Angiography Reveals That Fluid-Attenuated Inversion Recovery Vascular Hyperintensities Are Due to Slow Flow, Not Thrombus

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Angiographic images obtained ≤6 hours after MR imaging were reviewed. The location of occlusions and stenoses within arterial seg-
ments was noted and graded. The direction of flow in blood vessel segments and routes of collateral blood flow were detailed. Angiographic collaterals were graded on a 5-point scale (Table 1), and all data were abstracted by using a standardized form.7 The study was approved by the University of California, Los Angeles institutional review board.

**Results**

Seventy-four patients fulfilled inclusion criteria (Table 1). Mean age was 63.4 years, and 48% were women. All patients underwent urgent investigation with MR imaging, which included FLAIR sequences within 6 hours before conventional angiography. The median time from MR imaging to angiography was 2.9 hours (interquartile range [IQR], 1.1–4.7 hours). FVH were noted in 53/74 (72%) studied patients presenting with acute stroke seen urgently for endovascular recanalization.

When present, FVH were found within the vascular territory of the ischemic stroke in all studied patients as determined by initial DWI, MR imaging, and angiography. FVH were present in 33/35 (94%) cases of proximal middle cerebral artery (MCA, M1) ischemia (occlusion/stenosis) and in only 2/5 cases of vertebrobasilar ischemia. FVH were seen with cases of internal carotid artery (ICA) occlusions extending into the MCA (carotid L) and extending into both the anterior cerebral artery (ACA) and the MCA (carotid T). FVH were also seen with combined ICA and MCA occlusion. Across all cases, FVH were never visualized outside the involved vascular territory.

FVH were most commonly situated in the Sylvian fissure.

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**Table 1: Characteristics and imaging findings in study patients**

<table>
<thead>
<tr>
<th>Features</th>
<th>Data</th>
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<tbody>
<tr>
<td>No. of patients</td>
<td>74</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>Mean, 63.4</td>
</tr>
<tr>
<td>Sex</td>
<td>36 Women (48%)</td>
</tr>
<tr>
<td>Median time from MRI to angiography (hr)</td>
<td>2.9 (IQR, 1.1–4.7)</td>
</tr>
<tr>
<td>FVH present</td>
<td>53/74 (72%)</td>
</tr>
<tr>
<td>FVH in arterial territory of ischemia</td>
<td>53/53 (100%)</td>
</tr>
<tr>
<td>Location of FVH</td>
<td></td>
</tr>
<tr>
<td>Sylvian fissure</td>
<td>50/53 (94%)</td>
</tr>
<tr>
<td>Temporal lobe</td>
<td>47/53 (89%)</td>
</tr>
<tr>
<td>Frontal lobe</td>
<td>28/53 (53%)</td>
</tr>
<tr>
<td>Parietal lobe</td>
<td>18/53 (34%)</td>
</tr>
<tr>
<td>Discontinuity or gap in FVH</td>
<td>26/53 (49%)</td>
</tr>
<tr>
<td>FVH not noted on angiography</td>
<td>21 (28%)</td>
</tr>
</tbody>
</table>

**Angiographic findings in FVH-negative cases**

- MCA M1 occlusion: 1
- MCA M1 stenosis with anterograde flow: 2
- MCA M2 occlusion: 2
- Distal (M3 or greater) occlusion: 8
- ICA occlusion without MCA occlusion: 2
- Vertebrobasilar occlusion: 3
- Posterior cerebral occlusion: 2
- Anterior choroidal occlusion: 1

**Note:** MRI indicates MR imaging; FVH, fluid-attenuated inversion recovery vascular hyperintensities; MCA, middle cerebral artery; ICA, internal carotid artery.
The imaging signal-intensity characteristics of FVH are due to the sluggish flow of blood proximal and distal to large arterial occlusion. This altered flow results in the loss of flow voids on FLAIR because vessels appear hyperintense against a dark CSF background. In the setting of normal hemodynamics, there is loss of signal intensity in the blood vessels because blood protons have moved out of the imaging section when (94%) or adjacent to or within the temporal (89%), frontal (53%), and parietal lobes (34%). Discontinuity or a gap in FVH was defined as a segment of artery with decreased signal intensity on FLAIR relative to both proximal and distal vessels. The presence of an FVH gap was noted in 26/53 (49%) cases.

In a subset of 29 patients with angiographically documented isolated MCA occlusion, all except 1 had evidence of FVH distal to the occlusion on preprocedural MR images. In these 28 cases of MCA occlusion with demonstrated FVH, there was a high grade of leptomeningeal collateral blood flow appreciated. Twenty-two cases (79%) demonstrated excellent retrograde leptomeningeal collateralization of grade 3 or 4 (Fig 2). Six cases demonstrated some leptomeningeal collaterals (grades, 1 and 2). There were no cases with FVH noted distal to the MCA occlusion and absence of leptomeningeal collaterals (grade, zero). The lone case of isolated MCA occlusion with absence of FVH had a collateral grade of zero.

