Assessment of Cervical Venous Stenosis in Multiple Sclerosis Patients using 4D Flow MRI

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Purpose: It has recently been noted using vascular ultrasound and conventional venography that patients with multiple sclerosis (MS) may have anomalies of the cervical venous system, including stenoses and complex collateral pathways [1]. It is possible that such findings could relate to the disease pathogenesis, given the peri-venular location of most MS plaques. Temporally-resolved, volumetric phase-contrast MRI (known as 4D flow) is a promising approach for the dynamic characterization of blood flow [2]. In addition to anatomically characterizing the vasculature, it can also provide temporal information about flow pulsatility. As contrast media is not required, accurate bolus timing is not necessary. Finally, it allows complete evaluation of the venous system, including the intracranial regions, which is not possible with ultrasound. We therefore set out to investigate the use of 4D flow MRI to characterize venous flow in this population of patients.

Methods: 2D flow-compensated axial GRE TOF neck MRA, TRICKS contrast MRA/ MRV, and 4D flow sequences were performed in 14 patients with known MS who also underwent conventional catheter-based venography. 4D flow was acquired in a coronal slab, post single-dose IV contrast, with a Venc of 40 cm/s. Using in-house software implemented in Java/SWT, the velocity waveforms were interrogated at several points in the venous system. Flow waveforms were assessed using the phasicity index defined as $(Q\text{-}Q_{min})/Q_{max}$ for each point in the cardiac cycle. We further devised a novel method of visualization of 4D flow data, which we have named velocity-weighted projection cine angiography (VW-PCA), in which the voxel with the highest superior-to-inferior velocity is projected to form MIP-like images. We compare the diagnostic utility of these images to conventional venography.

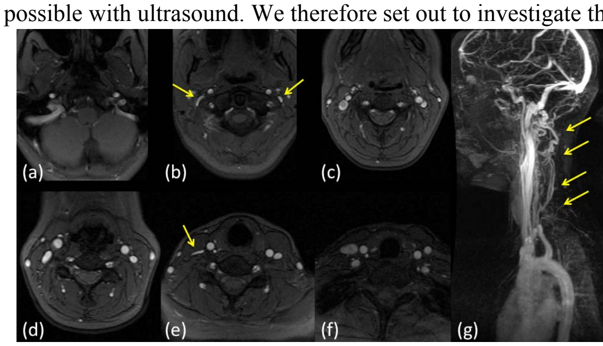

Fig 1: Characteristic locations of venous abnormalities. In the upper neck (a-c), flattening is often seen near C1 (arrows, b). In the lower neck (d-f), flattening can be seen between the SCM and anterior scalenes on the right (arrows, e). (g) Sagittal MIP from the TRICKS images shows prominent posterior epidural collaterals.

Results and Discussion: We found that 9 of 14 patients (64%) demonstrated internal jugular (IJ) stenoses sufficient to cause dilated collateral venous pathways in the neck. These collateral pathways demonstrate near constant flow over the cardiac cycle, rather than the typical pulsatile pattern of the IJ vessels in the neck [3]. Many of these patients show diminutive flow in one or both IJ veins, with characteristic areas of flattening near the C1 lateral masses as well as in the lower neck, between the sternocleidomastoid and the anterior scalene muscles (**Fig 1**). These findings contrast with prior ultrasound studies that show that the majority of brain blood flow drains via the IJ's in the supine position in normal subjects [4,5]. In patients with patent jugular veins, the venous waveforms demonstrate gradual dampening of phasicity as they are traced from the low IJ to the transverse sinus (**Fig 2**). Patients with stenoses show a more rapid dampening of phasicity and altered transmission of the velocity peak. We also show that lesions apparent on VW-PCA images derived from the 4D flow data correlate well with conventional venography (**Fig 3**).

