Aneurysms of the Anterior Communicating Artery and Gross Anomalies of the Circle of Willis*

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The various theories of development of aneurysms of the intracranial vessels are well known. Although early investigators thought embolic and inflammatory reactions were important factors in their formation, later workers stressed the probable importance of developmental defects of the media at sites of branching, supplemented by degenerative changes of the internal elastic membrane. Turnbull suggested that cerebral aneurysms formed as a result of degeneration of the media at sites of inherent weakness of the media as at points of branching. Forbus concluded, however, that although a small diverticulum may occur at the site of a medial defect associated with the bifurcation of an artery, an "anatomical" aneurysm will not develop while the internal elastic membrane is still intact. He concluded further that miliary aneurysms as such are not congenital malformations but are acquired lesions arising from a combination of focal weakness in the vessel wall, secondary to a congenital defect of the media and degeneration of the internal elastic membrane, due to continued overstretching of this membrane. While some have, in general, supported this theory of the development of aneurysms, others have dissented. Bassett and Lemmen remarked that most aneurysms of the cerebral arteries represent vestiges of the primitive circulatory system.

It is now well known that the incidence of gross anatomical anomalies of the circle of Willis is high. Approximately 60 years ago, however, Blackburn finding at autopsy that 52 per cent of the circles of Willis in a group of psychiatric patients were anomalous, concluded that anomalies of the circle of Willis might be a cause of psychiatric illness. Actually, if by normal we mean a completely symmetrical circle with thread-like communicating arteries illustrated in current texts (Fig. 1), then the incidence of anomalous circles is probably even greater than 50 per cent. In the treatment of intracranial aneurysms with subarachnoid hemorrhage, gross anatomical anomalies of the circle have been considered more as a factor in circulatory intolerance of carotid occlusion than as a cause of the aneurysm itself. Chase mentioned that gross congenital anomalies of the circle of Willis are very common and suggested that these anomalies may be expected to be accompanied by structural defects in the walls of the vessels. Wilson et al., however, reported that in 85 per cent of 40 aneurysms found on the anterior communicating artery were associated with hypoplasia of the first portion of one anterior cerebral artery. Stehbens stated that this was the only anatomical variation that he was able to correlate with the location of cerebral aneurysm in a study of 251 brains with 333 aneurysms.

Asymmetry of the circle of Willis seems to be primarily the result of a difference in size, and, in turn, a difference in the pattern of

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![Fig. 1. Normal circle of Willis. It is complete, symmetrical and has thread-like communicating arteries.](image-url)
branching of the internal carotid arteries.\textsuperscript{8,9} There are 2 relatively common, variations from the normal pattern of branching of this artery. One is the persistence of the fetal pattern of trifurcation in which all 3 of the ipsilateral major cerebral arteries arise from the internal carotid while the posterior cerebral segment of the circle continues, as in the early fetus, to be a small, thread-like, posterior communicating type of vessel (Fig. 2). In the other common variation the artery divides into the middle cerebral artery and an unusually large anterior cerebral branch. The latter in turn, divides at the anterior pole of the circle into both anterior cerebral arteries. This pattern of terminal branching of the internal carotid artery has been termed anterior trifurcation (Fig. 3). The proximal part of the branch to the opposite side is oriented in the manner of the usual anterior communicating artery but is several times larger. It usually is connected to the opposite internal carotid by a hair-like, communicating type of vessel. The opposite, anterior cerebral segment of the circle, however, may be missing, in which case the contralateral internal carotid simply continues as the middle cerebral artery (Fig. 4) or may bifurcate into the posterior cerebral artery and the middle cerebral artery (Fig. 3).

As would be expected, there are many gradations between the normal bifurcation of the internal carotid and each of these forms of trifurcation. A form representing a transition stage between early fetal trifurcation and normal adult bifurcation has been described as transitional trifurcation.\textsuperscript{8} In addition to the anterior trifurcation pattern of terminal branching, the internal carotid may have a transitional posterior communicating branch (Fig. 5). When combined with a contralateral internal carotid that fails to bifurcate (Fig. 5), this is the most dominant form of internal carotid. Of interest also in Fig. 5 is the congenitally small vertebral artery and the relatively large contralateral vertebral artery. A great discrepancy in the caliber of the vertebral arteries is not uncommon but we have noted no consistent relation between the asymmetry of these arteries and the asymmetry of the circle of Willis.

**Material and Methods**

The present study is an analysis of 1,000 circles of Willis obtained at autopsy at Ochsner Foundation Hospital. The circles, with the subarachnoid portion of each vertebral artery, the basilar artery, and each major cerebral artery to the point of its first major division distal to the circle, were fixed in 10 per cent formalin.

The incidence of aneurysms in this series may be higher than expected for 2 reasons. Our neurosurgical service represents a relatively large proportion of the hospital population and thus a comparatively large number of patients with subarachnoid hemorrhage are admitted. Moreover, the series represents a special professional interest in the dissections and probably few aneurysms were overlooked.