Of the 74 patients included in this study, 44 had follow-up MR imaging within 72 hours of the initial MR imaging (median, 8.2 hours; IQR, 6.0–19.6). FVH were noted on only 18 of 44 follow-up MR images. In all patients with FVH on follow-up MR images, there was evidence of FVH on the preangiographic scan. In the 18 patients with persistent FVH, 16 had concurrent interpretable MRAs. All 16 of these patients showed absence or severe reduction of flow signal intensity in the affected arterial territory. There were 15 cases of follow-up imaging in which an MRA was performed and demonstrated normal flow signal intensity in the affected arterial territory; there was no evidence of persistent FVH in any of these cases.

Discussion
This study describes the angiographic characteristics of patients who underwent FLAIR imaging and DSA within 6 hours in the setting of acute stroke, who were being considered for revascularization. MR imaging is increasingly used to diagnose acute ischemic stroke,8 and recent studies have demonstrated that MR imaging may be superior to CT in the initial evaluation.9 Because time is of the essence in acute stroke, MR imaging sequence protocols for acute stroke need to address the impact and time of acquisition. FLAIR sequences have become a routine part of many standard MR imaging proto-

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Table 2: The ASITN/SIR collateral-flow grading system to determine angiographic collateral grade on pretreatment angiography

<table>
<thead>
<tr>
<th>ASTIN/SIR Collateral Grade</th>
<th>Definition</th>
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<tr>
<td>0</td>
<td>No collaterals visible to the ischemic site</td>
</tr>
<tr>
<td>1</td>
<td>Slow collaterals to the periphery of the ischemic site with persistence of some of the defect</td>
</tr>
<tr>
<td>2</td>
<td>Rapid collaterals to the periphery of ischemic site with persistence of some of the defect and to only a portion of the ischemic territory</td>
</tr>
<tr>
<td>3</td>
<td>Collaterals with slow but complete angiographic blood flow of the ischemic bed by the late venous phase</td>
</tr>
<tr>
<td>4</td>
<td>Complete and rapid collateral blood flow to the vascular bed in the entire ischemic territory by retrograde perfusion</td>
</tr>
</tbody>
</table>

Note: ASTIN/SIR indicates American Society of Interventional and Therapeutic Neuroradiology/Society of Interventional Radiology.

The imaging signal-intensity characteristics of FVH are due to the sluggish flow of blood proximal and distal to large arterial occlusion. This altered flow results in the loss of flow voids on FLAIR because vessels appear hyperintense against a dark CSF background. In the setting of normal hemodynamics, there is loss of signal intensity in the blood vessels because blood protons have moved out of the imaging section when...
the section-selective 180° pulse is applied, and a spin-echo is not formed. The longer the TE of a pulse sequence (as seen in T2, proton-weighted, and FLAIR sequences), the more evident are the flow voids. Absence of flow voids on proton-attenuation MR imaging sequences has previously been correlated with FVH.2

We found that FVH were associated with a high grade of collateral circulation, most often grade 3 or 4 and never zero. This finding is consistent with the observation that FVH reflect altered hemodynamics. In the setting of proximal arterial occlusion and robust collateralization, brain parenchyma distal to the occlusion is nourished via retrograde leptomeningeal collaterals.14 Although anterograde blood flow is relatively fast, retrograde flow is more sluggish. On angiography, retrograde blood flow arrives later than anterograde flow, often during the angiographic venous phase. This difference contrasts with the absence of flow, in which FVH may not be evident. The persistence of FVH on follow-up MR imaging was associated with decreased or absent flow signal intensity on MRA, suggesting persistent vessel occlusion. In contrast, the absence of FVH was seen in the setting of return of MR imaging flow signal intensity and also in settings with completed infarction.

Limitations of this study include the narrow population: patients with acute stroke who underwent angiography for possible endovascular intervention. MR imaging and angio- graphic studies were reviewed by physicians blinded to the other imaging technique, and there could be inter-reader variability in interpretation. This population is expected to have a very high rate of large- vessel occlusion and salvageable brain penumbra being considered for endovascular intervention and may not be generalizable. The strengths of this study include a close temporal relationship from initial MR imaging to angiography and high rates of follow-up neuroimaging.

The finding of FVH on MR imaging in acute stroke should suggest consideration of proximal arterial disease leading to retrograde collateralization. The finding is often transient and, when persistent, may reflect continued hemodynamic impairment. Prospective studies are warranted to evaluate the relative incidence of FVH systematically in patients presenting with acute stroke, and this neuroimaging marker may be especially important in instances in which MRA or perfusion MR imaging is unavailable or degraded by artifacts.

References

7. Higashida RT, Furlan AJ, Roberts H, et al, for the Technology Assessment Com-