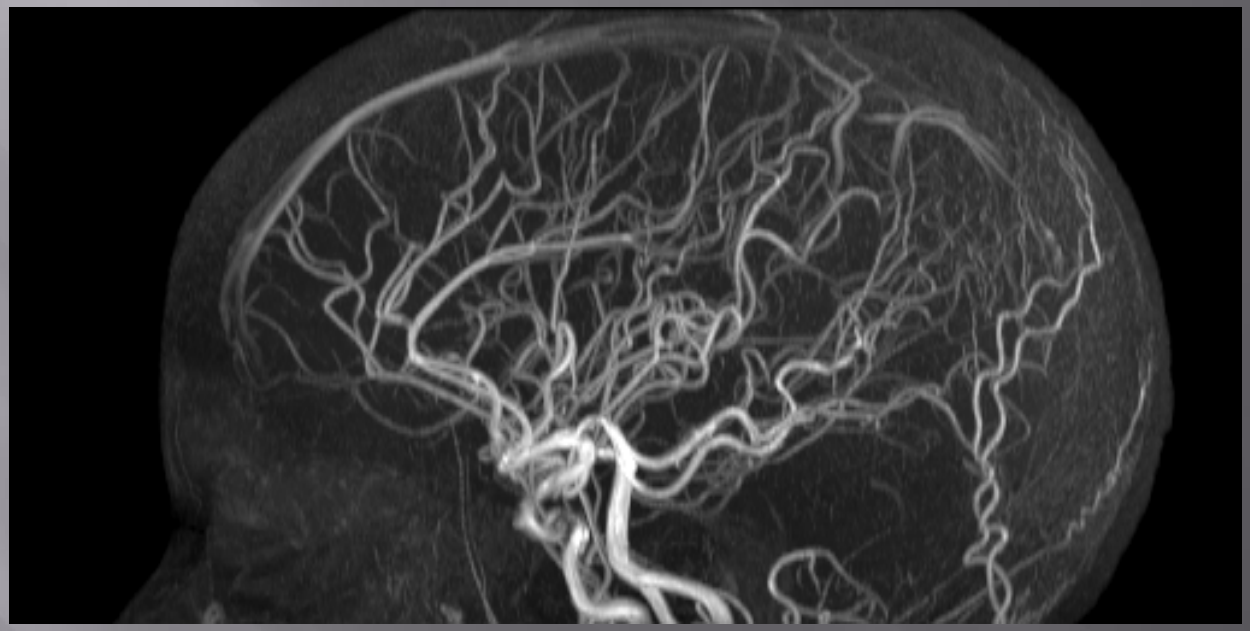
The application of SWI and SWIM in imaging stroke, traumatic brain injury and tumors



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Detroit, Michigan

Disclosures

I am affiliated with:

Wayne State University

McMaster University

The MRI Institute for Biomedical Research

and have an interest in

MR Innovations, Inc.

and have support from

Siemens Healthcare and

The National Institutes of Health

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- Giacomo Gadda, for image analysis
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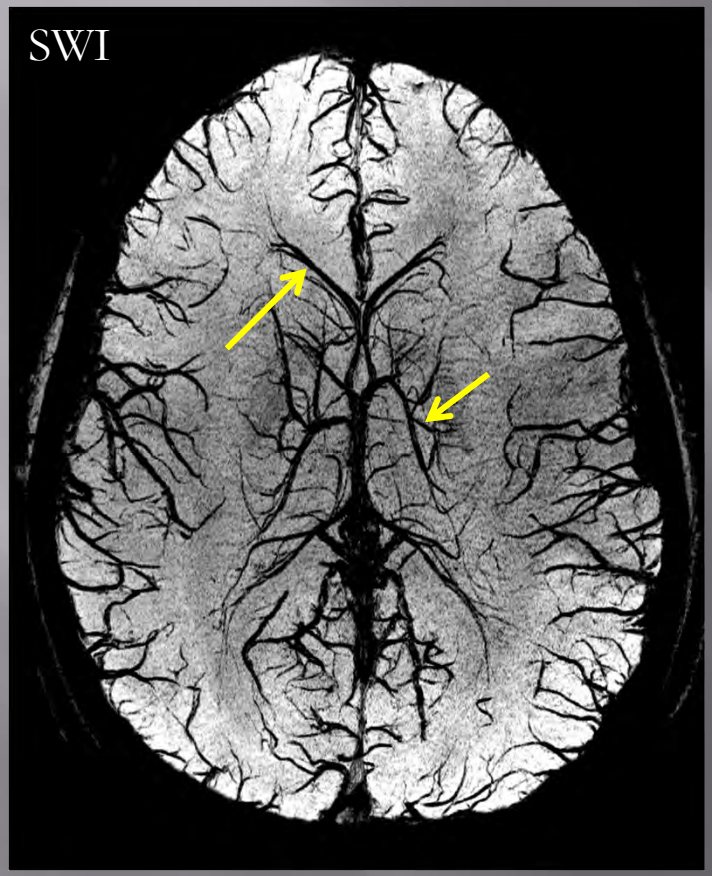
- Jaladhar Neelavalli, PhD for SWIM support
- Zhifeng Kou, PhD for TBI data

