Multicontrast High-Resolution Vessel Wall Magnetic Resonance Imaging and Its Value in Differentiating Intracranial Vasculopathic Processes

Mahmud Mossa-Basha, MD; William D. Hwang, MD; Adam De Havenon, MD; Daniel Hippe, MS; Niranjan Balu, PhD; Kyra J. Becker, MD; David T. Tirschwell, MD, MSc; Thomas Hatsukami, MD; Yoshimi Anzai, MD, MPH; Chun Yuan, PhD

Background and Purpose—Although studies have attempted to differentiate intracranial vascular disease using vessel wall magnetic resonance imaging (VWI), none have incorporated multicontrast imaging. This study uses T1- and T2-weighted VWI to differentiate intracranial vasculopathies.

Methods—We retrospectively reviewed patients with clinically defined intracranial vasculopathies causing luminal stenosis/irregularity who underwent VWI studies. Two blinded experts evaluated T1 precontrast and postcontrast and T2-weighted VWI characteristics, including the pattern of wall thickening; presence, pattern, and intensity of postcontrast enhancement; and T2 signal characteristics.

Results—Twenty-one cases of atherosclerosis (intracranial atherosclerotic disease [ICAD]), 4 of reversible cerebral vasocostriction syndrome, and 4 of vasculitis were identified, with a total of 118 stenotic lesions (81 ICAD, 22 reversible cerebral vasocostriction syndrome, and 15 vasculitic lesions). There was substantial to excellent inter-reader agreement for the assessment of lesional T2 hyperintensity ($\kappa=0.80$), pattern of wall thickening ($\kappa=0.87$), presence ($\kappa=0.90$), pattern ($\kappa=0.73$), and intensity ($\kappa=0.77$) of enhancement. ICAD lesions were significantly more likely to have eccentric wall involvement (90.1%) than reversible cerebral vasocostriction syndrome (8.2%; $P<0.001$) and vasculitic lesions (6.7%; $P<0.001$) and were also more likely to have T2 hyperintensity present than the other 2 vasculopathies (79% versus 6%–0%). There were also significant differences in the presence, intensity, and pattern of enhancement between all lesion types. Combining T1 and T2 VWI increased the sensitivity of VWI in differentiating ICAD from other vasculopathies from 90.1% to 96.3%.

Conclusions—Multicontrast VWI can be a complementary tool for intracranial vasculopathy differentiation, which often leads to more invasive workups when reversible cerebral vasocostriction syndrome and vasculitis are in the differential diagnosis. (Stroke. 2015;46:00-00. DOI: 10.1161/STROKEAHA.115.009037.)

Key Words: intracranial vasculopathy ■ magnetic resonance imaging ■ vascular diseases

Intracranial magnetic resonance vessel wall magnetic resonance imaging (VWI) is an emerging technique that shows significant promise in the evaluation of intracranial vasculopathies. Luminal imaging techniques traditionally used for the assessment of vasculopathy do not adequately assess vessel wall pathology and can be of limited value in differentiating between causes of intracranial vasculopathies. Commonly used diagnostic tests for evaluating intracranial vasculopathy include catheter angiography, lumbar puncture, and brain biopsy, but these tests are invasive and lack sensitivity and specificity.1,2

Patterns and intensity of postgadolinium enhancement of vascular lesions using T1 postcontrast VWI have been used to differentiate between vasculopathies and intracranial atherosclerotic disease (ICAD).3,4 ICAD generally reveals eccentric thickening with variable enhancement, whereas vasculitis shows smooth, intense, and homogeneous enhancement; and reversible cerebral vasoconstriction syndrome (RCVS) has minimal to no enhancement and minimal wall thickening,5-8 Overlap does exist, however, as ICAD can be circumferential whereas vasculitic lesions can show eccentric enhancement.7 In addition, many atherosclerotic plaques will only partially enhance and 18% will not enhance at all, limiting detection and evaluation of the outer boundary on T1 postcontrast imaging.9 Use of multicontrast VWI protocols can further help in the differentiation of such cases.

There have only been a few reports describing the intracranial vessel wall signal characteristics of contrast-weighting techniques besides T1 and postcontrast VWI, specifically proton density and T2-weighted sequences.10-14 In the setting of ICAD lesions, a juxtaluminal band of T2 hyperintensity...
on VWI has been described and shown to correspond to the fibrous cap on histology. In contrast, the T2 hypointense outer component of the plaque corresponds to areas rich in foamy macrophages and proteoglycans, and lipid rich necrotic core on T2-weighted VWI. To our knowledge, no reports have used T2-weighted high-resolution VWI and multicontrast protocols as a technique to discriminate between vasculopathies. In this study, we evaluated the imaging findings of different vasculopathies on T2 and T1 pre and postcontrast imaging to identify unique features and test their ability to correctly identify disease and develop an algorithm to differentiate intracranial vasculopathies. We also investigate the additional benefit of using multicontrast VWI over pre and postcontrast T1 alone to differentiate disease.

