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Relationship between the calibre of carotid arteries and the configuration of the circle of Willis in healthy older persons

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Aim. **Recent papers have pointed out that the severity of brain damage that follows carotid occlusion is largely influenced by the state of integrity and functionality of the circle of Willis. In spite of this, duplex scanning investigation of carotid arteries has traditionally been focused on the assessment of the degree of the stenosis, while other features, such as the calibre of carotid arteries and their possible asymmetry, have often been neglected. The aim of the present paper was to verify, in a cohort of older persons, whether, based on the calibre of internal carotid arteries and their possible asymmetry, abnormalities of the circle of Willis can be predicted. Such information could be used to identify high risk patients in whom the status of the circle of Willis should be investigated by MR angiography.**

Methods. **We studied 118 healthy older persons with both duplex scanning investigation of carotid arteries and MR angiography of the circle of Willis.**

Results. **We found that the finding of abnormal internal carotid artery calibres was always associated with abnormalities of the precommunicating segments either of the anterior or of the posterior cerebral arteries. Abnormalities of communicating arteries did not affect the calibre of internal carotid arteries, but abnormalities of anterior communicating arteries could always be detected by contralateral common carotid artery compression manoeuvres.**

Conclusion. **In conclusion our findings show that, in healthy older persons, duplex scanning investigation of carotid arteries may provide useful information about the integrity and functionality of the circle of Willis. Future studies should confirm our findings in patients with atherosclerotic lesions of internal carotid arteries.**

KEY WORDS: Carotid stenosis, ultrasonography - Circle of Willis - Aged - Aged, 80 and over - Magnetic resonance angiography.

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Recent papers have pointed out that the extension and severity of the brain damage that follows the occlusion of a carotid artery are strongly influenced by the state of integrity and functionality of the circle of Willis.[1-3] A full prediction of the status of the circle of Willis requires MR angiography. By using this technique, Kane *et al.*[4] have recently demonstrated that subjects with unilaterally absent or hypoplastic precommunicating segment of the anterior cerebral artery also show a significantly smaller ipsilateral intracranial internal carotid artery compared to the contralateral. These findings suggest that the absolute calibre of carotid arteries and their possible asymmetry should always be recorded during a duplex scanning examination, because such information may be important to establish the risk of major stroke. On the contrary, duplex scanning investigation has always been limited to the assessment of the degree of stenosis and of the embolic risk of the plaque.[5-7]

The aim of the present paper was to verify whether, based on the calibre of internal carotid arteries and their possible asymmetry, abnormalities of the circle of Willis can be predicted. Such information could be used to identify, by duplex scanning, high risk patients that should be further investigated by MR angiography.

TABLE I.—*The calibre of internal carotid arteries in the various groups, according to the configuration of the circle of Willis.*

Hypoplastic or absent vessel(s)	Number of subjects	Calibre of internal carotid arteries (mm) (mean+SD)	
		Right	Left
None (=complete configuration of the Circle of Willis)	54	4.32+0.27	4.27+0.29
Right posterior communicating artery	4	4.36±0.33	4.31±0.18
Left posterior communicating artery	11	4.50±0.15	4.28±0.22
Both posterior communicating arteries	17	4.46±0.17	4.59±0.17
Anterior communicating artery	3	4.29±0.65	4.38±0.29
Anterior communicating artery+ left posterior communicating artery	4	4.68±0.18	4.61±0.11
Right precommunicating segment of posterior cerebral artery	2	6.16±0.31	4.42±0.18
Left precommunicating segment of posterior cerebral artery	6	4.32±0.12	6.20±0.13
Both precommunicating segment of posterior cerebral artery	5	6.04±0.33	6.05±0.28
Left precommunicating segment of posterior cerebral artery +right posterior communicating artery	7	4.32±0.28	6.20±0.29
Left precommunicating segment of anterior cerebral artery +left posterior communicating artery	3	5.50±0.20	3.60±0.10
Left precommunicating segment of anterior cerebral artery +both posterior communicating artery	1	5.3	3.6
Left precommunicating segment of anterior cerebral artery+ left precommunicating segment of posterior cerebral artery	1	5.3	4.5

Materials and methods

One-hundred and 18 consecutive healthy volunteers, 60 males and 58 females, aged from 65 to 88 years (mean 75.9±SD 4.9) underwent duplex scanning investigation of carotid arteries and MR angiography of the circle of Willis.

