Journal of Cardiovascular Surgery, Dec 2002, 43, 6, ProQuest Medical Library
pg. 887

J CARDIOVASC SURG 2002;43:887-90

The circle of Willis in healthy older persons

C. MACCHI[1], R. MOLINO LOVA[1], B. MINIATI[1], M. GULISANO[2], C. PRATESI[3], A. A. CONTI[1, 4], G. F. GENSINI[1, 4]

[1]Department of Cardiovascular Medicine
Don Gnocchi Foundation, Florence, Italy
[2]Department of Human Anatomy and Histology,
[3]Department of Vascular Surgery,
[4]Department of Internal Medicine and Cardiology,
University of Florence, Italy

Background. **The current indication for carotid surgery is based upon the percentage of stenosis of the internal carotid artery. This approach shows many limitations, one of which is to presume the anatomical completeness of the circle of Willis in all patients who are evaluated. On the contrary, there is increasing evidence of a great natural variability in the configuration of the circle of Willis.**

Methods. **The aim of the present paper was to investigate, by magnetic resonance angiography, the variability of the circle of Willis in a cohort of 118 healthy older persons.**

Results. **The circle of Willis showed an entirely complete configuration in 47% of the subjects, a complete configuration of its anterior part in 90% of the subjects, and a complete configuration of its posterior part in 48.5% of the subjects.**

Conclusions. **These findings confirm the great variability of the circle of Willis even in healthy older persons and suggest that, in indicating carotid surgery, the configuration of the circle of Willis should also be taken into account.**

KEY WORDS: Circle of Willis - Cerebrovascular accident - Carotid stenosis, surgery - Aged - Magnetic resonance angiography.

The current indication for carotid surgery is based upon the percentage of stenosis of the internal carotid artery.

A recent statistical review [1] of the results of the NASCET [2, 3] and of the ECST [4, 5] has shown that in symptomatic patients with severe stenosis (NASCET >70% = ECST >80%) surgery reduces the relative risk of lethal or disabling ipsilateral stroke by 48% (95% CI = 27-73%) and that the number of patients needed to be operated on to prevent one lethal or disabling stroke is 15 (95% CI = 10-31). In symptomatic patients with less severe stenosis (NASCET 50-69% = ECST 70-79%) surgery reduces the relative risk of lethal or disabling ipsilateral stroke by 27% (95% CI = 15-44%) and the number of patients needed to be operated on to prevent one lethal or disabling stroke is 21 (95% CI = 11-125). Furthermore, the statistical review [6] of the results of the ACAS [7] has shown that in asymptomatic patients, though there is some evidence favouring surgery, the effect is, at best, barely significant and extremely small in terms of absolute risk reduction.

These results are not as brilliant as one would expect, probably because the approach to the prevention of major strokes just based upon the percentage of stenosis shows some limitations. The most obvious is to presume the anatomical completeness of the circle of Willis in all the patients who are evaluated. On the contrary, there is increasing evidence of a great natural variability in the configuration of the circle of Willis.[8] The authors themselves have already demonstrated, by using Magnetic Resonance (MR) angiography, the great natural variability in the configuration of the circle of Willis in a cohort of healthy subjects whose age ranged between 20 and 82 years.[9]

The aim of the present paper was to focus on the variability of the circle of Willis in a cohort of healthy older persons, investigated by using MR angiography.

Address reprint requests to: C. Macchi, Via Padule. 115, 50039 Vicchio (FI), Italy.