Methods

Patient Population and Clinical Diagnosis

After institutional review board approval, we reviewed consecutive patients from January 2011 to April 2014 with suspicion of intracranial vasculopathy who had VWI and, on luminal imaging, had appreciable intracranial arterial stenosis or irregularity. There were a total of 68 patients, who had 77 high-resolution VWI studies performed. Patients were further stratified into diagnostic vasculopathy categories by stroke neurologists who had access to clinical data, but were blinded to the VWI at our institution. The clinical diagnosis of atherosclerosis required ≥2 vascular risk factors (hypertension, hyperlipidemia, diabetes mellitus, obesity, coronary artery disease, men age≥50, and women age≥60) and failure to meet clinical criteria for central nervous system (CNS) vasculitis or RCVS. For the diagnosis of CNS vasculitis, patients were required to have clinical suspicion for CNS vasculitis and tissue or serological support for the diagnosis, including either a positive brain biopsy during the hospital admission, cerebrospinal fluid infection/inflammation, or evidence of systemic vasculitis. Exclusion criteria for CNS vasculitis included ≥1 vascular risk factor, evidence of a reversible process on follow-up luminal imaging, or previous vasculitis treatment. The diagnosis of RCVS required a classic presentation of thunderclap headache after a typical inciting event and progressive improvement of intracranial stenoses on follow-up luminal imaging. Exclusion criteria for RCVS were ≥2 vascular risk factors, clinical evidence of CNS vasculitis, or previous immunosuppressive therapy. The diagnosis was also cross-checked with the clinical evaluation at the time of inpatient care, and there was no diagnostic discrepancy in the included cases.

MRI Protocol

Patients were scanned on a 3T Siemens Trio MR scanner (Siemens Healthcare, Erlangen, Germany). The MR VWI protocol included 3-dimensional (3D) time of flight magnetic resonance angiography (in-plane resolution, 0.53x0.47; slice thickness, 0.53 mm; repetition time/echo time, 20/3.69 ms; flip angle, 18°; field of view, 205x184 mm; time, 5:40 minutes), T1 (0.4x0.35 in-plane resolution; slice thickness, 2 mm; repetition time/echo time, 1000/10 ms; averages, 4; matrix, 448x448; field of view, 180x158 mm; GRAPPA factor, 2; turbo factor, 18; time, 36 s per slice), precontrast and postcontrast T1 alone to differentiate disease.

Imaging Interpretation

Two readers (M.M.B. with 4 years of experience with intracranial VWI interpretation and W.D.H. with 2 years of experience) who were blinded to the patient clinical information and diagnosis reviewed the images independently. The second reader (W.D.H.) was used to establish inter-reader agreement for the imaging interpretation. The VWI criteria evaluated in this study have previously been described in the literature as differentiating vasculopathy characteristics. After a training session, evaluating a subset of VWI cases that were excluded and review of a packet of pertinent VWI articles, the 2 readers independently assessed the lesions on T2-weighted sequences for the presence or absence of juxtaluminal T2 hyperintense band and wall signal characteristics. T2-weighted lesion signal characteristics were assessed relative to gray matter. Comparing T1 precontrast and postcontrast imaging, the lesions were assessed for the presence and intensity of enhancement based on a previously established scale, in which grade 0 or no enhancement indicates expected normal vessel wall enhancement, grade 1 enhancement represents enhancement less than that of the pituitary infundibulum, and grade 2 enhancement represents that equal to or greater than the enhancement intensity of the pituitary infundibulum. In addition, the pattern of enhancement was assessed as focal, heterogeneous, or diffuse enhancement. Diffuse enhancement was defined as complete enhancement of the lesion, heterogeneous as incomplete lesion enhancement, and focal enhancement was defined as a point or short linear region of lesion enhancement. The pattern of vessel wall involvement was categorized as eccentric or circumferential using both T1 precontrast and post-contrast VWI. Standard protocol time of flight magnetic resonance angiography was referenced when assessing VWI lesions. The artery of involvement for each lesion was also documented.

Statistics

Categorical variables were summarized as count (percentage) in each of the vasculopathy groups. Permutation tests were used to compare the groups. The group labels were permuted across patients instead of lesions to account for the potential dependence between lesions from the same patient. Sensitivity and specificity were used to evaluate how well combinations of imaging findings could discriminate between vasculopathies. Cohen’s κ was used to evaluate inter-reader agreement for the imaging findings. Beyond inter-reader agreement, the interpretation of the more experienced reader (M.M.B.) was used for imaging data analysis. Confidence intervals were calculated using the nonparametric bootstrap with the bias-corrected and accelerated method. Patients were resampled to preserve dependence between lesions from the same patient, and the resampling was stratified by vasculopathy group. Because the bootstrap could not be used to calculate confidence intervals when sensitivity or specificity was 100%, Clopper and Pearson intervals were instead in those cases. All statistical calculations were conducted with the statistical computing language R (version 3.1.1; R Foundation for Statistical Computing, Vienna, Austria). Throughout, 2-tailed tests were used with statistical significance defined as P<0.05.

