

# Intracranial Vessel Wall MRI

Luigi Cirillo<sup>\*1,2,3</sup>; Arianna Rustici<sup>\*1,3,4</sup>; Tommaso Kaswalder<sup>2</sup>; Ciro Princiotta<sup>2</sup>; Massimo Dall'Olio<sup>2</sup>; Caterina Tonon<sup>1,3</sup>; Domenico Zacà<sup>5</sup>; Raffaele Lodi<sup>1,6</sup>

<sup>1</sup>Department of Biomedical and Neuromotor Sciences (DIBINEM), University of Bologna, Italy

<sup>2</sup>UOC di Neuroradiologia, IRCCS Istituto delle Scienze Neurologiche di Bologna, Italy

<sup>3</sup>Programma Neuroimmagini Funzionali e Molecolari, IRCCS Istituto delle Scienze Neurologiche di Bologna, Italy

<sup>4</sup>UO di Neuroradiologia OM, IRCCS Istituto delle Scienze Neurologiche di Bologna, Italy

<sup>5</sup>Siemens Healthcare Srl, Milano, Italy

<sup>6</sup>IRCCS Istituto delle Scienze Neurologiche di Bologna, Italy

*\*These authors contributed equally and share first authorship.*

## Introduction

To date, MR is the only clinically available imaging modality that allows to image the brain vessels beyond the 'lumen techniques', depicting both the lumen and the vessel walls with high sensitivity and low invasiveness [1]. Besides standard MR angiography (MRA) sequences, some MR sequences for vessel wall imaging have been introduced into clinical practice [2]. These MR sequences allow to depict the vessel walls at high resolution, and are becoming emerging techniques for evaluating cerebrovascular diseases.

Although vessel wall MRI (VW MRI) sequences are widely reported to be effective and efficient [3], there are no commercially available sequences optimized for intracranial imaging. In fact, VW MRI requires a very complex signal because the signal from both the blood inside the lumen and from the outer cerebrospinal fluid (CSF) must be suppressed.

This article describes the technical aspects of our VW MRI sequence<sup>1</sup> so that other institutions can develop their own sequence for the diagnosis and follow-up of cerebrovascular pathologies.

## Technique

We developed our optimized protocol on a 3T MAGNETOM Skyra system (Siemens Healthcare, Erlangen, Germany). It is based on a T1-weighted 3D SPACE sequence. Specific parameters have been modified to achieve sufficient signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) for vessel wall imaging. Moreover, we set parameters to obtain isotropic 3D imaging, achieve good suppression of CSF and blood, and reduce scan time (to avoid artifacts caused by patient motion) [4, 5]. The total scan time is 7 minutes 10 seconds.

Sequence parameter	
Acquisition time	7:10 min
Orientation	Coronal
Type	3D
Slice for slab	80
Slice oversampling	10.0%
Slice thickness	0.60 mm
FOV read (mm)	160 mm
FOV phase (%)	82.8%
Phase oversampling	20%
Phase resolution	100%
Voxel size	0.3 × 0.3 × 0.6
TR (ms)	1000 ms
TE (ms)	38 ms
ETL	211 ms
Flip angle (°)	T1 variable
Bandwidth (Hz/pixel)	514 Hz/Px
k-space filling	Interpolation with zero-filling
PAT mode	GRAPPA
Accel. factor PE	2
Ref. lines PE	24
Fat suppression	None
Dark blood	Off

**Table 1:** Our sequence parameters for vessel wall MRI at 3T.

<sup>1</sup>Work in progress. The application is still under development and not commercially available. Its future availability cannot be ensured.

Our VW MRI sequence is a 3D multi-slab acquisition (80 slices per slab, each with 0.60 mm slice thickness) acquired in coronal plane, with a rectangular field of view (FOV read = 160 mm; FOV phase = 82.8%) (Table 1). To reduce the slab boundary artifact, we use oversampling in the slice direction (slice oversampling = 10.0%). To avoid the wrap-around artifact, we use phase oversampling (phase oversampling = 20%; phase resolution = 100%).

