Imaging veins, oxygen extraction fraction, arteries and vessel wall using susceptibility weighted imaging (SWI) and susceptibility mapping (SWIM)

E. Mark Haacke
Department of Radiology,
Wayne State University
Detroit, Michigan
Conflicts of Interest

- Support from Siemens Medical Systems
- DoD grant on SWI and SWIM
- NIH grant on USPIO susceptibility
Qualitative SWI versus quantitative susceptibility mapping (QSM) or SWIM
0.5mm isotropic resolution, TE = 20ms, 3T
Imaging veins and blood products using SWI and SWIM\textsuperscript{1-3}

Differentiating calcium from blood using SWIM
200mg caffeine pills (a, d) or 1000mg diamox IV injection (c, f).

Compared to the control condition (b,e), significant oxygen saturation changes are observed post-challenge on veins throughout the brain.

Caffeine: flow change = $-27\% \pm 9\%$ and $\Delta Y = -0.09 \pm 0.02$
Diamox: flow change = $+40\% \pm 7\%$ and $\Delta Y = +0.10 \pm 0.01$
Sequence diagram of the fully flow-compensated double-echo SWI sequence\textsuperscript{5}

Image courtesy of Dongmei Wu
Imaging veins and arteries using double echo SWI\textsuperscript{5}
Images courtesy of Meiyun Wang, Zhengzhou

Thrombus dominates the SWI image (TE = 7.5ms)
First echo MIP

First echo MRA like signal

Thrombus dominates the SWIM image (TE = 7.5ms)
Second echo (17.5ms) true SWI

Note the asymmetrically prominent cortical veins
First echo SWI phase image
Imaging veins and arteries using an interleaved rephased/dephased double echo SWI\textsuperscript{6}

Small arteries around 250 microns and possibly down to even 100 microns are becoming visible.

\[250\mu \times 250\mu \times 500\mu\] resolution
Simultaneous MRV and MRI using a double echo interleaved SWI rephased/dephased sequence\textsuperscript{7}

At 3T, veins are more naturally suppressed because they have $T2^* = 25\text{ms}$ while arteries have a $T2^*$ closer to 70-80ms. Images acquired with a resolution of 0.5mm x 0.5mm in-plane and 1mm thick slice. 0.5mm in-plane resolution.

Images courtesy of Yongquan Ye, PhD
Imaging stroke patients with SWI and PWI\textsuperscript{8,9}:

Note that the MTT region indicating reduced perfusion matches the area highlighting the veins in the SWI image which corroborates the fact that flow is reduced and that the deoxyhemoglobin levels are increased in this territory. After treatment both the increases in MTT and evidence of the asymmetrically prominent cortical veins disappears.

Images courtesy of Dr. Yu Luo.
Visualizing Oxygen Extraction Fraction and Brain Iron

**Green** - deoxyhemoglobin levels in the veins

**Blue** represents iron in the basal ganglia and midbrain
Stroke: Isolating poor flow using a threshold in SWIM\textsuperscript{9,10}

Imaging headache and idiopathic intracranial hypertension
Asymmetrically prominent cortical veins are seen bilaterally
Abnormal dural sinuses and jugular vein
Imaging vessel wall using SWI and SWIM\textsuperscript{11,12}

Carotid vessel wall plaque, TE = 5ms

TE = 15.6ms
0.5mm x 0.5mm x 1mm sagittal acquisition
8 minutes without parallel imaging
2008 time frame
0.37 radian phase shift
This may be a case of vulnerable plaque.
Here you can see what appears to be a small thrombus on the inside wall. If that is the case, it could break off and become an embolus causing a stroke. SWIM validates it is iron and therefore likely blood.
Representatives from the following cities presented:
Academic speakers from Shanghai, Zhengzhou, Tianjin, Shenyang, Seoul, Detroit, and a speaker from Siemens Healthcare from Beijing

AGENDA: GOALS FOR AN INTEGRATED STROKE IMAGING PROTOCOL
• The use of SWI and SWIM in revealing changes in oxygen saturation
• Intracranial black blood T1 imaging pre/post contrast to evaluate atherosclerosis
• Monitoring patients from the acute to sub-acute stage
• Creating a database for this new 4-tiered stroke protocol

2nd Annual MRI Workshop on Stroke and Traumatic Brain Injury
• Tentatively scheduled for August, 2015 in Beijing
Conclusions and Future Directions for Non-contrast Uses of SWI/SWIM

- Imaging veins and arteries simultaneously using a multi-echo SWI sequence
- Quantifying oxygen extraction fraction and iron
- Imaging vessel wall in the head, neck, abdomen and legs to study atherosclerosis and vulnerable plaque
This talk can be found at www.swim-mri.com

5) Dongmei Wu, Saifeng Liu, Sagar Buch, Yongquan Ye, Yongming Dai and E. Mark Haacke. A Fully Flow Compensated Multi-echo Susceptibility Weighted Imaging Sequence: Acceleration and Background Field Effects on Flow Compensation (manuscript submitted for publication to MRM).
Dr. Satish Kristnhamurthy from Syracuse University has previously shown that macromolecules (dextran) are transported from the ventricles into the brain tissue and are rapidly concentrated in the perivascular space surrounding microvessels throughout the brain.

Hypothesis

These macromolecules are then cleared from the perivascular space by passing through the endothelium and into the blood (via the venous system) and are transported out of the brain.
Clearance of iron dextran for a normal rat versus delayed clearance for the hydrocephalic rat

SWI (TE=7.71ms) at 7T pre, 1 hour and 1h30m for a normal rat (#7) (top row) and a hydrocephalic rat (#16) (bottom). The hydrocephalic rat has high Fe-Dextran concentration in the lateral ventricles compared to the normal rat. The injection side lateral ventricle has higher Fe-dextran concentration.
Susceptibility maps can be used to follow the Fe-Dextran

The timings are pre contrast, 50 minutes (central column) and 1.5h (right column). The dextran remained in the CSF channels, LV, 3rd ventricle aqueduct, 4th ventricle and resulted in higher concentration and permeated to the parenchyma from the CSF channels.

SWIM showed no uptake in normal rats (first row) and significant uptake in the veins for the hydrocephalic rats over time (second row).