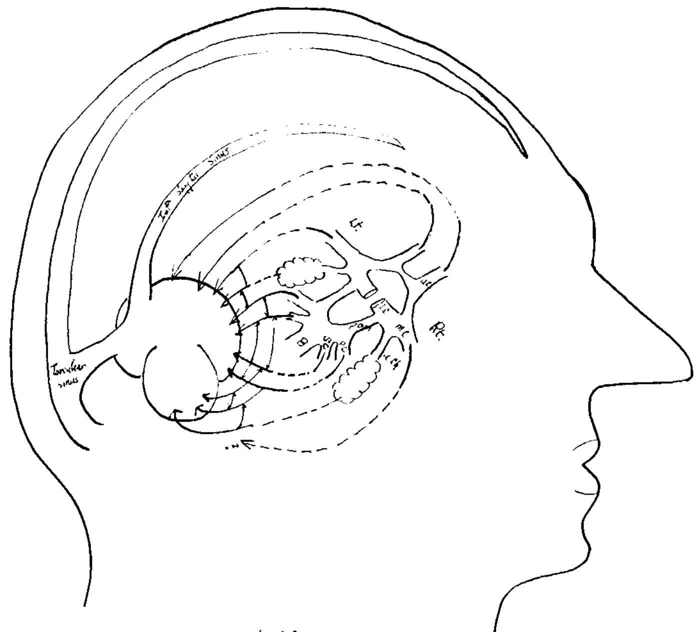
CASE 21. D.B. (9 mos) ♂



[BRAIN SIDE]

CASE No. 22.
4 days old (9 mos) ♂



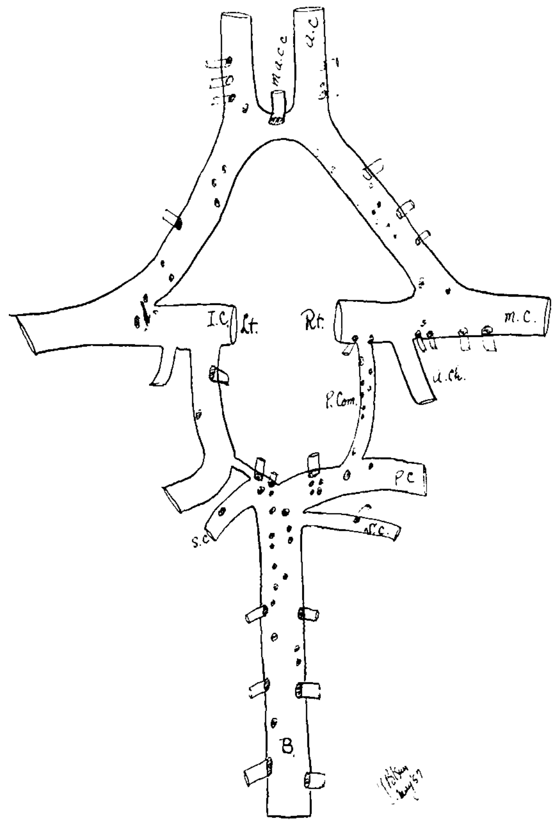


CASE No. 22.

4 days old (9 mos) ♂.

