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**The Measurement of the Calibers and Blood-Flow Velocities  
of the Arteries of the Circle of Willis:  
A Statistical Investigation of 120 Living Subjects  
using Transcranial Color-Doppler Ultrasonography**

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*Key words:* caliber, blood-flow velocity, circle of Willis.

SUMMARY

We have examined 120 subjects (52 men, 68 women; age range: 19 to 89) with no vascular pathology. In each subject, we used transcranial color-doppler ultrasonography to measure the calibers and blood-flow velocities of the anterior, middle, and posterior cerebral arteries (ACA, MCA, and PCA, respectively). Generally, the mean measured calibers were lower than those that have been described in cadaveric studies by other investigators. The mean caliber of the MCA was found to be higher than those of the ACA or PCA; this difference was statistically significant ( $p < 0.05$ ). With age, the calibers of the ACA, PCA and PCA tended to increase, but this trend was not statistically significant. We have noted a statistically significant difference between the left and right sides, the arteries of the left being larger than those of the right. However, there was no statistically significant relationship between vessel caliber and age, sex, or body weight, though the women's arteries tended to be narrower than those of the men.

With respect to the maximal and mean blood-flow velocities, no statistically significant relationships with regard to side (left or right), sex, age, or body weight were demonstrable. However, the mean and maximal blood-flow velocities of the MCA were found to be statistically higher than those of the ACA or PCA ( $p < 0.02$ ). This was especially true under the age of 60 ( $p < 0.01$ ).

## INTRODUCTION

Many studies of the cerebral circulation have been performed, because of both its clinical importance and the frequency of anomalies and irregularities of the arterial circle described by Willis in the 17<sup>th</sup> century. Numerous investigators have described the characteristics and anomalies of this circle (Mori, 1893; Peli, 1902; Cavatorti, 1909; Elliot-Smith, 1909; Adachi, 1928; Decker and Hipp, 1958; Mortillaro *et al.*, 1963; Fazio *et al.*, 1965, 1970; Lazorthes and Gouazé, 1968; Orlandini, 1970; Gulisano *et al.*, 1982; Orlandini *et al.*, 1985).

Nonetheless, the subjects of these morphological studies of the circle of Willis, including measurement of the caliber and length of its arteries, were cadavers.

The arterial calibers and the velocities of blood flow within the arteries of the circle of Willis are extremely important parameters in the clinical evaluation of cases of cerebral thrombosis (Lindegaard, *et al.*, 1986) and hemorrhage (Aaslid, *et al.*, 1984, 1986). These measurements are equally important for the detection and assessment of the influence of vessel hypoplasia (Sedzimir, 1959; Tönnis and Schiefer, 1959; Wollschläger and Wollschläger, 1966; Krayenbuhl *et al.*, 1979).

The aim of this investigation was to measure the calibers and blood-flow velocities of the principle arteries of the circle of Willis in healthy, living human subjects. We have compared our measurements with those reported in the above-cited cadaveric studies. Furthermore, we have compared the arteries of the left and right sides with respect to caliber and blood-flow velocity, and we have examined the influence of sex, age, and body weight on these variables.

## MATERIALS AND METHODS

We have examined 120 healthy, living subjects (52 men, 68 women; age range: 19 to 89) with no vascular pathology. In each subject, we measured the calibers and blood-flow velocities of the anterior cerebral artery (ACA) at a point 2 cm from its origin, the middle cerebral artery (MCA) at a point 1 cm from its origin, and the posterior cerebral artery (PCA) at a point 1 cm from the origin of the posterior communicating artery.

We used an Acuson 128XP color doppler ultrasound system that generated 2MHz color duplex sectorial waves. The examination of the cerebral arteries was performed via the temporal window; in the case of the arteries concerned, the temporal squama is in most cases the only part of the cranium that permits the transmission of ultrasonic waves.

## RESULTS

The mean calibers of the arteries studied are reported in *Table A*. The mean values of maximal and mean blood-flow velocity are reported in *Tables B* and *C*,

TABLE A - Average Calibers (mm  $\pm$ SD)

	Males		Females	
	DX	SN	DX	SN
ACA	1.8 $\pm$ 0.82	2.1 $\pm$ 0.77	1.7 $\pm$ 0.69	1.9 $\pm$ 0.71
MCA	2.6 $\pm$ 0.90	2.7 $\pm$ 0.84	2.4 $\pm$ 0.81	2.5 $\pm$ 0.69
PCA	2.0 $\pm$ 0.68	2.2 $\pm$ 0.70	1.9 $\pm$ 0.59	2.1 $\pm$ 0.74

TABLE B - Values of transcranial doppler systolic velocities.

	Males		Females	
	DX	SN	DX	SN
ACA	79.6 $\pm$ 18.1	78.1 $\pm$ 17.3	77.4 $\pm$ 17.5	76.9 $\pm$ 16.9
MCA	93.1 $\pm$ 17.2	92.3 $\pm$ 16.5	92.3 $\pm$ 19.1	89.8 $\pm$ 18.3
PCA	53.6 $\pm$ 16.8	52.2 $\pm$ 18.1	52.3 $\pm$ 16.6	53.2 $\pm$ 15.9

All values are cm/sec  $\pm$  Standard Deviation.

