Consistency of commonly applied vessel segmentation methods for magnetic resonance venography

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INTRODUCTION: The magnetic susceptibility of venous blood allows intracranial veins to be directly imaged with MRI, without an extrinsic contrast agent, using susceptibility-weighted imaging[1] (SWI) and, more recently, quantitative susceptibility mapping[2] (QSM). Multiple post-processing techniques (such as vessel enhancing filters) have been proposed and used in many studies for identifying major veins for neurosurgical planning and examining anomalies[3]. Whilst different filters enhance different image features, this rarely poses a problem for visual analysis where the human eye, in combination with contrast and brightness manipulation, can compensate. However, when used for quantitative research purposes[4], the variation between image filters is important. Furthermore, the growing use of QSM introduces an additional source of variation. In this study we compare filtering techniques across a large dataset of elderly subjects using both SWI and QSM. We examine correlation between voxel intensities, as well as regional voxel density measurements, in post-processed and thresholded images.

METHOD: 100 healthy elderly subjects (age > 70 years) were recruited, as part of the ASPREE study, and scanned on a 3T Siemens Skyra with a 32-channel head and neck coil. A single echo, fully flow compensated, GRE sequence was used (TE=20ms, TR=30ms, Voxel=0.9x0.9x1.8mm^3, Matrix=256x232x72, FA=15). Standard magnitude and SWI images were obtained directly from the Siemens console (IDEA version VD13A), and raw k-space data was saved. HARPARELLA[5] was used for background field removal and phase unwrapping on individual coil images. Coil images were combined using a sensitivity-weighted sum. QSM was calculated using MEDI[5]. SPM8 was used for segmentation on a T1-weighted MPRAGE image to generate white matter (WM), grey matter (GM) and cerebrospinal fluid (CSF) masks. The T1 and GRE images were registered using FLIRT. Vessel enhancement was performed on the SWI and QSM using a second-order phase difference[6] (SPD) filter and vesselness[7] (VN) filter. The original (raw) and enhanced images were converted to a binary venous mask using an Otsu threshold. Venous density was calculated for the entire brain, and for sub-regions, as the sum of venous voxels divided by the sum of voxels in the region. The density measurement from each filter-image combination was analysed using a Pearson correlation.

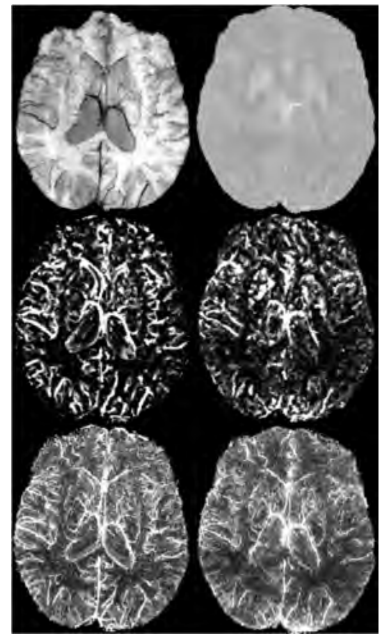

Figure 1: Maximum (minimum for SWI) intensity projections across 9mm (5 slices). Columns (left to right): SWI, QSM. Rows (top to bottom): Raw, VNF, SPD.

		QSM			SWI		
		Raw	VN	SPD	Raw	VN	SPD
QSM	Raw	1	0.33	0.41**	0.41*	-0.24	0.33
	VN		1	0.40*	0.27	0.07	0.33
	SPD			1	0.33	0.23	0.81**
SWI	Raw				1	-0.03	0.46**
	VN					1	0.33
	SPD						1

Table 1: Pearson correlation of venous density values. (*$p<0.01$, **$p<0.001$).

RESULTS: Figure 1 shows, for a single example subject, maximum intensity projections (minimum for SWI) of the QSM and SWI images, and the two filters applied to each image. The Pearson correlation ρ value for each combination of filter-image, for the cohort as a whole, is given in Table 1. Figure 2 shows density values from QSM and SWI plotted against each other for the two filters and raw values. The most significant finding is the consistency of QSM and SWI images post-processed with the SPD filter ($p < 0.001$). This tight correlation between QSM and SWI for the SPD filter is evident in Figure 2. Images filtered with the VN filter did not show a significant correlation with themselves on different modalities, nor with raw images. No significant correlation was found between the filters on SWI, and a weak correlation was found between the filters on QSM.

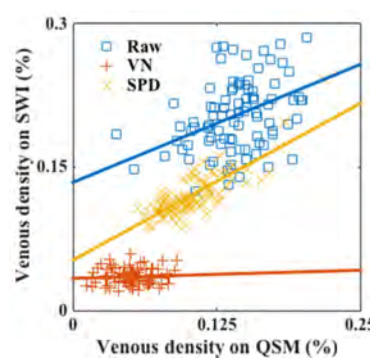

Figure 2: Venous density per subject grouped by technique and plotted as QSM against SWI.

DISCUSSION: This work examined the consistency of techniques applied to SWI and QSM, and to our knowledge this is the first study of its kind. A complicating factor of this study may have been the age of the subjects, as using susceptibility contrast for venous masks in the elderly is particularly difficult due to the accumulation of iron in the brain with age. However, highly consistent results were observed for the SPD filter regardless of image modality. Correlations were also observed between raw and SPD processed images of the same modality.

CONCLUSION: The choice of vessel-enhancement filter may influence findings and potentially hinder meta-analysis. The SPD filter produced the most consistent results when applied to both SWI and QSM images. Future work will examine the source of variations between filters and explore more complex segmentation techniques, alternatives to Otsu thresholding, and assessing the accuracy of these methods against known venous vasculature from manual segmentations.

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