Results

Clinical Diagnoses and Characteristics

Of the 68 cases reviewed, a total of 21 ICAD, 4 RCVS, and 4 vasculitis cases were selected for the study based on inclusion criteria. There were a total of 118 stenotic lesions (81 lesions in ICAD, 22 lesions in RCVS, and 15 lesions in vasculitis patients) in the included cases. The 4 patients with vasculitis had the following diagnoses: primary angiitis of the CNS, varicella vasculitis, tuberculosis vasculitis, and systemic autoimmune disease not otherwise specified with CNS vasculitis. Thirty-nine cases were excluded because of alternate diagnoses (n=16), vasculopathy not otherwise specified (n=6), normal imaging and clinical examination.
(n=4), and limited examination because of motion degradation (n=4) or limited sequences performed because of interrogation of multiple vascular beds including intracranial and carotid arteries (n=3).

Patient demographic and clinical history are summarized in Table I in the online-only Data Supplement. Patients with ICAD on average had 4.2±1.3 vascular risk factors, significantly more compared with RCVS (0.75±0.5) and vasculitis (0.5±0.57), P<0.001. There were no significant differences in arterial territory involved between the 3 vascular pathologies.

### VWI Characteristics

Examples of typical VWI patterns of ICAD, vasculitis, and RCVS are shown in Figure 1. Table 1 shows differential vasculopathy VWI findings. There was a significant difference in the T2-weighted VWI appearance of ICAD relative to RCVS and vasculitis. Seventy-nine percent of ICAD lesions showed at least a component of lesional T2 hyperintensity, significantly >0% of vasculitis lesions (P<0.001) and 0% of RCVS lesions (P<0.001). ICAD lesions predominantly showed a thin juxtaluminal band of T2 hyperintensity with underlying T2 hypointense component (n=59; 73%). None of the vasculitis or RCVS lesions showed T2 hyperintense components or heterogeneous signal. Lesion appearances on T2 VWI are summarized in Table II in the online-only Data Supplement.

The pattern of vessel wall involvement on T1-weighted VWI showed a significant difference between ICAD and vasculitis (P<0.001) and between ICAD and RCVS (P<0.001). Ninety percent of ICAD lesions showed eccentric wall thickening when compared with 7% of vasculitis and 18% of RCVS.

Enhancement patterns and characteristics showed significant differences between the various vasculopathies. On T1

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**Figure 1.** Vessel wall magnetic resonance imaging (VWI) findings of vasculitis (VS; A), intracranial atherosclerotic disease (ICAD; B), and reversible cerebral vasoconstriction syndrome (RCVS; C). A, Vasculitis: coronal maximum intensity projection (MIP) time of flight (TOF) magnetic resonance angiography (MRA) (left) shows multifocal arterial stenosis involving the left A2 anterior cerebral artery (ACA), bilateral middle cerebral artery (MCA), and right P1 posterior cerebral artery (white arrows). On T2 VWI (left middle) centered over the left ACA lesion, there is circumferential vessel wall thickening with homogeneous isointense signal intensity (thick arrow). On T1 precontrast image (right middle), circumferential vessel wall thickening (black arrows) can be seen. On T1 postcontrast VWI (last image), there is corresponding homogeneous, circumferential vessel wall enhancement (short arrow). B, Atherosclerosis: coronal MIP TOF MRA image (first image) shows stenosis of the distal right M1 MCA (arrow). On T2 VWI (left middle), there is a juxtaluminal T2 hyperintense band (black arrowhead), with subjacent lesional hypointensity (thick white arrow) corresponding to the MRA stenosis. On T1 precontrast VWI (right middle image), isointense lesion shows eccentric anterior vessel wall involvement (black arrow). On T1 postcontrast VWI (last image), there is heterogeneous lesional enhancement (short white arrow). C, RCVS: axial MIP TOF MRA image (first image) shows multifocal intracranial arterial stenosis, with focal stenosis of the left A1 ACA (white arrow). Axial T2 VWI (left middle image) shows corresponding minimal wall thickening with T2 isointense signal (thick black arrows) at the site of left A1 ACA lesion. On axial T1 precontrast VWI (right middle), there is minimal circumferential vessel wall thickening (thin black arrows) corresponding to the stenosis. On T1 postcontrast VWI (last image), there is no evidence of significant wall enhancement (short white arrow). The contralateral A1 ACA, a normal arterial segment on MRA shows mild perivascular enhancement (curved arrow) likely representing venous enhancement.
postcontrast VWI, there was a significant difference in the presence and intensity of vessel wall enhancement between ICAD versus RCVS (P<0.001) and vasculitis versus RCVS (P<0.03), as most RCVS lesions showed no enhancement. There was a significant difference in the lesion enhancement pattern between ICAD and vasculitis (P=0.042), as all vasculitis lesions showed diffuse enhancement (no lesions showed heterogeneous or focal enhancement), whereas ICAD lesions showed diffuse (60%), heterogeneous (26%), or focal (15%) enhancement, respectively.