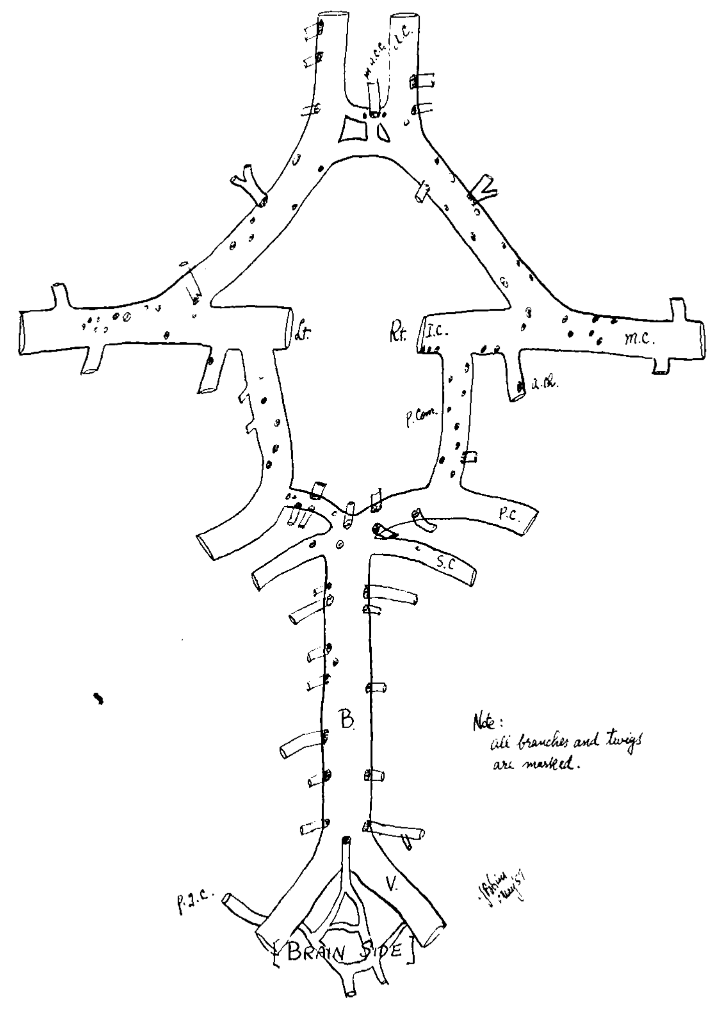
[Schematic view from Right lateral side]

CASE No.23 D.B.(9 mos) ♀

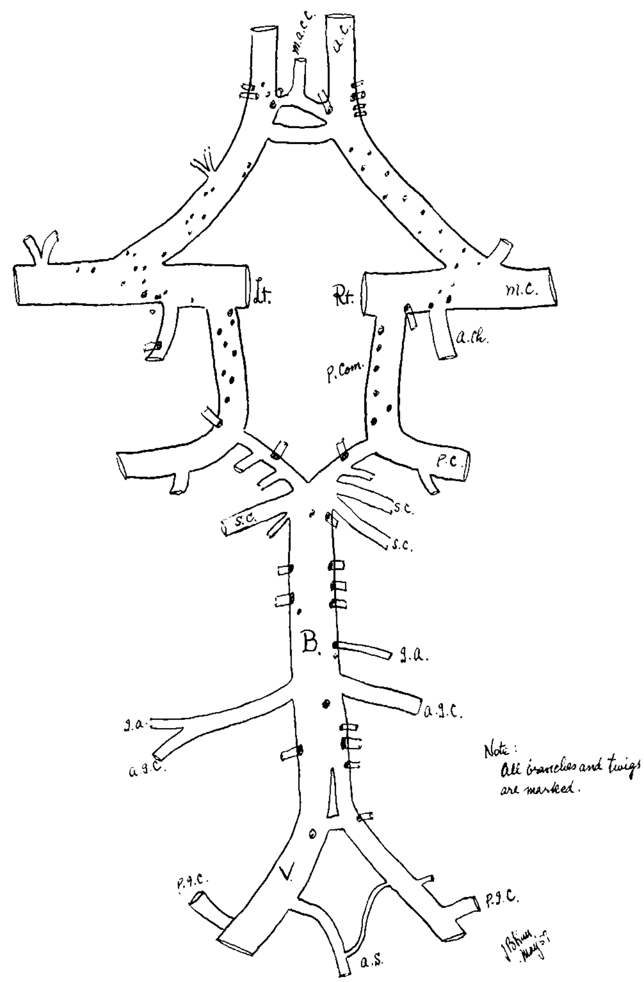


[BRAIN SIDE]