**Fig. 2.** Anomalous circle of Willis. It is complete but asymmetrical due to fetal trifurcation of the left internal carotid artery and normal bifurcation of the right internal carotid.

**Fig. 3.** Anomalous circle of Willis. It is complete but asymmetrical due to anterior trifurcation of the left internal carotid artery and reverse bifurcation of the right internal carotid.
Results

Among the 1,000 circles examined, an early fetal pattern of trifurcation of one internal carotid artery was found in 14.3 per cent and both internal carotids in 0.84 per cent. Anterior trifurcation was present in 6.5 per cent and a modified form in 4.9 per cent of the circles examined. The latter was characterized by a larger anterior cerebral segment on one side. Another type of circle in this group showed anterior trifurcation of one internal carotid, with an unusually large posterior communicating branch. This is the most dominant type of internal carotid artery and it was found in 0.14 per cent of circles in the present group (Fig. 5). In general, the caliber of the anterior communicating artery varies directly with the difference in caliber of the anterior cerebral segments of the circle.

There are 3 main groups of anomalies of the anterior communicating artery: 1. pronounced enlargement of the artery associated with anterior trifurcation; 2. branching or duplication of the anterior communicating artery; 3. persistence of the midline artery of the corpus callosum. The most common of these anomalies is branching or duplication of the anterior communicating artery which often occurs with a completely symmetrical circle. Persistence of the midline artery of the corpus callosum is relatively common and also occurs frequently in an otherwise symmetrical and normal circle.

However, with pronounced or even moderate dominance of one anterior cerebral segment of the circle, the anterior communicating artery is always grossly enlarged and it is in association with this anomaly that we have found an unusual incidence of aneurysms in this study. For example, in 1,000 circles studied, there were 67 aneurysms, 26 of which were located on the anterior communicating artery. Fifteen were on circles demonstrating typical anterior trifurcation or modified anterior trifurcation. Since the incidence of these types of anomalous circles in the entire group of circles was 77 per cent, it is evident that there was an unusually high incidence of aneurysms with this type of anomaly. Actually, 22.5 per cent of the aneurysms occurred on a type of circle constituting only 77 per cent of the total group.

It should be emphasized that variations of the pattern of branching of the internal carotid artery and the associated anomalies of the circle of Willis are not simply anatomical curiosities to be observed only at autopsy, a large percentage of them can be identified by

Fig. 4. Anomalous circle of Willis. It is incomplete because of absence of one anterior cerebral segment of the circle. One internal carotid demonstrates anterior trifurcation; the other simply continues as the middle cerebral artery.

Fig. 5. Anomalous circle of Willis. One internal carotid artery demonstrates anterior trifurcation plus a transitional posterior communicating branch; the other fails to bifurcate.
angiography. The relative importance of each carotid flow to the over-all cerebral blood flow and the efficiency with which the circle of Willis will function as a route for collateral circulation can be evaluated quite accurately. The most strategic surgical approach and the best method of isolating the aneurysm can be planned by analyzing the angiograms and correlating the pattern of branching of each internal carotid artery and the variations of the circle of Willis which consistently accompany the particular pattern of branching of each internal carotid artery. The following case demonstrates the angiographic picture of anterior trifurcation of the left internal carotid artery and the relative contributions of each internal carotid to the aneurysm and to the over-all anterior cerebral blood flow.

Report of Case

A 46-year-old laborer complained of headache. The history and physical findings were characteristic of subarachnoid hemorrhage from a ruptured intracranial aneurysm. Lumbar spinal puncture revealed grossly bloody cerebrospinal fluid, and the left lateral carotid angiogram demonstrated the ipsilateral middle and anterior cerebral arteries and the contralateral anterior cerebral artery distal to the circle (Fig. 6A). There was an aneurysm in the region of the anterior portion of the circle, and in the anteroposterior projection (Fig. 6B) it appeared to arise in the midline. In this projection, the caliber of the anterior cerebral segment of the circle appeared larger than that of the middle cerebral artery, a characteristic of anterior trifurcation of the internal carotid artery. Moreover, there was severe spasm of the anterior cerebral arteries distal to the circle. Neither the right lateral nor the right anteroposterior angiogram visualized the aneurysm well but injection of contrast medium into the right common carotid artery with compression of the opposite common carotid artery showed the aneurysm as well as the rather prominent difference in caliber of the anterior cerebral segments of the circle (Fig. 6C). The aneurysm was isolated by sacrificing only the anterior communicating artery.

It should be noted that although the anterior cerebral segment of the circle opposite the enlarged anterior cerebral segment of anterior trifurcation is sometimes absent, this should not be assumed to be the case even though angiography with contralateral carotid compression fails to demonstrate it.