Table 1. Distribution and VWI Characteristics of the Vasculopathy Groups (n=118 Lesions in 29 Patients)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Vasculopathy Group*</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICAD, n=81</td>
<td>VS, n=15</td>
</tr>
<tr>
<td>T2 hyperintensity</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td></td>
<td>64 (79.0)</td>
<td>17 (21.0)</td>
</tr>
<tr>
<td>T1 wall thickening</td>
<td>Eccentric</td>
<td>Circumferential</td>
</tr>
<tr>
<td></td>
<td>73 (90.1)</td>
<td>8 (9.9)</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>CE†</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td></td>
<td>74 (97.4)</td>
<td>2 (2.6)</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>CE intensity†</td>
<td>Grade 2</td>
<td>Grade 1</td>
</tr>
<tr>
<td></td>
<td>31 (40.8)</td>
<td>43 (56.6)</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>CE pattern† (for those with CE)</td>
<td>Focal</td>
<td>Diffuse</td>
</tr>
<tr>
<td></td>
<td>11 (14.9)</td>
<td>44 (59.5)</td>
</tr>
<tr>
<td></td>
<td>Absent</td>
<td>0 (0.0)</td>
</tr>
</tbody>
</table>

CE indicates contrast enhancement; ICAD, intracranial atherosclerotic disease; RCVS, reversible cerebral vasoconstriction syndrome; VS, vasculitis; and VWI, vessel wall magnetic resonance imaging.

*Values are number (%).
†Enhancement could not be assessed in 5 lesions, all from atherosclerosis.

The sensitivity and specificity for the most important imaging findings in differentiating the vasculopathy groupings are shown in Table 2. The sensitivity and specificity of the presence of lesional T2 hyperintense components in differentiating ICAD from vasculitis and RCVS was 79% and 100%, respectively. The pattern of wall involvement had a sensitivity of 90.1% and specificity of 86.5% in differentiating ICAD. When T2 VWI and lesional pattern of wall involvement are both considered (if either lesion T2 hyperintensity or eccentric wall involvement was present), the sensitivity for ICAD differentiation rose to 96.3%, whereas the specificity did not change. The presence or absence of contrast enhancement had a sensitivity of 100% and specificity of 82% in differentiating vasculitis from RCVS. The VWI findings described above were used to create a diagnostic tree, shown in Figure 2.

**Subgroup Analysis**

As described above, 90% of ICAD lesions showed eccentric wall involvement; however, 8 of 81 showed circumferential wall thickening (Figure 3), a pattern which is more typical of vasculitis or RCVS. For 40 lesions in 13 patients that showed circumferential wall involvement (Table 3), we investigated other imaging parameters that could potentially differentiate ICAD lesions from vasculitis and RCVS. For circumferential lesions (8 ICAD, 14 vasculitis, and 18 RCVS), there was a significant difference of appearance on T2 VWI between ICAD and vasculitis (P=0.02), as well as ICAD and RCVS (P=0.02), with ICAD showing lesion T2 hyperintense components, whereas vasculitis and RCVS did not have lesional T2 hyperintensity. There was also a significant difference in intensity of enhancement between ICAD versus RCVS (P<0.01) and vasculitis versus RCVS (P<0.03), as RCVS lesions showed no (grade 0) enhancement. With reliance only on the pattern

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**Table 2. Observed Per-Lesion Sensitivity and Specificity for Vasculopathy Diagnoses Based on T2 HI, EWT, and CE**

<table>
<thead>
<tr>
<th>Findings</th>
<th>Differential Diagnosis</th>
<th>Sensitivity % (95% CI)*</th>
<th>Specificity % (95% CI)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2 HI: present vs absent</td>
<td>ICAD vs VS/RCVS</td>
<td>79.0 (67.6–87.2)</td>
<td>100 (90.5–100)</td>
</tr>
<tr>
<td>T1 EWT: present vs absent</td>
<td>ICAD vs VS/RCVS</td>
<td>90.1 (77.4–96.4)</td>
<td>86.5 (71.1–94.9)</td>
</tr>
<tr>
<td>T2 HI+T1 EWT†</td>
<td>ICAD vs VS/RCVS</td>
<td>96.3 (86.6–99.9)</td>
<td>86.5 (77.1–94.9)</td>
</tr>
<tr>
<td>CE: present vs absent†</td>
<td>RCVS vs ICAD/VS</td>
<td>81.8 (69.6–91.7)</td>
<td>97.8 (93.9–99.9)</td>
</tr>
<tr>
<td>CE: grade 2 vs grade 0/1†</td>
<td>RCVS vs ICAD/VS</td>
<td>100.0 (84.6–100)</td>
<td>44.0 (32.0–54.9)</td>
</tr>
</tbody>
</table>

CE indicates contrast enhancement; CI, confidence interval; EWT, eccentric wall thickening; HI, hyperintensity; ICAD, intracranial atherosclerotic disease; RCVS, reversible cerebral vasoconstriction syndrome; and VS, vasculitis.