CASE No. 24 D.B.(8 mos) ♂

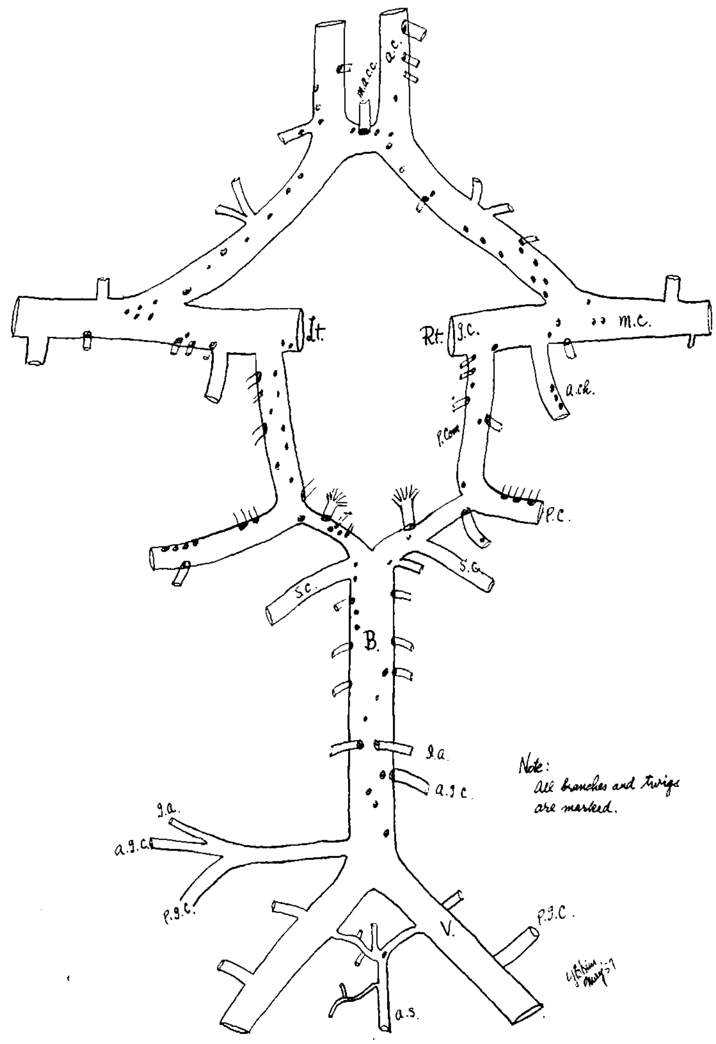


CASE No. 25 D.B. (9 mos) ♂



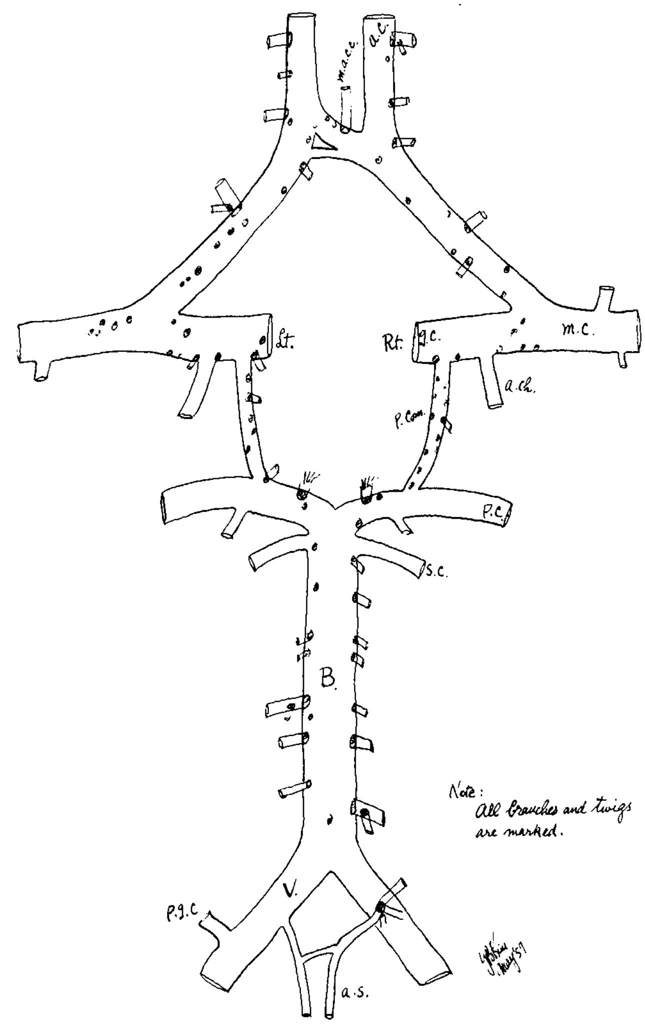
[BRAIN SIDE]

