Assessment of Intracranial Collateral Flow by Using Dynamic Arterial Spin Labeling MRA and Transcranial Color-Coded Duplex Ultrasound

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Background and Purpose—To evaluate the potential of a new dynamic MRA sequence (DynAngio) based on arterial spin labeling for the assessment of intracranial collateral flow.

Methods—Twelve patients with unilateral internal carotid artery obstruction were investigated. Different patterns of collateral flow were compared between DynAngio, transcranial color-coded duplex ultrasound, and time-of-flight MRA.

Results—There was a good agreement between the methods, with sensitivities between 80% and 90%. Small collateral vessels were detected more frequently with DynAngio compared to time-of-flight MRA.

Conclusion—DynAngio provides anatomic and similar to transcranial color-coded duplex ultrasound functional information on collateral flow for the assessment of intracranial hemodynamics. (Stroke. 2008;39:1894-1897.)

Key Words: carotid stenosis ■ collateral circulation ■ diagnostic imaging ■ magnetic resonance angiography ■ transcranial ultrasound

The first pathoanatomical description of the intracranial arterial circle by Fallopius and Johann Jakob Wepfer1 dates back to 1561 and 1658, whereas its anastomotical function was discovered by Sir Thomas Willis2 in 1664. To date, it is still of high relevance to study collateral function of the circle of Willis, because this may allow the estimation of the individual patient’s risk and prognosis of subsequent stroke.3,4

Transcranial color-coded duplex ultrasound (TCCD) and time-of-flight MRA (TOF-MRA) are well-established noninvasive methods for the evaluation of intracranial collateral flow (CF), whereas digital subtraction angiography is considered the gold standard.5,6 Arterial spin labeling is a MR technique using magnetization of inflowing blood to obtain subsequent images of its arrival into the intracranial circulation. We compared a new arterial spin labeling based dynamic angiography (DynAngio)7 with TCCD and TOF-MRA for the assessment of intracranial CF in patients with severe unilateral internal carotid artery (ICA) obstruction.

Patients and Methods

We prospectively studied 12 patients after hemispheric stroke or TIA (6 women; mean age, 65 years; age range, 45 to 85 years) with severe (>80%) unilateral ICA stenosis or occlusion causing CF as diagnosed by TCCD. The study was approved by the local ethics committee and written informed consent was obtained.

TCCD was performed using a Philips HDI 5000 system (Philips Medical Systems) with a 2- to 4-MHz sector transducer from the transtemporal approach. According to standard ultrasound protocols,8 mean flow velocities from all major intracranial arteries including the anterior communicating artery and both posterior communicating arteries (PCoA) were assessed. Relevant anterior collateral flow (aCF) via anterior communicating artery to the middle cerebral artery was defined to be present when the color-coded Doppler signals and Doppler spectra showed flow reversal in the A1 segment of the anterior cerebral artery ipsilateral to ICA obstruction. Relevant posterior collateral flow (pCF) through the PCoA was defined to be present when the flow in the ipsilateral PCoA was directed from the P1 segment of the posterior cerebral artery to the ICA (Figure 1). If the PCoA was not detectable pCF was established by a side-to-side difference of mean flow velocities in the P1 segments of ≥20%.9

MRA studies were performed with a 1.5-Tesla MR system (Magnetom Sonata; Siemens Medical) within 6 hours from TCCD examination. The DynAngio sequence combines a flow-alternating inversion recovery scheme with a segmented FLASH Look-Locker sampling strategy.7 This results in consecutive time-resolved images of blood inflow into the arterial tree. Thirty-six different phases of inflow with a temporal resolution of 36 ms and an interpolated in-plane resolution of 0.52 mm were acquired within 2 minutes 20 seconds. Color-coded parameter maps were calculated for each voxel using the mean signal of the time series and the time when the maximum of the signal curve is reached (Figure 2).

We assessed CF on TOF-MRA based on the hypothesis that visible collateral arteries are patent and potentially capable of supplying CF.10 In addition to vessel visibility, CF on DynAngio was evaluated on the basis of blood bolus arrival times. aCF was defined to be present when there was an at least 36 ms earlier appearance of blood in the contralateral A1 segment and consecutive blood inflow to the ipsilateral middle cerebral artery. pCF was considered relevant.
when the side-to-side difference of blood bolus arrival times between the P1 segments was \( \geq 36 \) ms with an earlier appearance of the ipsilateral P1 segment, or when there was blood flow from the ipsilateral PCoA toward the middle cerebral artery.