All patients received a detailed description of the research project and signed an informed participation consent.

All potential participants were evaluated for exclusion criteria. The evaluation included a medical history, a physical examination and routine blood tests. Subjects with history or evidence of cerebrovascular events, affected by hypertension, diabetes or severe dyslipidemia were excluded, as well as subjects with internal carotid arterys atherosclerotic lesions at duplex scanning investigation.

Duplex scanning investigations were performed by the same physician with the subject in the supine position, by an Acuson 128XP System, using a 7 MHz probe, for imaging, and a pulsed 5 MHz Doppler for analysis of flows. The lumen of internal carotid arteries was measured as the largest obtainable value in the longitudinal section, and checked against the value calculated from the smallest obtainable circumference in the transverse section, 15 mm distally to the bulb, as in the NASCET.[8] All the subjects underwent compression manoeuvres of the contralateral common carotid artery, applied low in the neck, proximal to the sternal head of the clavicle, for 3 to 5 heart beats, to avoid systemic cardiovascular reactions. A positive response was defined as an increase in Peak Systolic Velocity (PSV) of at least 20% in the examined internal carotid artery increased.[9-12]

Three-dimensional time-of-flight MR angiographies were performed by the same radiologist using a NT-1.5 Gyroscan apparatus from Philips Medical Systems. A segment of the circles of Willis was classified as hypoplastic when the diameter was less than 0.8 mm.[13] Posterior cerebral arteries whose main stem originated from the ipsilateral internal carotid artery, instead of from the basilar artery, were defined as foetal posterior cerebral arteries. The analysis of variations of the circle of Willis was focused on the anatomical completeness of the circle itself. Less hemodynamically important variants of the circle, such as the presence of accessory anterior or middle cerebral arteries, were not considered in this study.

Subjects were grouped according to the configuration of the circle of Willis.

Differences of internal carotid artery calibres across groups were tested by 1-way ANOVA. Ninety-five percent confidence intervals of differences were calculated, too.[14]

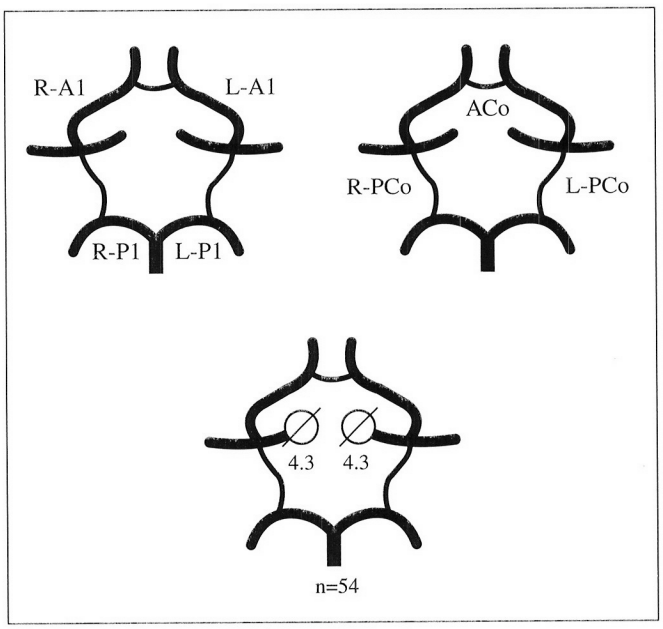

Fig. 1.—Top: vascular segments constituting the circle of Willis. Bottom: calibre of internal carotid arteries in normally configurated circles of Willis.