*Confidence intervals calculated using the bootstrap except when sensitivity/specificity was 100%, in which case Clopper–Pearson CIs were used.
†Diagnose atherosclerosis if either T2 HI or EWT is present.
‡Enhancement could not be assessed in 5 lesions, all from atherosclerosis patients.
of wall thickening on T1-weighted VWI and expected disease patterns, 8 ICAD, 1 vasculitis, and 4 RCVS lesions would have likely been mischaracterized.

Inter-Reader Agreement

There was substantial inter-reader agreement for the assessment of lesional T2 hyperintensity (κ=0.80), pattern of wall thickening (κ=0.87), presence (κ=0.90), and pattern of enhancement (κ=0.73) and enhancement intensity (κ=0.77).

Discussion

Multicontrast intracranial VWI for the characterization of vasculopathy has not been well studied for intracranial vascular disease. We report the first use of T2 and T1 precontrast and postcontrast VWI to differentiate between ICAD, RCVS, and vasculitis. This study shows that T2 hyperintensity assessment has the same order of agreement as the pattern of vessel wall involvement on T1 VWI in differentiating ICAD from vasculitis and RCVS, whereas the presence and intensity of lesion postcontrast enhancement help to differentiate RCVS from vasculitis and ICAD. The use of T2-weighted VWI can be additionally advantageous for patients with contraindications to gadolinium contrast agents including patients with severe contrast allergies and renal insufficiency. In this setting, T2-weighted and noncontrast T1-weighted VWI can be used to differentiate ICAD from RCVS and vasculitis.

In this study, there was substantial inter-reader agreement for the imaging parameters we studied, indicating that VWI characteristics can be assessed consistently. We found that the presence of a T2 juxtaluminal hyperintense band overlying a T2 hypointense component, eccentric wall involvement, and diffuse, heterogeneous, or focal lesion enhancement are all characteristics that can reliably identify ICAD, whereas diffuse, homogeneous, circumferential lesion enhancement without lesion T2 hyperintense signal is most common with vasculitis. RCVS is characterized by mild circumferential wall thickening, with usually no wall enhancement and typically no appreciable T2 wall signal abnormality. None of the vasculitis or RCVS lesions showed lesional T2 hyperintensity or mixed hyperintense and hypointense T2 signal. Although both T2 signal characteristics and vessel wall pattern of disease involvement can differentiate ICAD from vasculitis and RCVS, for ICAD lesions that were concentric in nature, T2 VWI could help in differentiating the causes of underlying disease.

Multiple authors have previously described the appearance of ICAD on T2 VWI, specifically with the presence of intraluminal T2 hyperintense vessels, representing the fibrous cap, and a deeper T2 hypointense component, thought to represent the lipid rich necrotic core. Most of the studies assessing or describing T2 VWI characteristics of ICAD were small series or case reports that did not assess other vasculopathic diseases to determine the prevalence of lesion T2 hyperintensity nor did any of these studies assess the frequency of the presence of juxtaluminal T2 hyperintense lesion components with ICAD.

Swartz et al performed a small case series evaluation of intracranial vasculopathies, which included cases of ICAD and CNS inflammatory disease. ICAD predominantly showed eccentric wall enhancement, whereas CNS inflammatory vasculopathy showed diffuse circumferential vessel wall enhancement. Mandell et al assessed consecutive cases with multifocal segmental arterial stenosis on angiographic imaging with follow-up luminal imaging and found that CNS vasculitis showed vessel wall enhancement and thickening, whereas RCVS showed minimal to no enhancement. Obusez et al compared 13 patients with RCVS and 13 with primary angiitis of the CNS on T1 postcontrast VWI and found that 9 vasculitic patients showed smooth circumferential vessel wall enhancement and thickening, 3 showed eccentric enhancing lesions with wall thickening, whereas 1 showed no enhancement. This was in contradistinction to RCVS, where 10 patients showed smooth circumferential wall thickening with negligible to mild wall enhancement. These studies agree with our findings of disease enhancement characteristics and pattern; however, none of these studies evaluated the contribution of T2-weighted VWI and only relied on T1 postcontrast imaging characteristics.

Li et al evaluated 49 middle cerebral artery stenoses in 48 patients with suspected atherosclerosis using T2 VWI. The 20 ICAD lesions found showed focal or eccentric wall

![Diagram](Image)

**Figure 2.** Proposed diagnostic algorithm for vasculopathy differentiation. With the presence of T2 hyperintense components, the lesion would represent intracranial atherosclerotic disease (ICAD). Without T2 hyperintensity, eccentric lesions would most likely represent ICAD as well. For noneccentric lesions, the absence of enhancement indicates reversible cerebral vasocostriction syndrome (RCVS), whereas grade 1 or 2 enhancement indicates vasculitis most likely. VS indicates vasculitis.
thickening, 13 of 20 lesions showed heterogeneous T2 signal, whereas 7 lesions showed homogeneous signal intensity. Although this study agrees with our findings in relation to lesion T2 signal characteristics and eccentric wall involvement in ICAD, the study does not comparatively evaluate intracranial vasculopathies.