TABLE I.—*Configuration of the circle of Willis in 118 healthy older persons.*

No of hypoplastic or absent vessels	No. of subjects	Hypoplastic or absent vessels	Sex		Side			Part	
			M	F	L	R	C	A	P
None	54	—	28	26	—	—	—	—	—
1	15	Posterior communicating artery	7	8	11	4	—	—	15
	8	Pre-communicating segment of posterior cerebral artery	4	4	6	2	—	—	8
	3	Anterior communicating artery	1	2	—	—	3	3	—
2	17	Both posterior communicating arteries	10	7	17	17	—	—	34
	5	Both pre-communicating segments of posterior cerebral artery	1	4	5	5	—	—	10
	7	Left pre-communicating segment of posterior cerebral artery+ right posterior communicating artery	4	3	7	7	—	—	14
	4	Anterior communicating artery+ left posterior communicating artery	3	1	4	—	4	4	4
	3	Left pre-communicating segment of anterior cerebral artery+ left posterior communicating artery	1	2	6	—	—	3	3
	1	Left pre-communicating segment of anterior cerebral artery+ left pre-communicating segment of posterior cerebral artery	—	1	2	—	—	1	1
3	1	Left pre-communicating segment of anterior cerebral artery+ left posterior communicating artery+ right posterior communicating artery	1	—	2	1	—	1	2
Total	118		60	58	60	36	7	12	91

Materials and methods

One-hundred-eighteen healthy volunteers, 60 males and 58 females, aged from 65 to 88 years (mean 75.9±S.D. 4.9) underwent MR angiography of the circle of Willis. Sixty-nine subjects (58%) belonged to the series previously published by the authors.[9] and 49 subjects (42%) were newly recruited. All the subjects signed the informed consent to be included in the study.

A preliminary echo-Doppler evaluation of carotid and vertebral arteries excluded any extracranial vascular disease. No history of previous adverse cerebrovascular event was reported. No subject was affected by hypertension, diabetes mellitus or other major systemic diseases.

Three-dimensional time-of-flight MR angiographies (3D-TOF-MRA) were performed using a NT-1.5 Gyroscan apparatus from Philips Medical Systems (200×200 mm field of view, 256×256 matrix size, 0.61 sq.mm pixel area, 0.78×0.78 mm pixel resolution), as suggested by Krabbe-Hartkamp.[8] Fifty 1.2 mm thickness sections, with 0.6 mm overlap, were acquired.

Circles of Willis were classified as deficient if one or more of the component segments were hypoplastic (diameter <0.8 mm) or absent.[8]

Attention was paid to differentiating the posterior communicating artery from the anterior choroidal artery, both originating from the internal carotid artery and with a backward course: only the vessel also communicating with the posterior cerebral artery was considered as a posterior communicating artery.

Posterior cerebral arteries whose main stem originated from the ipsilateral internal carotid artery, instead of from the basilar artery, were defined as fetal-type posterior cerebral arteries.

The analysis of variations of the circle of Willis focused on the anatomical completeness of the circle itself. Less hemodynamically important variants of the circle, such as the partial fusion of the two anterior cerebral arteries or the presence of accessory anterior or middle cerebral arteries, were not considered "anomalies" for this study.

The χ^2 test was used to compare the prevalence of incomplete circle in males and females, right *versus* left side and anterior *versus* posterior part of the circle of Willis.

Results

The circle of Willis showed an entirely complete configuration in 47% of the subjects, a complete ante-

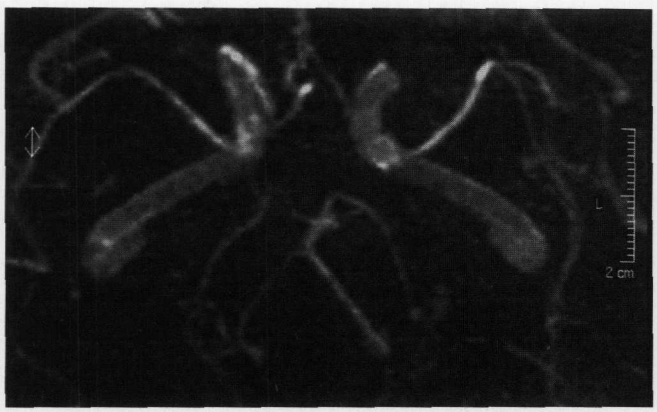

Fig. 1.—3D-TOF-MRA showing an example of absence of the left posterior communicating artery.

Fig. 2.—3D-TOF-MRA showing an example of absence of both posterior communicating arteries.

rior part of the circle in 90% of the subjects, and a complete posterior part of the circle in 48.5% of the subjects. Fetaltype posterior cerebral arteries were present in 18% of the cases.