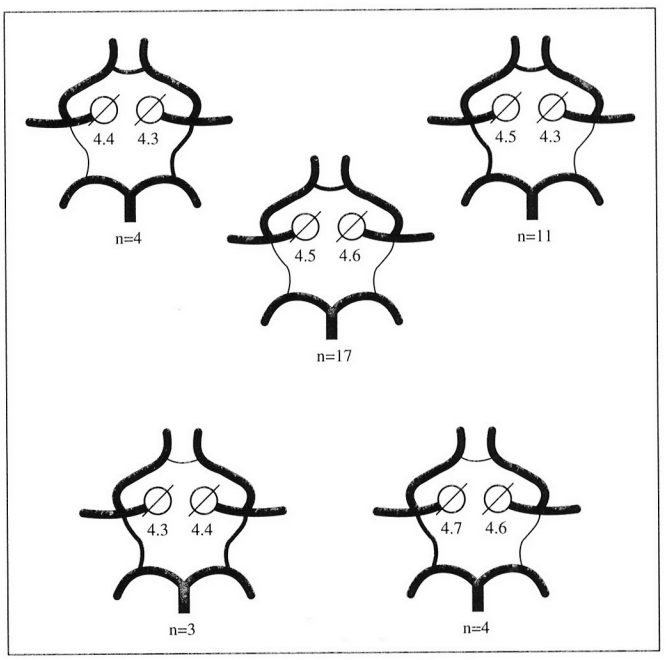

Fig. 2.—Top: calibrate of internal carotid arteries in circles of Willis with anbormalities of the posterior communicating artery. Bottom: calibre of internal carotid arteries in circles of Willis with abnormalities of the anterior communicating artery, alone or associated with abnormalities of the posterior communicating artery.

Results

Table I shows the calibre of internal carotid arteries in the various groups according to the configuration of the circle of Willis. Figure 1 shows a schematic drawing of a normal circle of Willis (top) and the related calibres of internal carotid arteries (bottom). The calibres of internal carotid arteries of the participants in whom the MR angiography showed abnormalities limited to the anterior or posterior communicating arteries, even in association, were similar to those with a normal circle of Willis (Figure 2, top and bottom). Subjects with unilateral foetal posterior cerebral artery, alone or associated with abnormalities of the anterior or posterior communicating arteries, showed significantly larger ipsilateral internal carotid arteries compared both to their own contralateral internal carotid artery ($p<0.001$, 95% IC 1.7-2.1 mm) and to the internal carotid arteries of subjects with a complete circle of Willis ($p<0.001$, 95% IC 1.7-2.1 mm) (Figure 3, top). Subjects with bilateral foetal posterior cerebral arteries showed significantly larger internal carotid arteries compared to the internal carotid arteries of subjects with a complete circle of Willis ($p<0.001$, 95% IC 1.4-2 mm), (Figure 3, bottom). Subjects with unilateral hypoplasia or absence of the precommunicating segment of the anterior cerebral artery showed a significantly smaller ipsilateral internal carotid artery compared both to their own contralateral internal carotid artery ($p<0.001$, 95% IC 1.5-2.1 mm) and to the internal carotid arteries of subjects with a complete circle of Willis ($p<0.001$, 95% IC 0.4-1 mm), (Figure 4, top). No subject presented with bilateral hypoplasia or absence of the precommunicating segment of the anterior cerebral artery. The only one subject with left foetal posterior cerebral artery and left hypoplastic precommunicating segment of the anterior cerebral artery showed a normal left internal carotid artery and a large right internal carotid artery (Figure 4, bottom).