Three different patterns of CF were defined for comparison of TCCD and MRA results: type 1 recruitment of aCF and pCF, type II aCF only, and type III pCF only. Sensitivity, specificity, and positive and negative predictive values of DynAngio and of TOF-MRA to detect CF in comparison to TCCD were calculated.

**Results**

The Table lists the CF patterns as detected by TCCD, TOF-MRA, and DynAngio.

DynAngio allowed detailed visualization of the dynamics of inflowing blood to the circle of Willis and its main branches in high quality in 11 of 12 patients (91.6%). Both A1 segments were detected in 10 of 12 patients on DynAngio and TOF-MRA. The dynamic character of the time-resolved information allowed direct visualization of anterior communicating artery more frequently with DynAngio compared to TOF-MRA (8 vs 5 patients). The ipsilateral P1 segment was visible in all patients, whereas both PCoAs were detected more frequently with DynAngio (8 vs 5 patients).

On TCCD both A1 segments were detected in 10 patients with reversal of flow in the ipsilateral A1 segment in 9 of 10 patients; direct visualization of the anterior communicating artery was possible in 2 cases. P1 segments could be detected in all patients and pCF was present in 9 patients. However, the ipsilateral PCoA was visible in 3 cases only.

There was a good overall agreement (79.2%) between TCCD and MRA findings (Table). The sensitivity of DynAngio for the detection of CF was 84.2% (aCF, 80%; pCF, 88.9%), and the positive predictive value was 88.9%. Specificity and negative predictive values were moderate (50%) because of the low number of cases with absent collateral flow included to this analysis. The sensitivity of TOF-MRA was 81% (aCF, 80%; pCF, 81.8%); positive predictive value was 94.4% (aCF, 88.9%; pCF, 100%). Specificity (66.7%) and negative predictive values were moderate (33.3%).

**Discussion**

DynAngio provides detailed anatomic and dynamic blood flow information in the circle of Willis. It demonstrates indications of CF and corresponds well with TOF-MRA and TCCD findings. Our results are consistent with a recent study.

![Figure 1. TCCD example of CF in a patient with left ICA occlusion. Recruitment of aCF is represented by the reversal of flow in the left A1 segment and by the high flow velocities in the anterior communicating artery and the contralateral A1 segment. Compared to the contralateral artery the flow velocity is \( \geq 20\% \) higher in the left P1 segment as criteria for relevant pCF. The normal flow velocity of the left middle cerebral artery may indirectly imply that the CF can be considered efficient.](https://example.com/fig1.png)
using DynAngio for quantification of extracranial carotid stenosis with respect to associated CF.11

Similar to TCCD, DynAngio allows the evaluation of functional changes attributable to the combination of temporal and spatial data. Given the short acquisition time and highly dynamic character, DynAngio also appears preferable over previous TOF-MRA sequences when using saturation slabs to obtain information on flow directionality and CF.6 TCCD and DynAngio both provide hemodynamic information from intracranial vessels and have the potential to determine velocity and directionality of blood flow.12

For the assessment of short vessel segments with a small diameter, e.g., PCoA, spatial resolution and time resolution are of great importance. Determination of flow directionality is particularly difficult in small arteries because it requires demonstration of blood inflow on consecutive time-resolved DynAngio images. Nevertheless, flow directionality of anterior and posterior collateral arteries was definable in the majority of patients using this technique. In 3 patients DynAngio was even able to detect blood flow in the PCoA when TOF-MRA was unable to demonstrate this vessel segment, indicating that DynAngio may be more sensitive to detect small and low-flow collaterals. When confirmed in larger study populations the use of DynAngio is likely to add complementary information to other techniques for noninvasive assessment of CF, which may altogether limit the need to perform digital subtraction angiography.

Table. Comparison of DynAngio, TOF-MRA, and TCCD for Assessment of Different Patterns of CF

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Pattern of CF (TCCD)</th>
<th>Pattern of CF (DynAngio)</th>
<th>Pattern of CF (TOF-MRA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–6</td>
<td>Agreement* 10 (83.3%)</td>
<td>12 (100%)</td>
<td></td>
</tr>
<tr>
<td>7–9</td>
<td>Agreement* 5 (83.3%)</td>
<td>3 (50%)</td>
<td></td>
</tr>
<tr>
<td>10–12</td>
<td>Agreement* 4 (66.7%)</td>
<td>4 (66.7%)</td>
<td></td>
</tr>
<tr>
<td>1–12 Overall agreement* 19 (79.2%)</td>
<td>19 (79.2%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Combined calculation for aCF and pCF.

References
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