On VWI, CNS vasculitis typically shows circumferential diffuse wall enhancement and thickening.3,5 Pfefferkorn et al3

Table 3. Subgroup Analysis Lesions Without Eccentric Wall Thickening on T1 (n=13 Patients With 40 Lesions)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Vasculopathy Group*</th>
<th>PValue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICAD, n=8 VS, n=14 RCVS, n=18</td>
<td>ICAD vs VS ICAD vs RCVS VS vs RCVS</td>
</tr>
<tr>
<td>T2 hyperintensity Present</td>
<td>5 (62.5) 0 (0.0) 0 (0.0)</td>
<td>0.023 0.023 &gt;0.99</td>
</tr>
<tr>
<td>Absent</td>
<td>3 (37.5) 14 (100.0) 18 (100.0)</td>
<td>0.60 0.008 0.027</td>
</tr>
<tr>
<td>CE intensity† Grade 2</td>
<td>4 (50.0) 9 (28.1) 0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>Grade 1</td>
<td>4 (50.0) 5 (15.6) 0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>Grade 0</td>
<td>0 (0.0) 0 (0.0) 18 (100.0)</td>
<td></td>
</tr>
</tbody>
</table>

CE indicates contrast enhancement; ICAD, intracranial atherosclerotic disease; RCVS, reversible cerebral vasospasm syndrome; and VS, vasculitis.

*Values are number (%).†Enhancement could not be assessed in 1 atherosclerotic lesion.
suggested that the intensity of enhancement may differentiate ICAD from vasculitis. In their study, all cases of primary angiitis of the CNS showed moderate to strong lesion enhancement, whereas ICAD showed moderate enhancement. These investigations agree with our findings characterizing postcontrast enhancement in the setting of ICAD and CNS vasculitides; however, they did not compare the various vasculopathies nor did they assess the pattern of vessel wall involvement, intensity, or pattern of enhancement or T2 VWI findings. In this study, we were not able to find a significant difference in the intensity of lesion enhancement between ICAD and vasculitis.

Limitations include that this study was a retrospective evaluation, with limited imaging performed or motion degradation for some of the examinations resulting in their exclusion. In addition, the VWI studies were performed based on clinical needs, which could create a selection bias based on the stroke neurologist’s ordering patterns. A few studies were excluded because of unclear clinical diagnosis as determined by the inclusion and exclusion criteria and clinical evaluation, to better define the study group with clear clinical diagnosis. We realize that ICAD may arise with 1 or no vascular risk factors which can complicate evaluation, but we decided to exclude such cases to present more clearly defined clinical cases. Our study did not include histopathologic evaluation to confirm the causes of vascular disease; however few studies differentiating intracranial vasculopathy will include histology. Intracranial vasculopathies included in this study were limited to ICAD, RCVS, and vasculitis, and the findings of this study cannot be generalized to include other intracranial vasculopathies. Our findings need to be prospectively evaluated to address validation and generalizability. The number of cases included in this study is relatively few in this study, but these conditions are rarely compared with ICAD, and few institutions will have a large population of CNS vasculopathies. Our findings need to be prospectively evaluated to better define the study group with clear clinical diagnosis. In addition, the VWI studies were performed based on clinical needs, which could create a selection bias based on the stroke neurologist’s ordering patterns. A few studies were excluded because of unclear clinical diagnosis as determined by the inclusion and exclusion criteria and clinical evaluation, to better define the study group with clear clinical diagnosis.

### Summary

This study shows that T2-weighted VWI is a complementary tool in the differentiation of intracranial vasculopathy, especially in differentiating between ICAD and RCVS or vasculitis, and between RCVS and vasculitis. In addition, the combination of T2 and T1 precontrast and postcontrast VWI can increase the sensitivity and specificity for differentiating disease. In the setting of contraindications to gadolinium contrast administration, T2 and T1 noncontrast VWI may also be reliably used to differentiate ICAD, RCVS, and vasculitis.

### Disclosures

Dr Tirschwell received research grants from National Institutes of Health (NIH) unrelated to this work. Dr Hatsukami received research grants from Philips Healthcare unrelated to this work. Dr Yuan received research grants from Philips Healthcare and NIH unrelated to this work, and he is a member of Philips Radiology Medical Advisory Network. The other authors report no conflicts.

### References

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SUPPLEMENTAL MATERIAL

Multi-Contrast High Resolution Vessel Wall MR Imaging and its Value in Differentiating Intracranial Vasculopathic Processes
## Online Supplemental Table I. Patient demographics and clinical history (N=29 patients).

