Distribution of cerebral blood flow in the circle of Willis: a population based MR angiography study

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Abstract

A population based study in 208 subjects was performed to determine the effect of anatomical variations in the circle of Willis (3D TOF) on volume flow (2D PC) in the internal carotid arteries (ICAs) and basilar artery (BA). The ICA volume flow in subjects with a complete configuration of the circle of Willis was 245±65 ml/min. In subjects with a missing A1 segment flow in the contralateral ICA (303±56 ml/min) was significantly increased (P<0.01). In subjects with an unilateral or bilateral fetal type posterior cerebral artery the ICA volume flow was increased (P<0.01) and the BA volume flow decreased (P<0.01).

Introduction

Adequate volume flow in the major brain feeding arteries is crucial to maintain cerebral blood flow and cerebral function. In an anatomically complete circle of Willis the ICA distributes flow into the ipsilateral anterior cerebral artery (ACA) and middle cerebral artery (MCA) and the BA distributes flow into both posterior cerebral arteries (PCAs). However, several studies have shown that up to half of healthy control subjects have an anatomical variant type of the circle of Willis, such as a missing A1 segment of the ACA or a fetal type PCA.[1,2] It is expected that these variations have a direct effect on volume flow in the ICAs and BA. Thusfar, no study has examined the importance of the anatomical variations in the circle of Willis in relation to the volume flow in the ICAs and the BA.

Methods

Two-hundred-eight consecutive patients (mean age, 59.9; range, 29 to 79 years), 182 male and 26 female were included. The MR investigations were performed on a 1.5-T whole-body system (Gyroscan ACS-NT, Philips Medical Systems, The Netherlands). On the basis of a localizer MRA slab in the sagittal plane, a 2-dimensional phase-contrast (2D-PC) section was positioned at the level of the skull base to measure the volume flow (ml/min) in the ICAs and the BA. To visualize the circle of Willis, 50 sections were obtained with a three-dimensional time-of-flight (3D TOF) technique with subsequent maximum-intensity projection (MIP) reconstruction. The anatomy of the anterior and posterior parts of each circle of Willis were assessed on a separate workstation on the basis of source images of the 3D TOF data set (figure 1, figure 2).

Results

A 3.1 ml/min decrease in total volume flow was found per annum of age increase for the entire group (figure 3: p<0.001). No significant male/female differences were found in prevalence of variant types of the circle of Willis. The mean age-corrected volume flow in the ICAs and BA of subjects with a missing A1 segment of the ACA are compared with subjects with present A1 segments of the anterior circle of Willis. The left and right ICA volume flow were pooled for the 197 subjects with presence of both A1 segments of the anterior circle of Willis. In subjects with a missing A1 segment (n=11) the volume flow in the contralateral ICA was significantly increased compared with the volume flow in the ICA in the presence of both A1 segments (*P*<0.01) and with the volume flow in the ipsilateral ICA (*P*<0.01). No significant differences in BA volume flow and total volume flow were found between the two groups. The mean age corrected volume flow (normalized to an age of 60 years, based on the 3.1 ml/min decrease per annum of age increase) in the ICAs and the BA of subjects with a unilateral or bilateral fetal type PCA was compared with subjects with no fetal type posterior PCA. The left and right ICA volume flow was pooled for the 158 subjects with no fetal type posterior configuration of the circle of Willis. We also pooled the left and right ICA flow for the 13 subjects with a bilateral fetal type PCA. In subjects with an unilateral fetal type PCA the volume flow in the ICA on the ipsilateral side (*P*<0.01) and the volume flow in the basilar artery (*P*<0.01) were significantly different compared with the corresponding volume flow in the ICA and BA in a circle of Willis with feeding of the PCAs from the basilar artery. In subjects with a bilateral fetal type PCA the volume flow in the ICA (*P*<0.01) and BA flow (*P*<0.01) were significantly different compared with subjects with feeding of the PCAs from the basilar artery. No significant differences were found in total volume between subjects with and without a variant type of the circle of Willis.

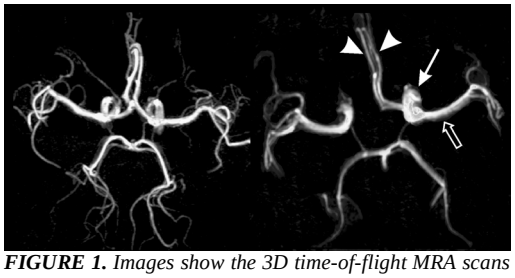

FIGURE 1. *Images show the 3D time-of-flight MRA scans (30/6.9, flip angle 20°) for an anatomical complete circle of Willis (left image) and for a variant type circle of Willis (right image) with a missing A1 segment of the anterior cerebral artery on the right. In this variant type circle of Willis the ICA on the left (arrow) is feeding both anterior cerebral arteries (one arrowhead each) and the ipsilateral MCA (open arrow).*

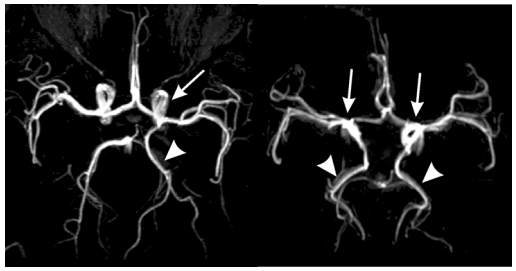

FIGURE 2. *Images show the 3D time-of-flight MRA scans (30/6.9, flip angle 20°) for a variant type circle of Willis with a unilateral fetal type PCA (left image) and a bilateral fetal type PCA (right image). In these fetal variant type circles the ICAs (arrows) on the side of the fetal type PCA are feeding the ipsilateral PCA in addition to the ipsilateral ACA and MCA. Arrow heads indicate fetal type PCAs.*

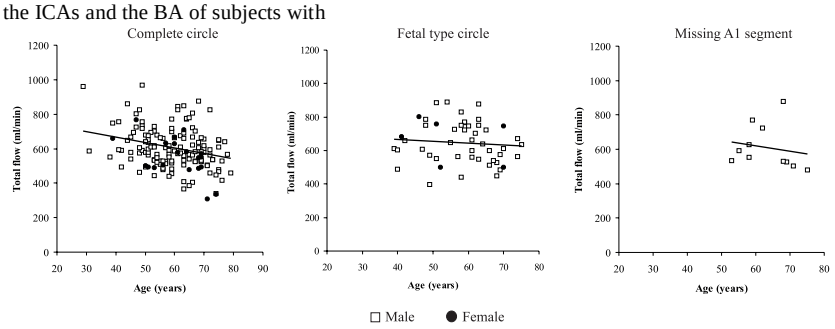

FIGURE 3. *Graphics show total volume flow (ml/min) according to age and sex as measured with 2D PC MRA (16/9, flip angle 7.5°) in 147 subjects with a complete circle of Willis, 50 subjects with a fetal type circle of Willis and 11 subjects with a missing A1 segment.*

Discussion and conclusions

In conclusion, discrepancies between previously suggested reference volume flow values of the ICAs and BA and actual flow values in individual patients are not necessarily based on vascular pathology but may be explained by a variant type of the circle of Willis. In the present study normal volume flow values of individual blood vessels to the brain were obtained for the most common variant types of the circle of Willis. These reference values may prove useful for the interpretation of volume flow values of the ICAs and BA in future clinical studies.

[1]Riggs HE et al, Arch Neurol 1963; p. 8-14

[2]Krabbe Hartkamp MJ Radiology 1998; p. 103-111