Compression manoeuvres of the contralateral common carotid artery were negative only in 12 subjects. Seven of them showed at MR angiography hypoplasia or absence of the anterior communicating artery and the remaining 5 subjects showed hypoplasia or absence of the pre-communicating segment of the anterior cerebral artery. No subject with integrity of the anterior part of the circle of Willis showed a negative response to compression manoeuvres of

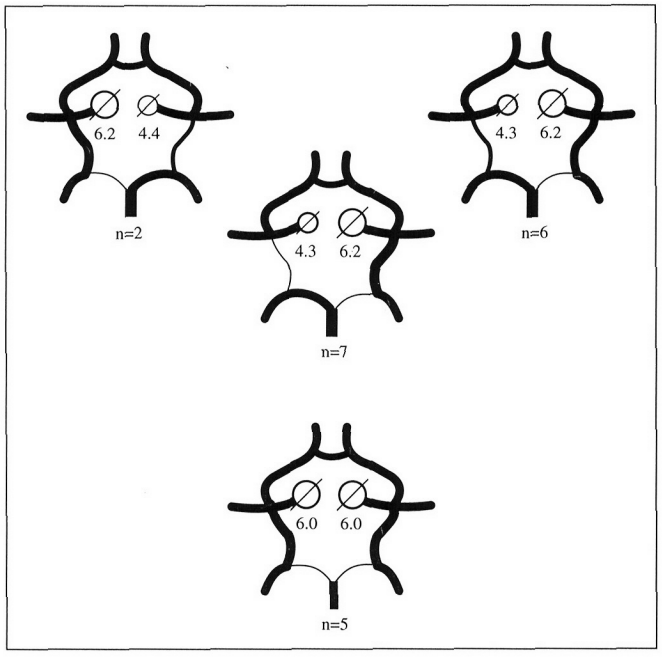

Fig. 3.—Top: calibre of internal carotid arteries in circles of Willis with abnormalities of the precommunicating segment of posterior cerebral artery (=foetal posterior cerebral artery), alone or associated with abnormalities of the posterior communicating artery. Bottom: calibre of internal carotid arteries in a circle of Willis with bilateral abnormalities of the precommunicating segment of posterior cerebral artery (=foetal posterior cerebral artery).

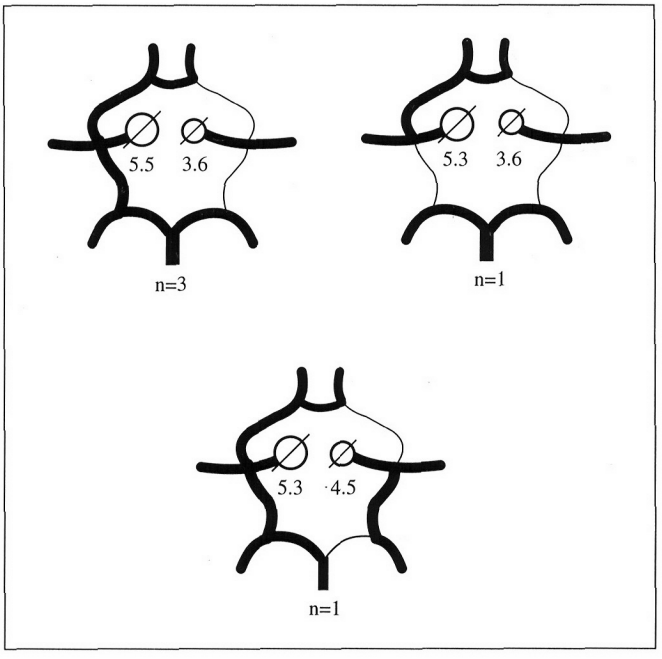

Fig. 4.—Top: calibre of internal carotid arteries in circles of Willis abnormalities of the precommunicating segment of the anterior cerebral artery, associated with abnormalities of the posterior communicating artery. Bottom: calibre of internal carotid arteries in a circle of Willis with abnormalities of the precommunicating segment of anterior cerebral artery, associated with abnormalities of the precommunicating segment of the posterior cerebral artery.

the contralateral common carotid artery. Figure 5 shows the response to compression manoeuvre in a subject with normal circle of Willis (top) and in a subject with hypo-aplasia of the anterior communicating artery (bottom). Figure 6 shows the response to compression manoeuvre in a subject with unilateral fetal posterior cerebral artery (top) and in a subject with hypo-aplasia of the precommunicating segment of the anterior cerebral artery (bottom).