Discussion

Although gross anatomic anomalies of the circle of Willis are common, certain relationships between the various segments of the circle are so consistent that if the pattern of branching of the internal carotid arteries is known, the anatomic pattern of the entire circle can be predicted accurately. For example, the caliber of the posterior communicating and the posterior cerebral segments of the circle varies inversely as compared with the caliber of the posterior cerebral artery immediately distal to the circle. If the left internal carotid artery maintains the early fetal form of trifurcation in which all 3 of the ipsilateral major cerebral arteries arise from it, the posterior cerebral segment of the circle will, without exception, be a small hair-like vessel similar to the "normal" posterior communicating artery. The opposite internal carotid artery may demonstrate normal bifurcation, early fetal trifurcation, or some gradation between these 2 patterns.

Angiographic study of the circle of Willis is least helpful in the anterior communicating segment. Of course, with carotid angiography the patency and caliber of the anterior communicating artery and certain anomalous patterns can be estimated by compressing the contralateral carotid flow as the contrast medium is injected. The caliber of the anterior communicating artery is extremely variable but, in general, if the anterior cerebral segments of the circle are equal or approximately so, it will be normal, i.e., hair-like. In general, the caliber of the anterior communicating artery varies directly with the degree of inequality of the anterior cerebral segments of the circle.

With anterior trifurcation of an internal carotid artery, the anterior communicating segment of the circle is always large. The presence of anterior trifurcation is suggested if the contralateral anterior cerebral artery distal to the circle is demonstrated by carotid angiography. The contralateral filling may, however, simply represent injection of the contrast medium with a force exceeding the pressure in the opposite anterior cerebral artery, or in the presence of complete occlusion of the opposite internal carotid artery. On the other hand, if there is filling of the contralateral anterior cerebral artery distal
to the circle and the caliber of the ipsilateral anterior cerebral segment of the circle is greater than that of the middle cerebral artery, anterior trifurcation is highly probable. The presence of anterior trifurcation is practically confirmed if, in addition, carotid angiography on the opposite side demonstrates failure of bifurcation, i.e., the internal carotid artery appears to continue as the middle cerebral without dividing in the usual manner; or reverse bifurcation, i.e., it divides into 2 major cerebral arteries but the posterior cerebral replaces the anterior cerebral.

It should be stressed that visualization of an aneurysm of the anterior communicating artery with carotid angiography only on one side does not always mean that there is anterior trifurcation of the internal carotid artery on the side of the aneurysm.

Wilson et al.\textsuperscript{14} and Stehbens\textsuperscript{12} referred to the unusually high incidence of aneurysms on the anterior communicating artery in the presence of hypoplasia of the first portion of one anterior cerebral artery. They apparently were referring to the same pattern of the circle that we have described as existing in the presence of anterior trifurcation of an internal carotid artery. We agree that this portion of this type of circle is unusually vulnerable to the formation of aneurysms.
We have not made extensive histologic studies. We are however impressed that with this pattern of branching of the internal carotid artery, the anterior communicating segment of the circle is exposed to the same pulsating blood flow as the other major arteries at the base of the brain rather than the relatively minimal flow that must occur through the normal anterior communicating artery. It is also interesting that practically all aneurysms of the anterior communicating artery arise from its anterior wall, i.e., the wall of the artery that would receive the greatest force of the pulse wave. Further, with anterior trifurcation, there is essentially a bifurcation of the anterior cerebral segment of the circle into the ipsilateral anterior cerebral artery distal to the circle and the anterior communicating artery. The unusually high incidence of aneurysms in anterior communicating segment of this type of circle may thus serve as support for Turnbull’s theory that the media are often “inherently” weak at points of branching.

These observations suggest that patients with a ruptured aneurysm of the anterior communicating artery would not do well following either proximal anterior cerebral ligation or carotid ligation as reported by McKissock et al. Since aneurysms of the anterior communicating artery are usually better visualized by angiography through one internal carotid than through the other, and since undoubtedly the artery that filled the aneurysm best would be chosen for ligation, it seems likely that most such liguations would deprive both cerebral hemispheres of the greater portion of their direct blood flow. This assumption is supported by the observation by McKissock et al. that the commonest cause of death in their surgical patients was postoperative cerebral infarction.

Summary

We have examined 1,000 circles of Willis for symmetry, size of component segments, and the presence of aneurysms and have classified the patterns of branching of the internal carotid arteries: 14.3 per cent of the circles demonstrated persistence of the early fetal pattern of trifurcation unilaterally and 0.84 per cent bilaterally; 10.7 per cent of the circles demonstrated some form of anterior trifurcation of one internal carotid artery. Of the total 67 aneurysms found, 26 were on the anterior communicating segment of the circle and 15 of these were on a circle with typical or modified anterior trifurcation of one internal carotid artery. Thus, 22.5 per cent of the aneurysms occurred on a type of circle representing 10.7 per cent of the total group.

We concluded that because the various patterns of branching of the internal carotid artery can be readily identified by angiography, and since they show a consistent relationship to other segments of the circle, the entire structure of the circle can be predicted quite accurately and its efficiency as a route for collateral blood flow evaluated.

References