With spin echo (SE) sequences, it is possible to adjust the TR (repetition time) and TE (echo time) to suit specific needs. We therefore set the TR to 1000 ms and the TE to 38 ms (Table 1), to achieve a CSF darkening effect by tailoring image contrast to T1 weighting and proton-density (PD) weighting (Table 2).

The black-blood effect is achieved by the intravoxel dephasing of moving blood spins within a long echo train length (ETL = 211 ms). A variable refocusing flip angle is used to compensate for the signal decay inherent in the long ETL.

The difference in the precession frequencies of the spins inside the voxels at the extremities of the FOV is set at 514 Hz/Px (bandwidth).

To reduce scan time, a parallel imaging acquisition technique (iPAT) called GRAPPA (Generalized Autocalibrating Partially Parallel Acquisitions) is used, with an acceleration factor (R) of 2, and 24 reference lines in the phase-encoding direction, to compensate for the under-sampling of the *k*-space (Table 1).

With those parameters, there is no need for an inferior outer volume suppression pulse to limit the inflow effects of blood, and no need for a fat-saturation pulse (Tables 1 and 2).

## Discussion

Intracranial VW MRI is a complex technique that requires elevated spatial and contrast resolution, and the ability to detect contrast enhancement after the administration of contrast medium.

Correctly visualizing the intracranial vessel walls relies on the suppression of the outer and inner structures. The signal of both the blood inside the lumen and of the outer CSF must therefore be suppressed. Although both structures are fluids, different suppression techniques are required because of their different properties. MR vendors have developed many different fluid-suppression techniques, each with some limitations [6, 7].

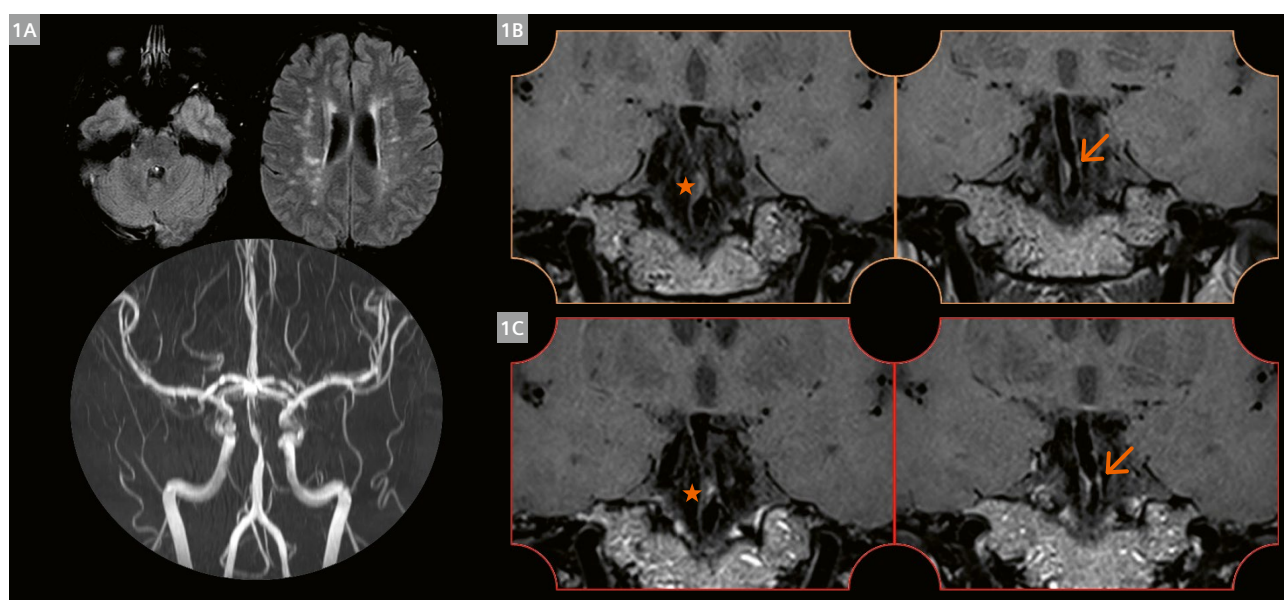
Due to the difficulty of generating one signal while suppressing others, and to the heterogeneity of scanners and coils, no sequences optimized for intracranial imaging are commercially available [8].