TABLE C - Values of transcranial doppler mean velocities.

	Males		Females	
	DX	SN	DX	SN
ACA	51 $\pm$ 12.2	50 $\pm$ 13	50.2 $\pm$ 11.3	49.9 $\pm$ 11.8
MCA	62.8 $\pm$ 10.8	63 $\pm$ 11.3	62.5 $\pm$ 13	61.9 $\pm$ 11.6
PCA	43 $\pm$ 11.3	44 $\pm$ 10.7	44.2 $\pm$ 10.7	42.8 $\pm$ 13

All values are cm/sec  $\pm$  Standard Deviation.

respectively. *Figures 1 and 2* illustrate the visualization and measurement of, respectively, the caliber and blood-flow velocity of the middle cerebral artery of one of the 120 subjects.

The mean calibers of the three arteries were lower than those reported in the cadaveric studies. However, the differences were generally not statistically significant. On the other hand, our results correlated well with the measurements of Orlandini, *et al.* (1985), who extrapolated the caliber from the calculated circumference.

*Table A* shows that, in both sexes, the middle cerebral artery was found to have a statistically significant ( $p < 0.05$ ) higher mean caliber as compared to either

the anterior or posterior cerebral artery. This finding agrees with those of the cadaveric studies. The mean arterial calibers were found to increase progressively with age, but this trend was not statistically significant. This confirms the findings of several other investigators (Kani, 1910; Juster 1953; Orlandini, 1970; Gulisano *et al.*, 1982). With respect to patient sex, there were no statistically significant differences ( $p > 0.5$ ), although the calibers of the men's arteries tended to be higher than those of the women. This accords with the results of Orlandini *et al.* (1985).

When the arteries of the two sides were compared, those of the left side were found to be larger than those of the right by a statistically significant margin, as also observed by Adachi (1928), Krayenbuhl and Jasargil (1957), Orlandini (1970), and Orlandini *et al.*, (1985).

In neither sex was there any statistically significant relationship between arterial caliber and body weight.

When the maximal and mean blood-flow velocities (*Tables B and C*) were considered, the values of the middle cerebral artery were found to be higher than those of either the anterior or posterior cerebral artery. In a comparison of middle and posterior cerebral arteries, the difference was statistically significant ( $p < 0.02$ ), especially below the age of 60 ( $p < 0.01$ ).

No statistically significant relationships were observed among blood-flow velocity; side, either in the same patient or in all patients; sex, age, and body weight.

#### DISCUSSION AND CONCLUSIONS

The calibers of the ACA and PCA were only slightly different. The caliber of the PCA tended to be higher than that of the ACA, but not in a statistically significant way. On the other hand, the higher caliber of the MCA in comparison to either of the other two arteries was statistically significant ( $p < 0.05$ ) in both sexes. This result agrees with those of Lanz (1979) and v Reutern (1992).

The values of mean caliber determined in this study were generally lower than those reported by Mori (1893), Peli (1902), Cavatorti (1908), Elliot-Smith (1909), Adachi (1928), or v Decker and Hipp (1958), but not by a statistically significant margin. In contrast, our results correlate well with those of Sedzimir (1959), Tönnis and Schiefer (1959), Wollschläger and Wollschläger (1966), Krayenbuhl *et al.*, (1979), and Orlandini, *et al.* (1985).

The mean calibers of the ACA, MCA, and PCA were found to increase with age, but not in a statistically significant way ( $p = ns$ ). This agrees with the findings of Kani (1910), Orlandini (1970), and Gulisano, *et al.* (1982). This suggest that this parameter does not influence significant alterations in cerebral blood flow.

The failure to demonstrate a relationship between body weight and the mean calibers of the ACA, MCA and PCA; the predominance of the left-sided values in men over those in women are in agreement with our earlier findings regarding the supra-aortic trunks (Macchi and Catini, 1993).

In 3% of our cases, calibers lower than 1 mm were measured. These vessels were considered hypoplastic, in observance of the 1 mm criterion established by Wollschläger and Wollschläger (1966).

The higher maximal and mean blood-flow velocities recorded in the MCA as compared with the other two cerebral arteries is consistent with its higher caliber. That no statistically significant relationship was found between blood-flow velocity and age does not indicate that no circulatory changes occur in old age. Rather, changes in peripheral resistance, which are indirectly evident in studies of diastolic velocity (Planiol *et al.*, 1972; Franceschi, 1980), are balanced by cerebral autoregulatory mechanisms. Furthermore, it is influenced by the hematocrit (Thomas, 1977; Harrison, 1981), a variable that was not considered in this study.

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FIGURE LEGEND

- Fig. 1 — Middle Cerebral Artery: method of visualization and measurement of the caliber using transcranial color doppler imaging.
- Fig. 2 — Middle cerebral artery: method of measurement of the blood flow velocity using transcranial color doppler imaging.



Figs. 1-2