Table II shows a simple algorithm for the diagnosis of abnormalities of the circle of Willis, based on the calibre of carotid arteries and their possible asymmetry.

Discussion and conclusions

Our findings show that in healthy older persons the calibre of internal carotid arteries reflects the anatomical variants of the circle of Willis involving the anterior and the posterior cerebral arteries, but is not influeced by the presence of anatomical variants involving the anterior and the posterior communicating arteries.

These findings may be explained by the fact that the anterior and the posterior cerebral arteries are functionally active in healthy subjects [15] and the congenitally increased, or decreased, flow in the ipsilateral internal carotid artery, respectively, in case of persistence of a foetal posterior cerebral artery and in case of hypoplasia or absence of the precommunicating segment of the anterior cerebral artery, is responsible for the increased, or decreased, calibre of the carotid vessel.

On the contrary, in the healthy subject the communicating arteries are functionally silent, due to the absence of pressure gradients between the right and the left side as well as between the anterior and the posterior part of the circle.[15] Once a gradient is evoked, as in compression manoeuvres, communicating arteries are recruited, and an increase of flow in the examined vessels may be easily detected.[9-12] In our cli-

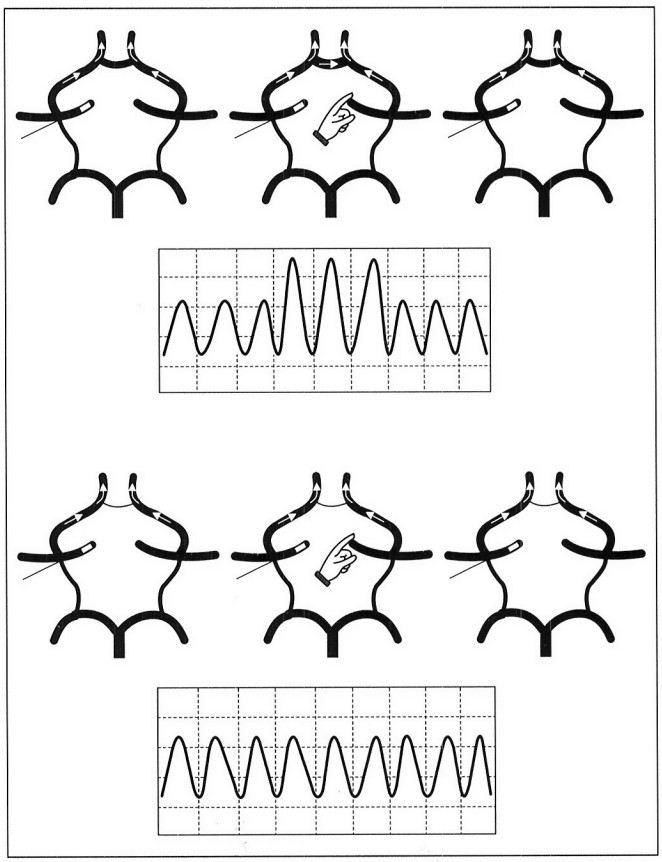

Fig. 5.—Top: compression manoeuvre in a subject with normal circle of Willis. Bottom: compression manoeuvre in a subject with hypo-aplasia of the anterior communicating artery.