CASE 26 14 hrs old (8 mos.) ♂



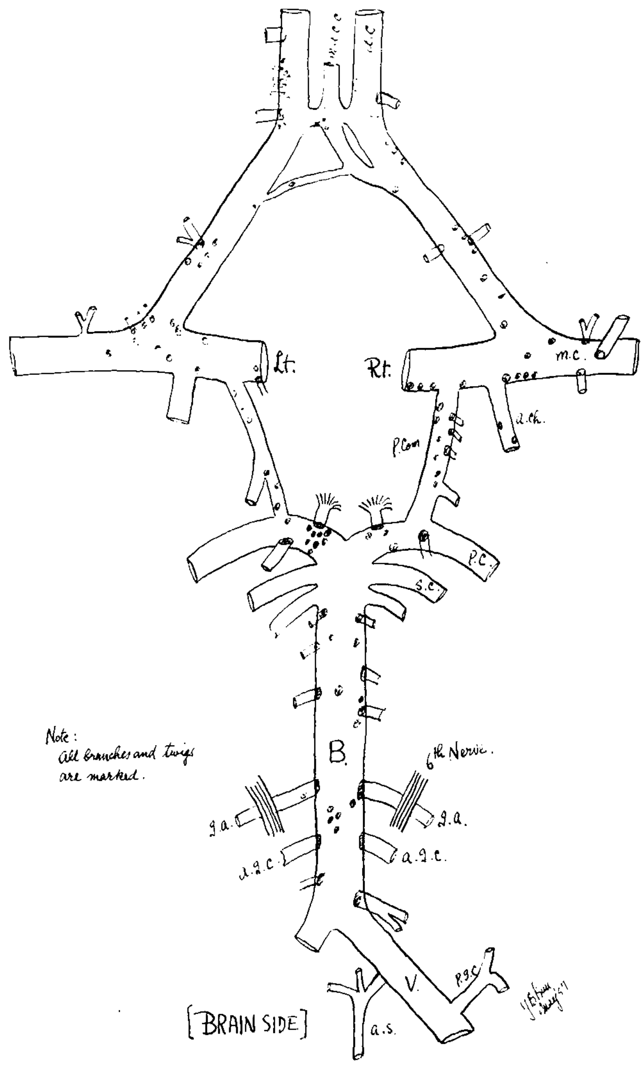
[BRAIN SIDE]

CASE No. 27 D.B. (8 mos) ♂



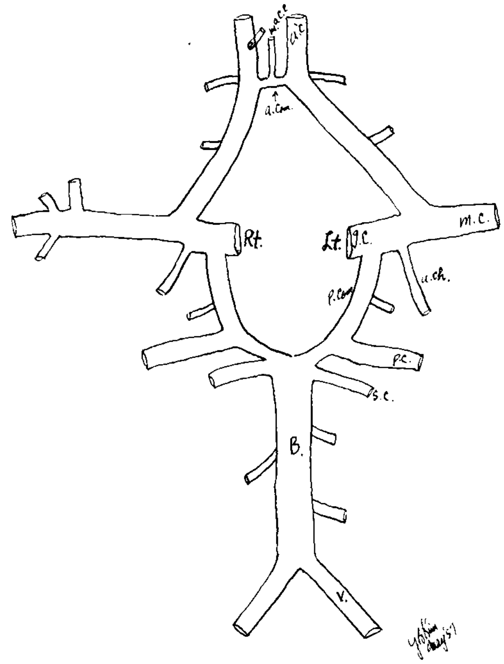
[BRAIN SIDE]

CASE No. 28 D.B. (8 mos) ♂



Note:
All branches and twigs
are marked.