The basis of our VW MRI sequence is a 3D SPACE sequence, which is a spin-echo sequence. As all spin-echo sequences are pulsed sequences, they allow us to obtain different weighting based on predefined timing parameters, such as TR and TE. We decided to maintain the contrast of our sequence intermediate between the T1 and PD weighting. This is because the T1-weighted sequences have the advantage of clearer enhancement after the administration of contrast medium, whereas PD-weighted sequences provide a higher SNR [8] (Table 2). Moreover, an intermediate T1/PD weighting achieves the required CSF suppression, due to its long T1 relaxation time (Table 2).

Many different and complex techniques have been developed to suppress flowing blood. Each of them has some limitations [6, 7]. The most commonly used suppression methods are the black-blood techniques [6]. They can be broadly classified as either flow-dependent or flow-independent [7]. Although blood-suppression techniques are not the subject of this paper, it must be noted that the black-blood techniques have several limitations and could lead to artifacts [7], the most common of which is the presence of a residual blood signal, which is due to insufficient blood suppression and can mimic or obscure vascular pathologies. This can occur in cases of stagnant, slow, or retrograde blood flows, and typically with flow-dependent techniques.

	T1-weighted	PD-weighted	T2-weighted
CSF	Dark	Light gray	Bright
Blood inside vessels	Bright	Dark	Dark
Advantages	<ul style="list-style-type: none"> <li>• High anatomical detail</li> <li>• High contrast to Gd</li> <li>• Relatively short lead times</li> </ul>	<ul style="list-style-type: none"> <li>• High SNR</li> <li>• High anatomical detail</li> </ul>	<ul style="list-style-type: none"> <li>• High tissue contrast</li> </ul>
Disadvantages	<ul style="list-style-type: none"> <li>• Low tissue contrast</li> </ul>	<ul style="list-style-type: none"> <li>• Reduced contrast enhancement</li> <li>• Reduced suppression of CSF</li> </ul>	<ul style="list-style-type: none"> <li>• Mid-level anatomical detail</li> <li>• Long standard sequences</li> </ul>

**Table 1:** Signal intensity, with advantages and disadvantages, for each MR weighting.



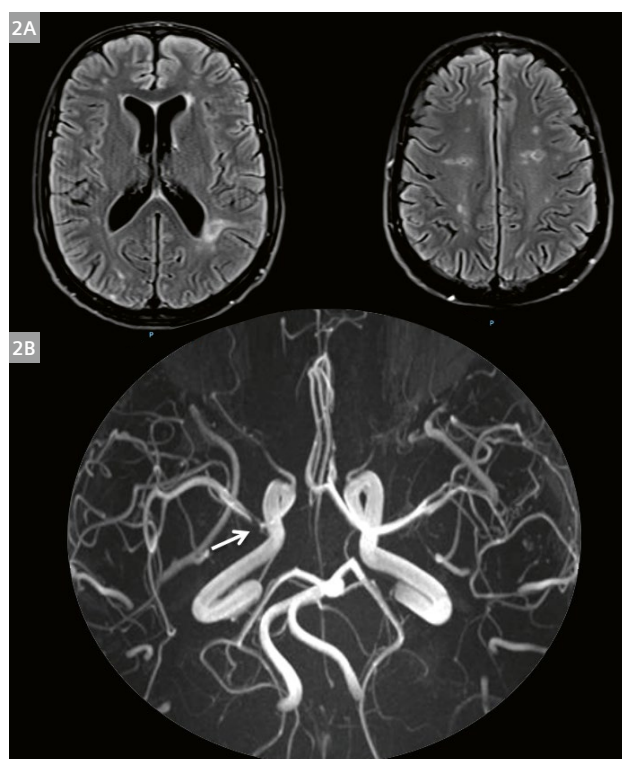
**1** (1A) A 55-year-old female patient with recent worsening of chronic headache underwent an MRI study. The FLAIR axial images showed multiple chronic embolic lesions in both the posterior and anterior circulation; the time-of-flight (TOF) sequence showed the presence of multiple caliber alterations in the intracranial arterial circulation, the worst of which was on the basilar artery. (1B, C) Pre- and post-contrast high-resolution vessel wall imaging, with the coronal reconstruction of the 3D acquisition showing a focal atheromatous plaque and wall thickening (arrow), and the absence of wall enhancement after the administration of contrast medium (star).