<table>
<thead>
<tr>
<th>Variable</th>
<th>ICAD (N=21)</th>
<th>VS (N=4)</th>
<th>RCVS (N=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Male 9 (42.9)</td>
<td>3 (75.0)</td>
<td>1 (25.0)</td>
</tr>
<tr>
<td>Age, years</td>
<td>53.8 ± 10.4</td>
<td>34.2 ± 12.3</td>
<td>43.2 ± 9.8</td>
</tr>
<tr>
<td>Stroke Diagnosis</td>
<td>Acute 4 (19.1)</td>
<td>4 (100.0)</td>
<td>3 (75.0)</td>
</tr>
<tr>
<td></td>
<td>Chronic 5 (23.8)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td></td>
<td>Absent 12 (57.1)</td>
<td>0 (0.0)</td>
<td>1 (25.0)</td>
</tr>
<tr>
<td>Tobacco use</td>
<td>Current 4 (19.1)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td></td>
<td>Former 9 (42.9)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td></td>
<td>Never 8 (38.1)</td>
<td>4 (100.0)</td>
<td>4 (100.0)</td>
</tr>
<tr>
<td>Prior medical history</td>
<td>Hypertension 20 (95.2)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td></td>
<td>Hyperlipidemia 18 (85.7)</td>
<td>0 (0.0)</td>
<td>1 (25.0)</td>
</tr>
<tr>
<td></td>
<td>Diabetes mellitus 13 (61.9)</td>
<td>1 (25.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td></td>
<td>Obesity 9 (45.0)</td>
<td>1 (25.0)</td>
<td>2 (50.0)</td>
</tr>
<tr>
<td></td>
<td>Coronary artery disease 4 (19.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
</tbody>
</table>

*Values are no. (%) or mean ± standard deviation.

## Online Supplemental Table II. Detailed description of lesion appearance on T2.

<table>
<thead>
<tr>
<th>T2 Appearance of Lesion</th>
<th>All (N=118)</th>
<th>AS (N=81)</th>
<th>VS (N=15)</th>
<th>RCVS (N=22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juxtaluminal T2 hyperintense band with underlying T2 hypointense component</td>
<td>59 (50.0)</td>
<td>59 (72.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diffusely T2 hyperintense</td>
<td>4 (3.4)</td>
<td>4 (4.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed T2 hyperintense and hypointense signal</td>
<td>2 (1.7)</td>
<td>2 (2.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diffusely T2 isointense</td>
<td>23 (19.5)</td>
<td>6 (7.4)</td>
<td>8 (53.3)</td>
<td>9 (40.9)</td>
</tr>
<tr>
<td>Diffusely T2 hypointense</td>
<td>5 (4.2)</td>
<td>3 (3.7)</td>
<td>11 (50.0)</td>
<td></td>
</tr>
<tr>
<td>Lesion not well appreciated on T2</td>
<td>25 (21.2)</td>
<td>7 (8.6)</td>
<td>7 (46.7)</td>
<td></td>
</tr>
</tbody>
</table>

Values are no. (%); Empty cells correspond to 0 lesions.
頭蓋内血管病変の鑑別におけるマルチコントラスト高解像度血管壁MRIの有用性

Multicontrast High-Resolution Vessel Wall Magnetic Resonance Imaging and Its Value in Differentiating Intracranial Vasculopathic Processes

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¹Departments of Radiology, University of Washington, Seattle; and ²Department of Neurology, University of Utah, Salt Lake City.

背景および目的：いくつかの研究では血管壁MRI (VWI) で頭蓋内血管病変の鑑別を試みているが、マルチコントラスト画像を取り入れたものはない。本研究では、頭蓋内血管病変を鑑別するために T1 強調 VWI と T2 強調 VWI を用いた。

方法：VWI 検査を施行し、血管内腔の狭帯・不整、頭蓋内血管病状を臨床的に診断された患者を後ろ向きに検討した。検討対象患者 2 名、血管壁の肥厚パターン、造影後増強効果の存在、パターン、強度、および T2 信号の特徴などの造影前後の T1 強調 VWI および T2 強調 VWI の特徴を評価した。

結果：アテローム硬化症（頭蓋内アテローム性動脈硬化症：ICAD）患者 21 例、可逆性脳血管障害症候群（RCVS）患者 4 例、血管炎患者 4 例が特定され、合計で 118 個の狭帯病変が認められた（ICAD：81 個、RCVS：22 個、血管炎病変：15 個）。病変の T2 高信号（κ = 0.80）、血管壁の肥厚パターン（κ = 0.87）、および造影後増強効果の存在（κ = 0.90）、パターン（κ = 0.73）、強度（κ = 0.77）の評価において、やや良いながら良好な観察者間一致が得られた。RCVS (8.2%, P < 0.001) や血管炎病変 (6.7%, P < 0.001) と比較して、ICAD 病変には異常な ( eccentricity ) 血管壁病変がより多く認められる傾向にあり (90.1%), T2 高信号も良い傾向にあった (79% 对 0%, P < 0.001)。また、造影増強効果の存在や強度、およびパターンにおいても病変タイプ間で明らかに差が認められた。T1 強調 VWI と T2 強調 VWI の組み合わせにより、ICAD と他の血管病変の鑑別における VWI の感度は 90.1% から 96.3% に増加した。