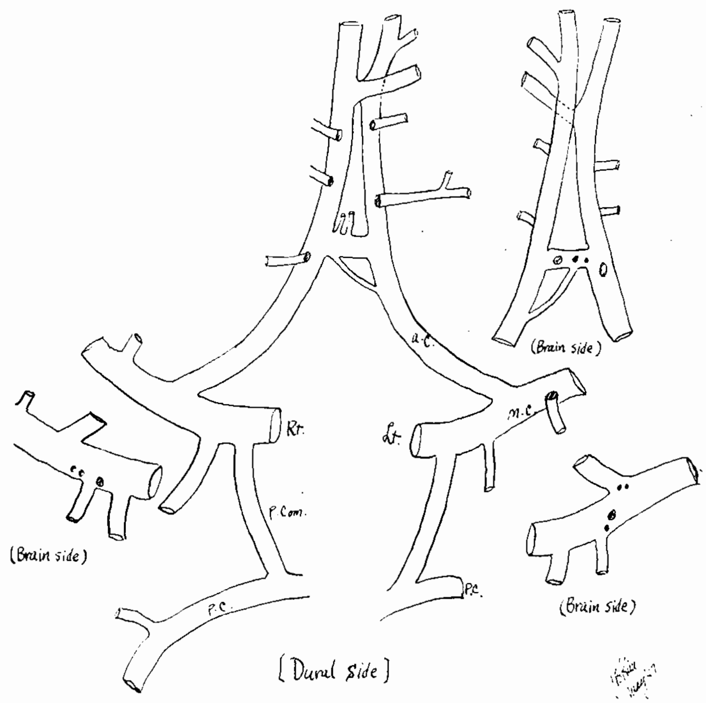
CASE No. 29 D.B. (9 mos) ♀



[DURAL SIDE]

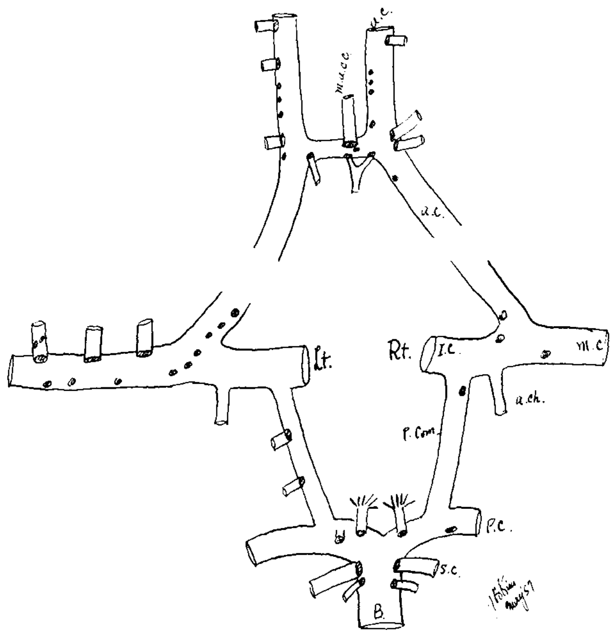
(Drawn from photographic picture, not examined under dissecting microscope.)

CASE No. 30 10 min old (9 mos) ♀



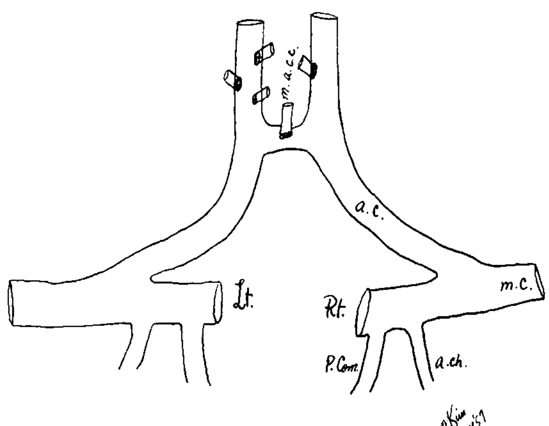
(Basilar and vertebral arteries were removed together with cerebellum and brain stem.)