Regardless of the suppression technique used, VW MRI does have pitfalls that should be noted [7]. For example, it is impossible to assess the presence of wall enhancement in the cavernous segment of the internal carotid artery. This is due to diffuse enhancement inside the cavernous sinus after contrast-agent administration [7].

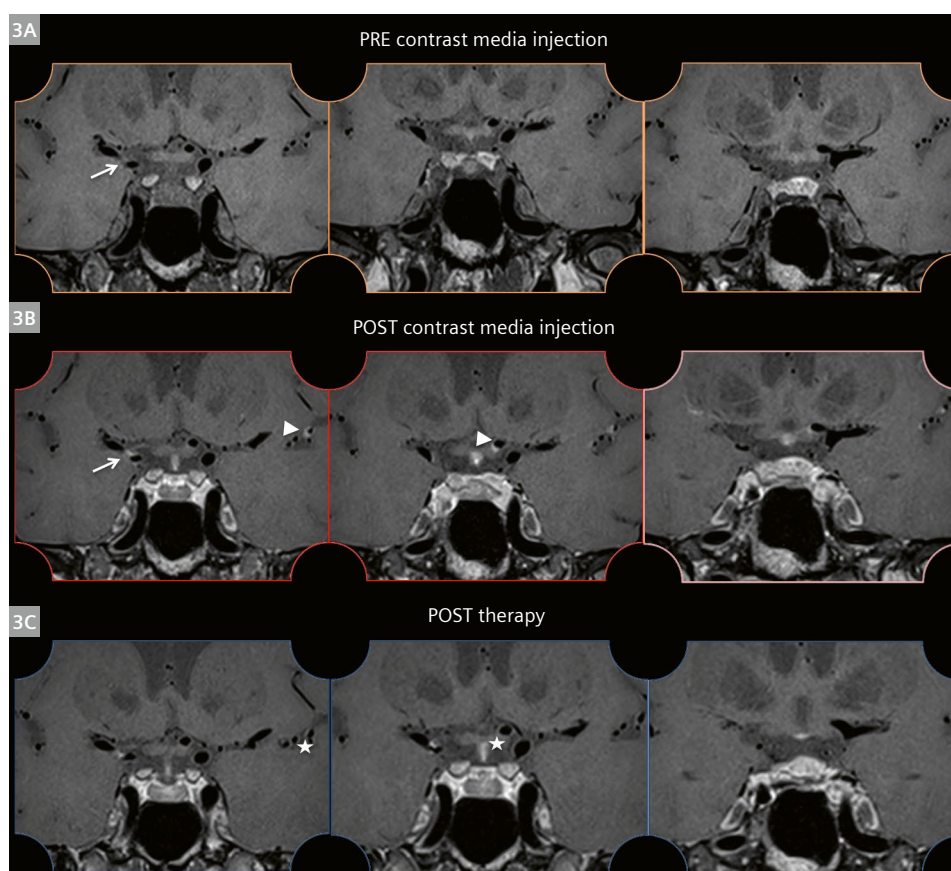
Aside from contrast resolution, the scan time is also important, because using sequences with long acquisition times in clinical practice may cause motion-induced artifacts. It is therefore necessary to reduce the scan time. MR vendors have provided various parallel imaging techniques to achieve this.

