# Removal of Arterial Vessels Contribution for Improved Quantification of Normalized Venous Volume in Patients with Sickle Cell Disease

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**Target Audience:** Scientists and clinicians interested in SWI and neuroimaging in sickle cell disease

**Purpose:** The most devastating complication in children with sickle cell disease (SCD) is stroke.[1] SCD patients at risk routinely undergo MR imaging with angiography to assess the integrity of their cerebrovascular system.[2] Three-dimensional gradient echo (3D-GRE) susceptibility-weighted imaging (SWI)[3] is used to visualize and investigate the integrity of the venous vasculature. A recent study of SWI in SCD reported decreased venous conspicuity in SCD patients compared to healthy controls.[4] In SWI, veins appear hypointense because of a change in magnetic susceptibility between deoxyhemoglobin and oxyhemoglobin. However, some irregular or tortuous arteries also appeared hypointense due to failure of flow compensation of the GRE sequence in SCD patients.[4] The mixture of decreased venous conspicuity and arterial vessels could lead to misinterpretation or concealment of venous vasculature abnormalities. In this study, we propose a post-processing technique to remove arterial vessel contamination in SWI exams, especially in SCD patients. Removal of the arterial vessels should enhance SCD SWI interpretation and improve quantification of venous conspicuity to investigate SWI's potential use as a biomarker in SCD.

**Methods:** Diagnostic SWI scans from 21 hemoglobin SS genotype patients (12 F, mean age, 12.9±3.7 years; 9 M, mean age, 12.3±3.9 years) were analyzed in this retrospective institutional review board approved study. Twelve exams were performed at 1.5T (Siemens Avanto and Symphony) and 9 exams at 3T (Siemens Trio). The SWI acquisition was a 3D T2*-weighted gradient-echo sequence with the following parameters (3T/1.5T): TE=25/40 ms, TR=56/60 ms, FA=20°, slice thickness=2 mm, matrix size=384x257x72, FOV=210x210 mm$^2$, and IPAT= 2. A sliding minimum intensity projection (mIP, 16 mm thick) was calculated from the SWI. The exam also included a 3D time-of-flight (TOF) MRA with the following parameters: TE=4.25 ms, TR=40 ms, FA=25°, slice thickness=0.8 mm, matrix size=512x512x82, FOV=210x210 mm$^2$, and IPAT= 2. Frequency of hypointense arterial contribution above the middle cerebral artery (MCA) was qualitatively assessed in the mIP SWI. The apparent venous contrast in the mIP SWI was quantified by segmentation of venous structures using a 2D Frangi vesselness filter[5] in MATLAB with filter parameters β=0.5 and c=20. The 2D Frangi vesselness filter can be used to segment hyperintense or hypointense tubular structure according to the sign of the 2$^{nd}$ eigenvalue. A normalized visible venous volume (NVVV) was calculated by dividing the volume of venous vesselness with probability >60% above the MCA from the total intracranial volume above the MCA (uNVVV = uncorrected). To remove any arterial contribution from NVVV, the MRA was realigned by normalized mutual information to the SWI using SPM8. The same 2D Frangi filter was used to segment the hyperintense arterial signal from the realigned MRA. An arterial mask was created by selecting voxels with a probability >75% and was dilated by 2 voxels in-plane. The mask dilatation was to minimize any vessel misalignment between the MRA and SWI. A corrected sliding mIP SWI and true NVVV (tNVVV) was calculated as describe above. However, voxels corresponding to the arterial mask were ignored in the mIP calculation (see Fig. 1).

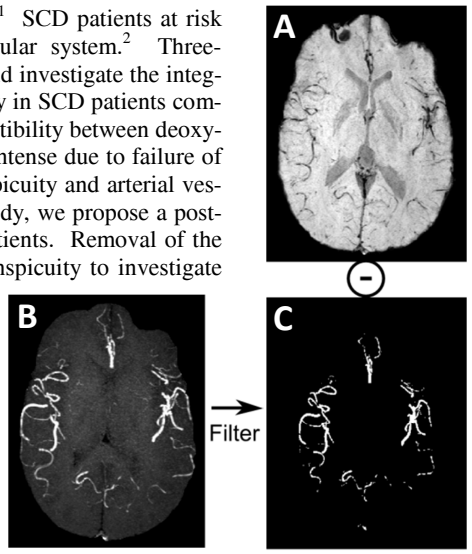


***Figure 1**: Representative SCD mIP SWI (A) with several hypointese vessels that could be interpreted as veins. The corresponding MIP TOF (B) of the mIP indicate that many of the hypointese vessels on the mIP SWI correlate with the hyperintense arterial signal from the TOF. The corrected mIP SWI (D) depicts the effectiveness of arterial signal removal.*

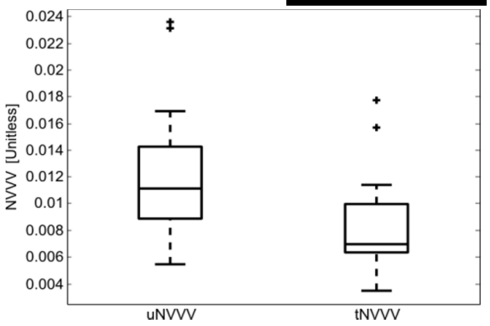


***Figure 2**: Box plot of the NVVV in 21 SCD patients before arterial signal correction uNVVV= 0.012± 0.005 and after correction tNVVV= 0.008±0.00 (mean±std).*

**Results:** The presence of arterial signal in the mIP SWI was observed in 18 of the 21 exams (86%). Interpreting only mIP SWI images in SCD, hypointese vessels would be interpreted as veins. However, corresponding maximum intensity projection (MIP) TOF images of the same volumes indicate that many of the hypointese vessels on the mIP SWI correlate with the hyperintense arterial signal from the TOF (Fig. 1A,B). By applying the proposed technique, the arterial contamination is effectively eliminated in the mIP SWI image as shown in Fig. 1D. The change in the visible venous vasculature from the uncorrected to corrected mIP SWI indicates a large arterial vessel contribution. Removal of the arterial signal from the mIP SWI decreased the NVVV by 32% (uNVVV=0.012±0.005, tNVVV=0.008±0.003, p<0.01 by repeated measures ANOVA, Fig. 2) in this cohort.

**Discussion/Conclusion:** Investigating possible physiological mechanism of decreased venous conspicuity in SCD patients requires accurate quantification of venous contrast. Upon qualitative review, arterial signal was found in a large proportion of SWI exams in our SCD patients. These arterial vessels presented as tortuous or twisted hypointese vessels. Quantification of venous contrast before and after arterial vessel removal indicated that approximately a third of the apparent venous volume by SWI was arterial. The proposed method of eliminating arterial signal from the SWI is limited by the quality, coverage, realignment, and segmentation of the accompanying MRA. Without removal of arterial vessels from the SWI exams of SCD patients, it is impossible to elucidate physiological mechanisms of decreased venous conspicuity.

**References:** [1] Ohene-Frempong K, *et al*. (1998) Blood. 91: 288-94. [2] Debaun MR, *et al*. (2006) Ment Retard Dev Res Rev. 12:192-9. [3] Reichenbach JR, *et al*. (2001) NMR Biomed 14:452-67. [4] Winchell AM. *et al*. (2013) AJNR: in print. [5] Frangi A, *et al*. (1998) MICCAI:130-37.