CASE No. 31 D.B. (9 mos) ♂



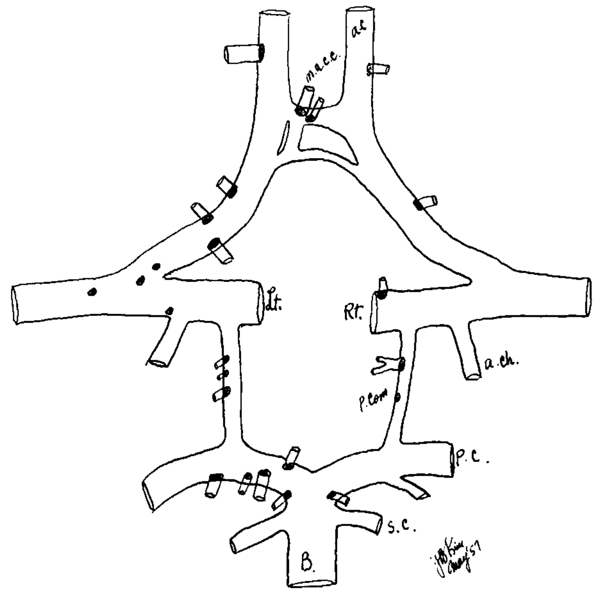
[Brain side]

CASE No. 32. 25½ hrs old (30 wks) ♀



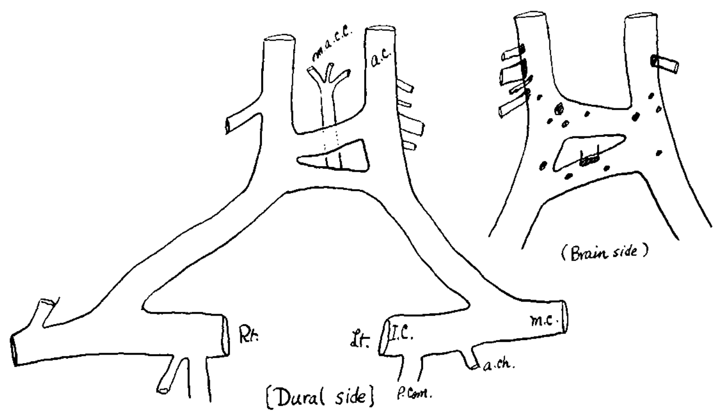
[BRAIN SIDE]

CASE No. 33 1 mos old (9 mos) ♂

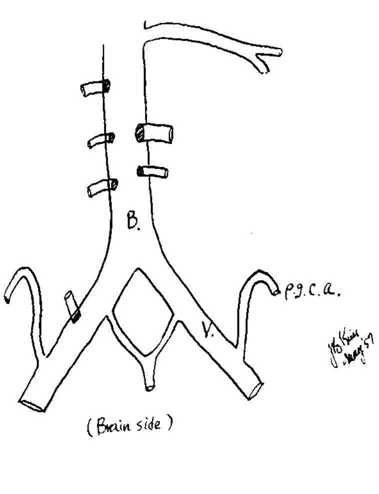


[BRAIN SIDE]

CASE No. 34 3 days old (35 wks) ♂

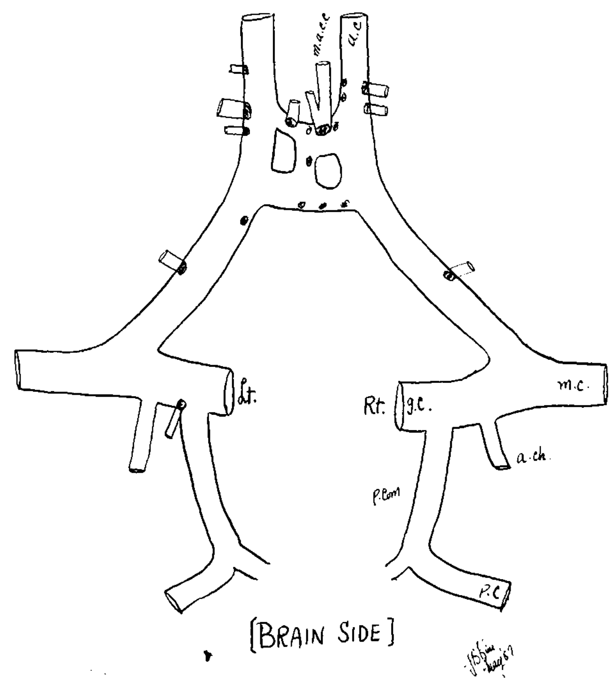


[Dural side]