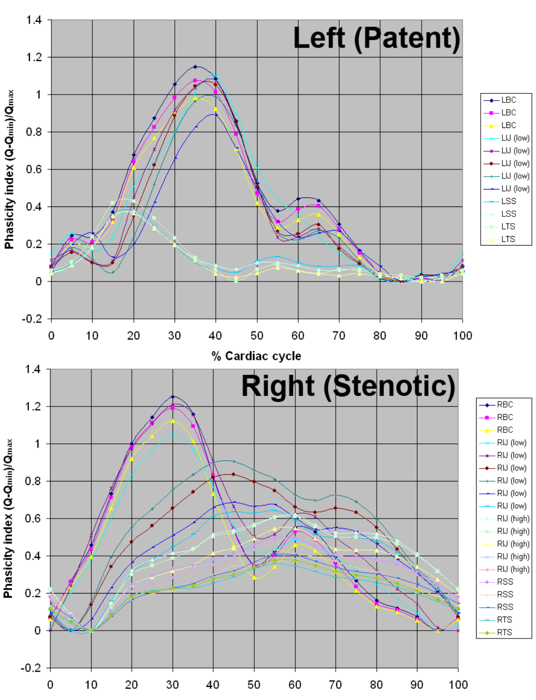

Fig 2: Phasicity of volumetric flow in a patient with a normal left IJ and a stenotic right IJ system. Assessments of the flow were made from the brachiocephalic veins (LBC and RBC), through the IJ veins, and into the transverse sinus (LTS and RTS). Typical pulsatile flow is seen in the proximal vessels bilaterally, while there is dampening of the waveforms more distally, which is more pronounced and occurs earlier on the stenotic right side.

Conclusions: 4D flow MRI can characterize flow-limiting venous stenoses by identifying the presence of collateral vessels, determining the contribution of each vessel to overall venous drainage, and documenting dampening of the venous pressure wave. We have confirmed prior reports of venous abnormalities in MS patients. Future studies will assess these methods in age-matched normal subjects. Such 4D flow approaches may be more widely useful to further our understanding of both normal and abnormal venous flow in a wide range of diseases.

References: 1. Zamboni et al., J Neurol Neurosurg Psych 2009;80:392; 2. Markl et al., JMRI 2003;17:499; 3. Sapira, The Art and Science of Bedside Diagnosis, Williams & Wilkins, 1990, 363ff; 4. Doepp et al., Neuroradiology 2004;46:565; 5. Schreiber et al., J Appl Physiol 2003;94:1802.

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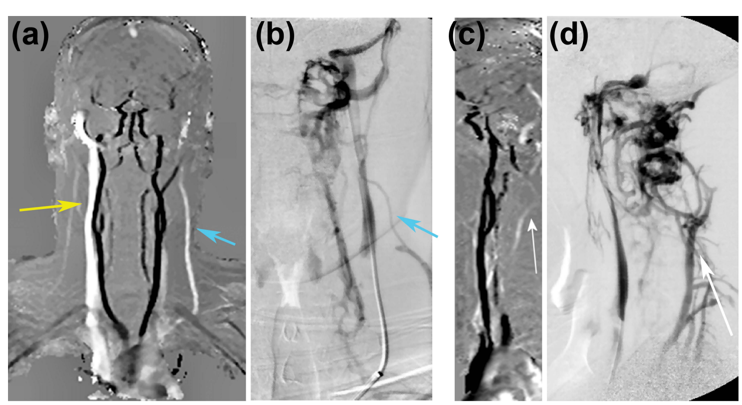

Fig 3: 4D flow projection angiogram (VW-PCA) images in a 39 year old man with multiple sclerosis (white = superior-to-inferior flow). (a) In AP view, the right IJ is widely patent (yellow arrow), but the left IJ is diminutive. There is a large left-sided external jugular vein (blue arrows). (c) On lateral view, prominent posterior epidural venous collaterals are also visualized (white arrows). Conventional venograms following injection of the left IJ in the (b) AP and (d) lateral projections confirm the MRI findings.