Table I shows the various types of configuration of the circle of Willis found in the study population.

Twenty-six subjects showed one hypoplastic or absent vessel, thirty-seven subjects showed two hypoplastic or absent vessels, and one subject showed three hypoplastic or absent vessels.

A total of 103 vessels were hypoplastic or absent: 12 in the anterior and 91 in the posterior part of the circle, 60 in the left side, 36 in the right side and 7 in the central part of the circle (anterior communicating artery).

Both in men and in women, the prevalence of an incomplete circle was more frequent in the posterior part and on the left side of the circle. The most frequent anomaly was, in fact, hypoplasia or absence of the left posterior communicating artery (32% of men and 29% of women). Figures 1 and 2 show, respectively, an example of absence of the left posterior communicating artery and of absence of both posterior communicating arteries.

The prevalence of incomplete circle of Willis was similar in men and in women, even when the comparison was restricted to the anterior or to the posterior part of the circle.

Compared with the results from the study previously published by the authors,[9] the present series showed a higher, though not statistically significant, percentage of normal circle of Willis (47% *vs* 41%).

Discussion

Our findings demonstrate that in healthy older persons the circle of Willis shows an entirely complete configuration in 47% of cases, a complete anterior configuration in 90% and a complete posterior configuration in 48.5%.

Before approaching the discussion of our results, technical limitations of 3D-TOF-MRA need to be made clear.

The signal intensity of blood flow within a vessel is dependent on the replenishment of fully magnetized spins at the entry of the imaging section.[9] Accordingly, nonvisualization of a vessel may be due either to the absence of the vessel or to a very slow or turbulent flow within the vessel itself. Completeness of the configuration of the circle of Willis evaluated by using 3D-TOF-MRA is, thus, expected to be underestimated, both in healthy subjects that may show a negligible flow across the communicating vessels due to the symmetrical blood supply to the circle of Willis, and in patients with severe stenosis or occlusion of the Internal Carotid artery that may show turbulent flow in one or more segments of the circle due to the presence of collateral pathways.

Though figures largely vary in the literature, according to the study population (healthy subjects or patients with cerebrovascular diseases) and to the method of investigation (autopsy or MR angiography),[8, 10-16] our findings confirm the great natural variability in the configuration of the circle of Willis in a study population of healthy older persons.

Focusing on available data about subjects free from

extracranial vascular disorders or neurological diseases, which are indeed few in the literature, Alpers *et al.*[11] by using anatomical dissection, reported a 52% prevalence of entirely complete configurations of the Circle. More recently Ross *et al.*,[16] by using three dimensional phase-contrast MR angiography, reported a detectable flow in both posterior communicating arteries in 48% of the 50 normal subjects investigated. Furthermore, Krabbe-Hartkamp,[8] by using 3D-TOF-MRA in 150 healthy or "relatively" healthy subjects, reported a 42% prevalence of entirely complete configurations, a 52% prevalence of complete posterior configurations and a 74% prevalence of complete anterior configuration. Eventually, Macchi *et al.*,[9] by using the same technique, reported in a previous paper a 41% prevalence of entirely complete configuration.

Considered as a whole, the results of the present study are consistent with previously reported data.

Worthy of interest is the fact that compared with our previous results [9] the present series, made up of older persons (75.9+4.9 *vs* 64.7+18 years), showed a higher, though not statistically significant, percentage of entirely complete configurations of the circle of Willis (47% *vs* 41%).

By using a complex mathematical model, Cassot *et al.*[17] have shown that the circle of Willis does behave as an intracranial blood pressure equalizer and is capable of fully compensating for the deficit of flow in case of severe stenosis or occlusion of a feeding vessel.

Furthermore, by using MR angiography, Hartkamp *et al.*[10] demonstrated that patients with severe carotid stenosis or occlusion and minor neurological deficits, are more likely to show a higher percentage of entirely complete configurations, complete anterior configurations and complete posterior configurations of the circle of Willis, compared to healthy controls.