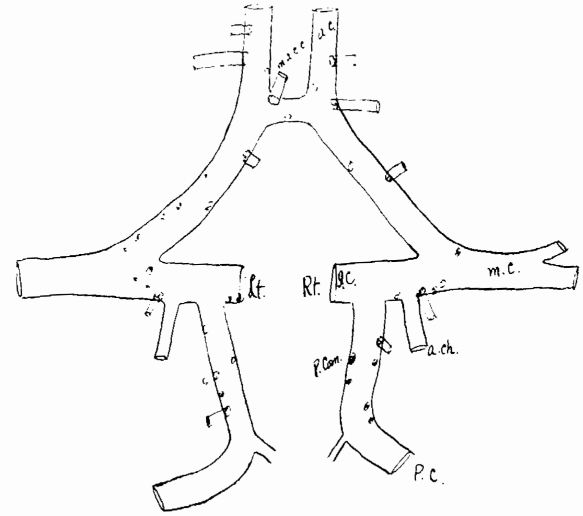


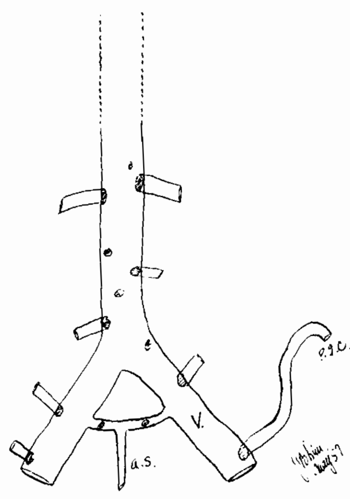
(Brain side)

CASE No. 35 2 days old (7 mos) ♀



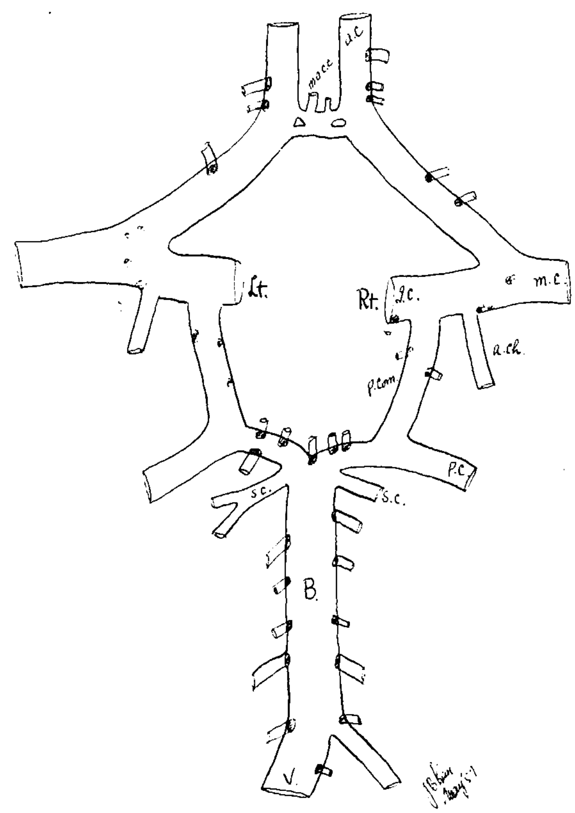
CASE No. 36 22 hrs old (8 mos) ♀.