We have reported our experience with a VW MRI sequence, a novel imaging tool that has been evolving in recent years. Its purpose is to diagnose and support treatment decisions for various cerebrovascular pathologies, such as CNS vasculitis (Fig. 1), reversible cerebral vasoconstriction syndrome (RCVS), intracranial atherosclerosis (Figs. 2, 3), aneurysms, dissections, moyamoya disease, and moyamoya-like diseases.

After performing more than 200 VW MRI examinations with the aforementioned sequence, we found it to be useful in the diagnosis of more than 97.1% of cases (31.7% of our VW MRI examinations were determined to be positive for vessel wall pathologies, while 65.4% were negative). The VW MRI was inconclusive in less than 3% of cases, due to motion artifacts or blood-suppression artifacts.



**2** (2A) A 48-year-old male patient with recent worsening of chronic headache. FLAIR axial images showed multiple chronic embolic lesions. (2B) MR angiography showed a focal stenosis of the right M1 segment at origin (arrow).



**3** Vessel wall MRI study before (3A) and after (3B) the administration of contrast media showed the presence of a slight circumferential enhancement in correspondence of the right M1 origin segment (arrow). Other pathological vessel wall enhancements were noticed on the left A1–A2 angle and the M2–M3 segments of the left middle cerebral artery (arrowheads). The laboratory test was positive for a T. pallidum infection, so the final diagnosis is a luetic CNS vasculitis. An MR control performed one month after medical therapy (3C) showed the disappearance of the pathological enhancement at the left A1–A2 angle of the anterior cerebral artery and the M2–M3 segments (stars).

Compared to other VW MRI sequences reported in the literature, ours has the advantage of being as simple as possible, since it uses no blood-suppression techniques, which avoids suppression-related artifacts.

## Contact

Luigi Cirillo  
Associate Professor of Neuroradiology  
Alma Mater Studiorum –  
University of Bologna  
IRCCS Istituto delle Scienze  
Neurologiche di Bologna  
Via Altura 3  
40133 Bologna  
Italy  
luigi.cirillo2@unibo.it



## References

- 1 Jung SC, Kang DW, Turan TN. Vessel and Vessel Wall Imaging. *Front Neurol Neurosci*. 2016;40:109–123.
- 2 Bhogal P, Uff C, Makalanda HL. Vessel wall MRI and intracranial aneurysms. *J Neurointerv Surg*. 2016;8(11):1160–1162.
- 3 Young CC, Bonow RH, Barros G, Mossa-Basha M, Kim LJ, Levitt MR. Magnetic resonance vessel wall imaging in cerebrovascular diseases. *Neurosurg Focus*. 2019;47(6):E4.
- 4 Rustici A, Merli E, Cevoli S, Donato MD, Pierangeli G, Favoni V, et al. Vessel-wall MRI in thunderclap headache: A useful tool to answer the riddle? *Interv Neuroradiol*. 2021;27(2):219–224.
- 5 Pensato U, Cevoli S, Cirillo L. Vessel Wall Imaging in Thunderclap Headache: A Reversible Cerebral Vasoconstriction Syndrome (RCVS) Case. *Headache*. 2020;60(10):2633–2635.
- 6 Henningson M, Malik S, Botnar R, Castellanos D, Hussain T, Leiner T. Black-Blood Contrast in Cardiovascular MRI. *J Magn Reson Imaging*. 2022;55(1):61–80.
- 7 Lindenholz A, van der Kolk AG, Zwanenburg JJM, Hendrikse J. The Use and Pitfalls of Intracranial Vessel Wall Imaging: How We Do It. *Radiology*. 2018;286(1):12–28.
- 8 Mandell DM, Mossa-Basha M, Qiao Y, Hess CP, Hui F, Matouk C, et al. Intracranial vessel wall MRI: Principles and Expert Consensus Recommendations of the American Society of Neuroradiology. *AJNR Am J Neuroradiol*. 2017;38(2):218–229.