結論：RCVS と血管炎の鑑別診断においては、より侵襲のない精密検査が必要となることが多く、マルチコントラスト VWI は頭蓋内血管病変の鑑別における補完的な手段となり得る。

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血管炎（VS: A）、頭蓋内アテローム性動脈硬化症（ICAD: B）、および可逆性脳血管障害候群（RCVS: C）の血管壁M RI検査（VWI）所見。A．血管炎：タイム・オブ・アフェイト（TOF）を用いた MF血管撮影（MPA）の冠状断最大断面断影（MIP）（左図の画像）より、左側 A2 前大脳動脈（ACA）、両側の中大脳動脈（MCA）、および右側 P1 後大脳動脈（白矢印）に多発性の動脈狭帯が見られる。左側 ACA 病変を中央に示す T2 VWI（中央左側）では、均等な等信号強度を示す外周性の血管壁肥厚がある（太い白矢印）。T1 造影前 VWI（中央右側）では、外周性の血管壁肥厚（黒矢印）が見られる。T1 造影後 VWI（右側）では、対応する瘤状血管壁造影増強効果が認められる（短い白矢印）。B．アテローム性動脈硬化症：冠状断 MIP TOF MRA 画像（左側）では、右 MCA M1 等位に狭帯がみられる（矢印）。T2 VWI（中央左側）では、内腔に沿って T2 高信号帯があり（黒矢印）、その下に MRA の狭帯部位に対応して低信号帯を示す病変（太い白矢印）がある。T1 造影前 VWI（中央右側）の等信号の病変は、異常な血管壁前面を示す（黒矢印）。T1 造影後 VWI（右側）では、不均一な造影増強効果が認められる（短い白矢印）。C．RCVS：転位断 MIP TOF MRA 画像（左側）では、多発性の頭蓋内動脈狭帯と左 ACA A1 に限局性の狭帯病変（白矢印）が見られる。転位断 T2 VWI（中央左側）では、狭帯を示す狭帯な外周性の血管壁肥厚（太い黒矢印）がある。T1 造影後 VWI（右側）では、頭蓋内血管壁の造影増強効果を示す所見は認められない（短い白矢印）。MRA 上では正常な血管に見え米対の ACA A1 に、血管周囲に軽度の造影増強効果（曲があった矢印）が認められ、静脈の造影増強効果を示していると考えられる。
두개내 혈관병증 감별에 사용되는 다중조영고
고해상 혈관벽 자기공명영상의 가치

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Abstract 13

두개내 혈관병증 감별에 사용되는 다중조영고
고해상 혈관벽 자기공명영상의 가치

결론
두개내 혈관병 진단은 RCVS와 혈관염이 감별 진단에 포함될 때 종종 잠재적인 검사를 필요로 한다. 이 때 다중조영 혈관벽 자기공명영상은 두개내 혈관병을 감별하는데 보완적인 수단이 될 수 있다.
Figure 1. Vessel wall magnetic resonance imaging (VWI) findings of vasculitis (VS; A), intracranial atherosclerotic disease (ICAD; B), and reversible cerebral vasoconstriction syndrome (RCVS; C). A. Vasculitis: coronal maximum intensity projection (MIP) time of flight (TOF) magnetic resonance angiography (MRA) (left) shows multifocal arterial stenosis involving the left A2 anterior cerebral artery (ACA), bilateral middle cerebral artery (MCA), and right P1 posterior cerebral artery (white arrows). On T2 VWI (left middle) centered over the left ACA lesion, there is circumferential vessel wall thickening with homogeneous isointense signal intensity (thick arrow). On T1 precontrast image (right middle), circumferential vessel wall thickening (black arrows) can be seen. On T1 postcontrast VWI (last image), there is corresponding homogeneous, circumferential vessel wall enhancement (short arrow). B. Atherosclerosis: coronal MIP TOF MRA image (first image) shows stenosis of the distal right M1 MCA (arrow). On T2 VWI (left middle), there is a juxtaluminal T2 hyperintense band (black arrowhead), with subjacent lesional hypointensity (thick white arrow) corresponding to the MRA stenosis. On T1 precontrast VWI (right middle image), isointense lesion shows eccentric anterior vessel wall involvement (black arrow). On T1 postcontrast VWI (last image), there is heterogeneous lesional enhancement (short white arrow). C. RCVS: axial MIP TOF MRA image (first image) shows multifocal intracranial arterial stenosis, with focal stenosis of the left A1 ACA (white arrow). Axial T2 VWI (left middle image) shows corresponding minimal wall thickening with T2 isointense signal (thick black arrows) at the site of left A1 ACA lesion. On axial T1 precontrast VWI (right middle), there is minimal circumferential vessel wall thickening (thin black arrows) corresponding to the stenosis. On T1 postcontrast VWI (last image), there is no evidence of significant wall enhancement (short white arrow). The contralateral A1 ACA, a normal arterial segment on MRA shows mild perivascular enhancement (curved arrow) likely representing venous enhancement.