An interesting hypothesis to explain these data might be the following: if the occlusion of a feeding vessel occurs in a patient with an important incompleteness of the circle of Willis, the chance of survival is very low. That is why survivors show a higher percentage of "normal" circle of Willis and why our older healthy subjects show a higher prevalence of entirely complete configurations of the circle of Willis.

Conclusions

In conclusion, our findings show that the configuration of the circle of Willis may vary largely in healthy older persons and that the probability of showing an entirely complete configuration of the circle is higher in healthy older persons compared with younger ones.

This suggests that "incompleteness" of the circle of Willis might represent a risk factor that should be taken into the due account even in indicating carotid surgery.

References

1. Cina CS, Clase CM, Haynes RB. Carotid endarterectomy for symptomatic carotid stenosis. Cochrane Database Syst Rev 2000;CD 001081.
2. North American Symptomatic Carotid Endarterectomy Trial (NASCET) Steering Committee. North American Symptomatic Carotid Endarterectomy Trial: methods, patients characteristics, and progress. Stroke 1991;22:711-20.
3. North American Symptomatic Carotid Endarterectomy Trial Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high grade carotid stenosis. N Engl J Med 1991;325:445-53.
4. European Carotid Surgery Trialists' Collaborative Group: MRC European Carotid Surgery Trial: interim results for symptomatic patients with severe (70-99%) or with mild (0-29%) carotid stenosis. Lancet 1991;337:1235-43.
5. No author listed. Randomized trial of endarterectomy for recently symptomatic carotid stenosis: final results of the MRC European Carotid Surgery Trial. Lancet 1998;351:1379-87.
6. Chambers BR, You RX, Donnan GA. Carotid endarterectomy for asymptomatic carotid stenosis. Cochrane Database Syst Rev 2000;CD001923.
7. Executive Committee for the Asymptomatic Carotid Atherosclerosis Study: Endarterectomy for Asymptomatic Carotid Artery Stenosis. JAMA 1995;273:1421-8.
8. Krabbe-Hartkamp MJ, van der Grond J, de Leeuw FE, de Groot JC, Algra A, Hillen B *et al.* Circle of Willis: morphologic variations on three-dimensional time-of-flight MR angiograms. Radiology 1998;207:103-11.
9. Macchi C, Catini C, Cerini F, Gulisano M, Pacini P, Cecchi F *et al.* Magnetic resonance angiographic evaluation of *circulus arteriosus cerebri* (circle of Willis): a morphologic study in 100 human healthy subjects. It J Anat Embryol 1996;101:115-23.
10. Hartkamp MJ, van der Grond J, van Everdingen KJ, Hillen B, Mali WP. Circle of Willis collateral flow investigated by Magnetic Resonance Angiography. Stroke 1999;30:2671-8.
11. Alpers BJ, Berry RG, Paddison RM. Anatomical studies of the circle of Willis in normal brains. Arch Neurol Psychiatr 1959;81:409-18.
12. Alpers BJ, Berry RG. Circle of Willis in cerebral vascular disorders. Arch Neurol 1963;8:398-402.
13. Riggs HE, Rupp C. Variation in form of the circle of Willis. Arch Neurol 1963;8:8-14.
14. Miralles M, Dolz JL, Cotillas J, Aldoma J, Santiso MA, Gimenez A *et al.* The role of the circle of Willis in carotid occlusion: assessment with phase contrast MR angiography and trans cranial duplex. Eur J Endovasc Surg 1995;10:424-30.
15. Brunereau L, Lévy C, Arrivé L. Anatomie du polygone de Willis en ARM 3D temps de vol avec analyse des partitions. J Radiol 1995;76:573-7.
16. Ross MR, Pelc NJ, Enzmann DR. Qualitative phase contrast MRA in the normal and abnormal circle of Willis. AJNR 1993;14:19-25.
17. Cassot F, Vergeur V, Bossuet P, Hillen B, Zagzoule M, Verges JPM. Effects of anterior communicating artery diameter on cerebral hemodynamics in internal carotid artery disease. A model study. Circulation 1995;92:3122-31.