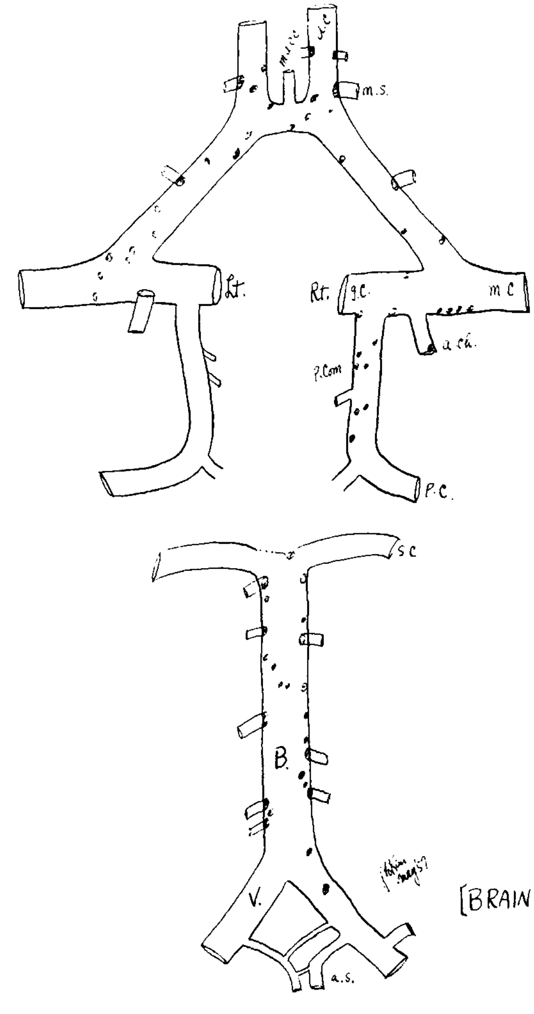
[BRAIN SIDE]

CASE No. 37 1 hr old (7 mos) ♀



[BRAIN SIDE]

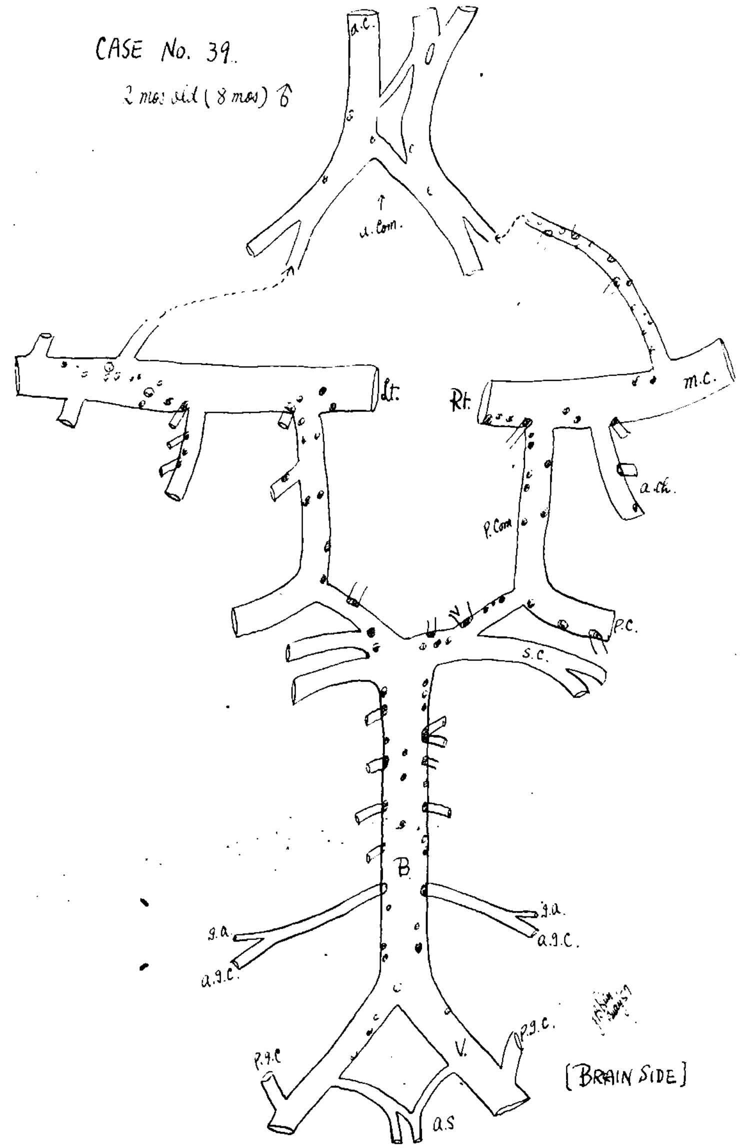
CASE No. 38 12 hrs old (8 mos) ♂



[BRAIN SIDE]

CASE No. 39.

2 mos. old (8 mos) ♂



[BRAIN SIDE]

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