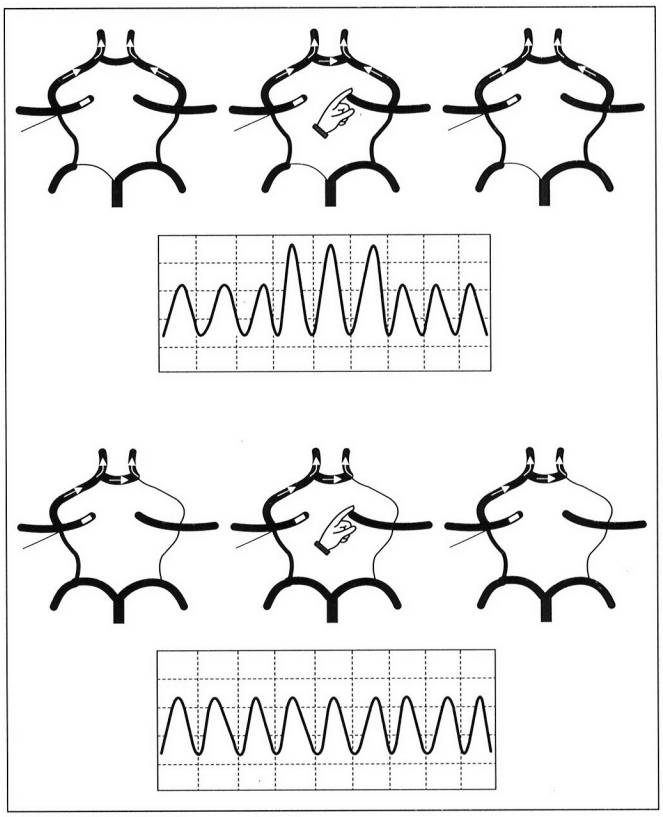

Fig. 6.—Top: compression manoeuvre in a subject with unilateral fetal posterior cerebral artery. Bottom: compression manoeuvre in a subject with hypo-aplasia of the precommunicating segment of the anterior cerebral artery, associated with hypo-aplasia of the posterior communicating artery.

TABLE II.—*Algorithm for the diagnosis of abnormalities of the circle of Willis based upon the calibres of internal carotid arteries.*

Symmetry/asymmetry	Contralateral common carotid artery compression manoeuvre	Diagnosis
Symmetric calibres (normal size)	Positive	Normal or hypo-aplasia of posterior communicating artery/ies
	Negative	Hypo-aplasia of anterior communicating artery
Symmetric calibres (larger size)	Positive	Bilateral foetal posterior cerebral artery
	Negative	(Not found)
Asymmetric calibres	Positive	Unilateral foetal posterior cerebral artery
	Negative	Hypo-aplasia of the precommunicating segment of the anterior cerebral artery

nical series the response to the compression manoeuvre was highly specific with no false positive result.

Compression manoeuvres, first described by Franceschi in the very beginning of the era of Doppler ultrasonography,[9] are currently used in transcranial Doppler [10-12] and are performed by compressing, in 2 steps, first the contralateral common carotid artery, with the Doppler sample in the precommunicating segment of the anterior cerebral artery, to test the functional patency of the anterior communicating artery, and secondly the ipsilateral common carotid artery, with the Doppler sample in the precommunicating segment of the posterior cerebral artery, to test the functional patency of the posterior communicating artery. However, the limited extension of the temporal acoustic window, especially in older patients, may seriously limit the number of subjects in whom a technically adequate examination can be obtained.[12, 16] Furthermore, the precommunicating segment of the posterior cerebral artery is only about 8 mm long and the Doppler sample may be unintentionally positioned in the postcommunicating instead of the precommunicating segment of the artery, causing an overestimation of abnormalities.[12, 17]

On the contrary, duplex scanning investigation of carotid arteries from the neck can be performed in almost all the patients, though even by using this technique, posterior communicating artery patency cannot be tested.

However, the importance of a functional posterior communicating artery in carotid obstructive diseases is not yet clear.[1, 10, 11, 15] Recently Hartkamp,[2] by using MR angiography, has demonstrated that survivors from unilateral internal carotid artery occlusion, with or without a significant contralateral carotid artery stenosis, rely on collateral flow *via* the anterior part of the circle of Willis, and that only survivors from bilateral internal carotid occlusion rely on collateral flow *via* the posterior part of the circle of Willis.

In conclusion our findings show that duplex scanning investigation of carotid arteries, besides providing the measure of the degree of stenosis, also provides useful information about the configuration of the circle of Willis in healthy older persons. Future studies should confirm our findings in patients with atherosclerotic lesions of the internal carotid artery.

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