Informational Websites

- Clinical applications of SWI and SWIM
- See www.swim-mri.com

- The role of abnormal venous flow in neurodegenerative diseases: MS as an example
- See www.ms-mri.com
- Our work in Detroit at Wayne State University
- See www.mrc.wayne.edu

Susceptibility Weighted Imaging



- Enhances the presence of ferritin, hemosiderin and deoxyhemoglobin
- Exquisite images from which brain damage, microbleeding and increases in deoxyhemoglobin can be diagnosed

Haacke EM et al. Susceptibility weighted imaging. Magnetic Resonance in Medicine, 52: 612; 2004.

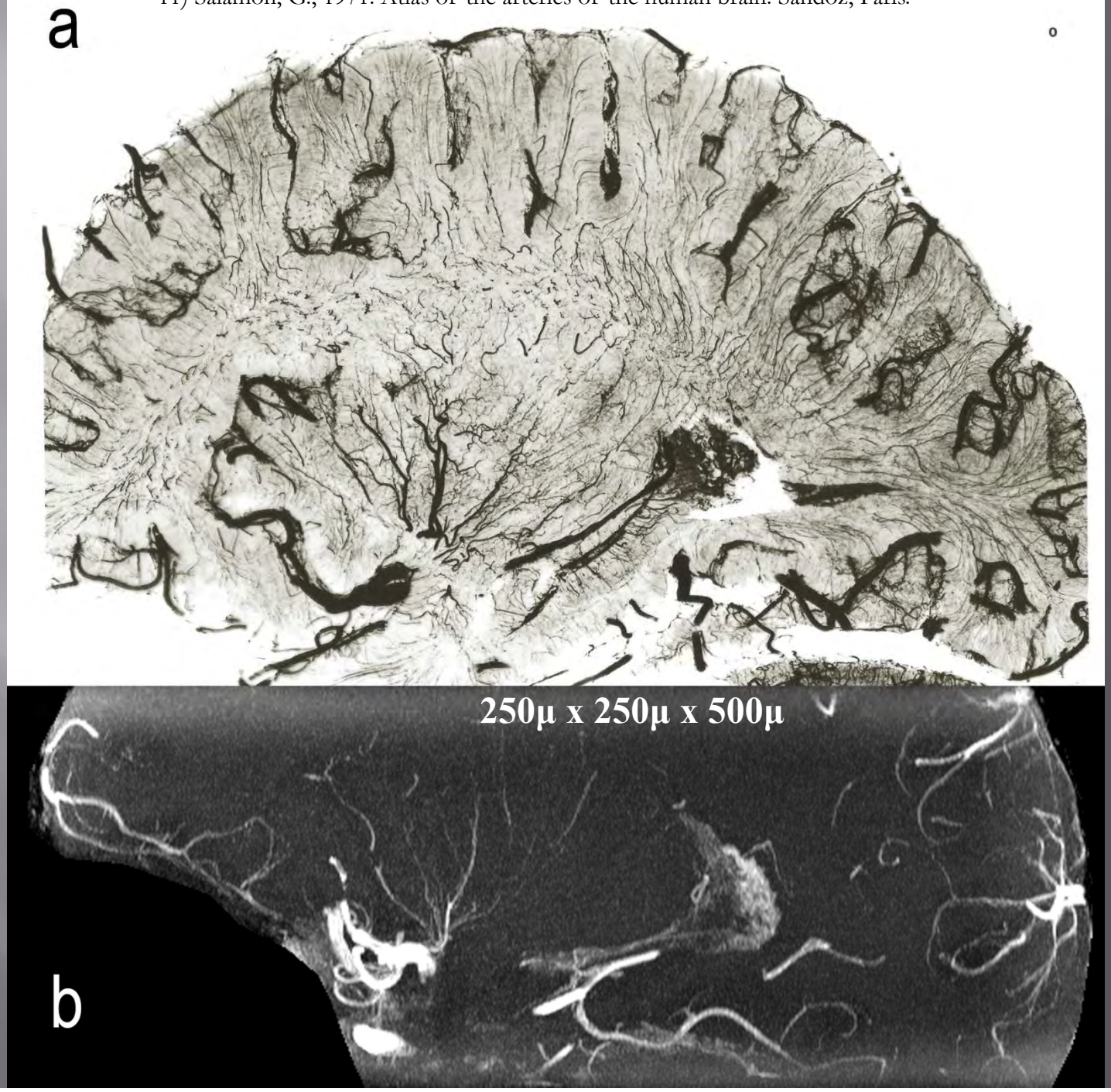
7T SWI

215μ x 215μ x 1000μ
TE = 16ms
TR = 45ms
FA = 25°
8 slice mIP

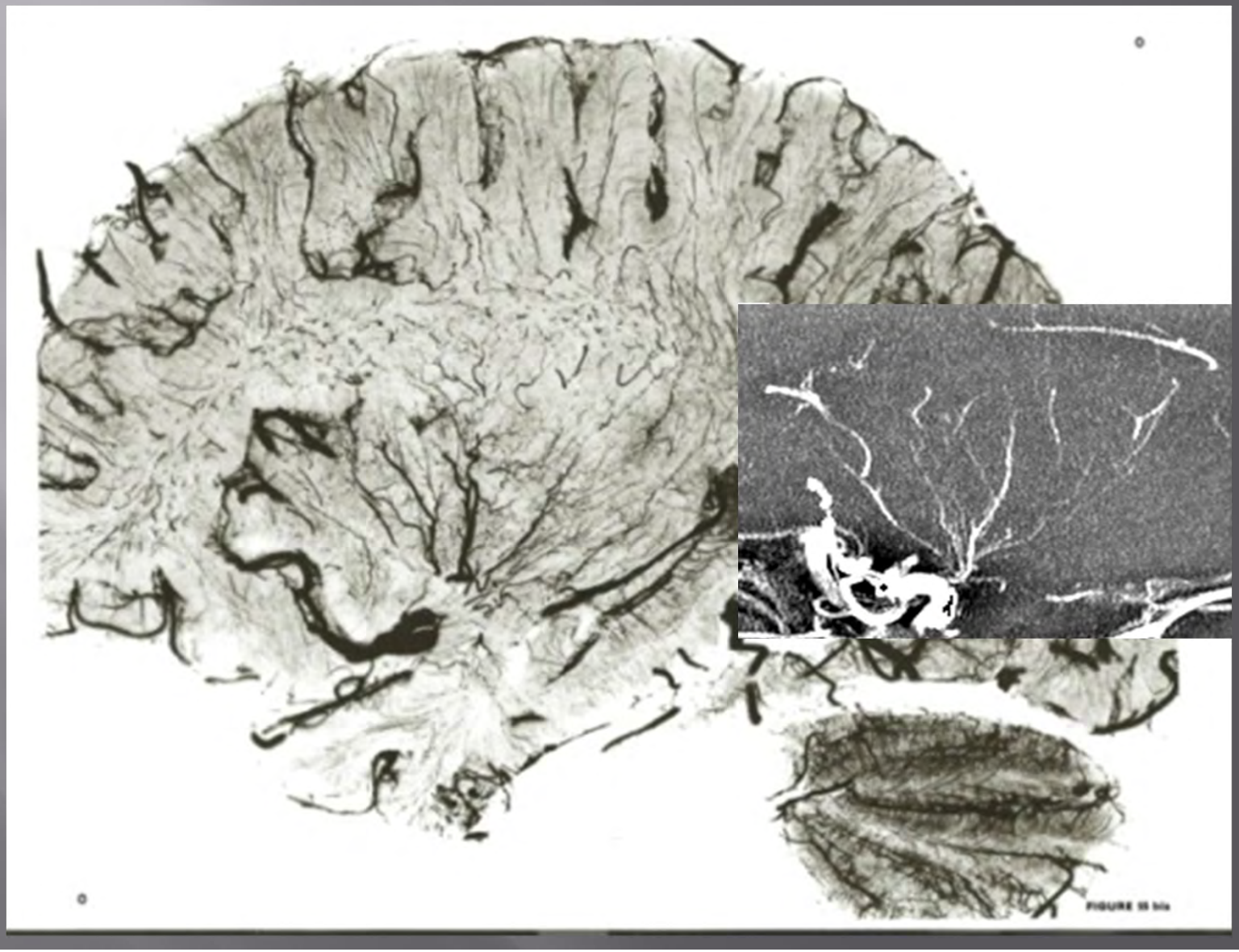
Image courtesy of Yulin Ge
New York University

High resolution MR angiography

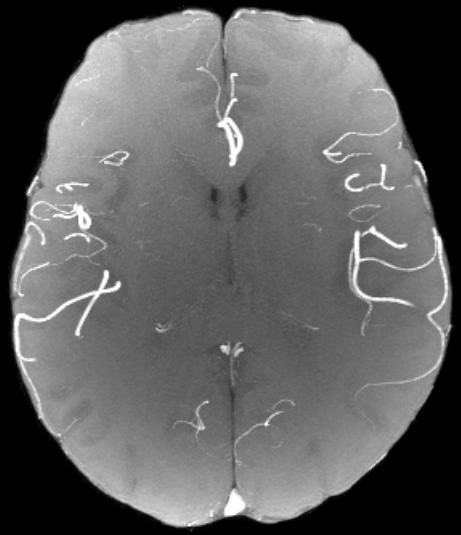
11) Salamon, G., 1971. Atlas of the arteries of the human brain. Sandoz, Paris.



Small arteries around 250 microns and possibly even smaller are becoming visible



MRA short echo SWI



RP-DP MRA

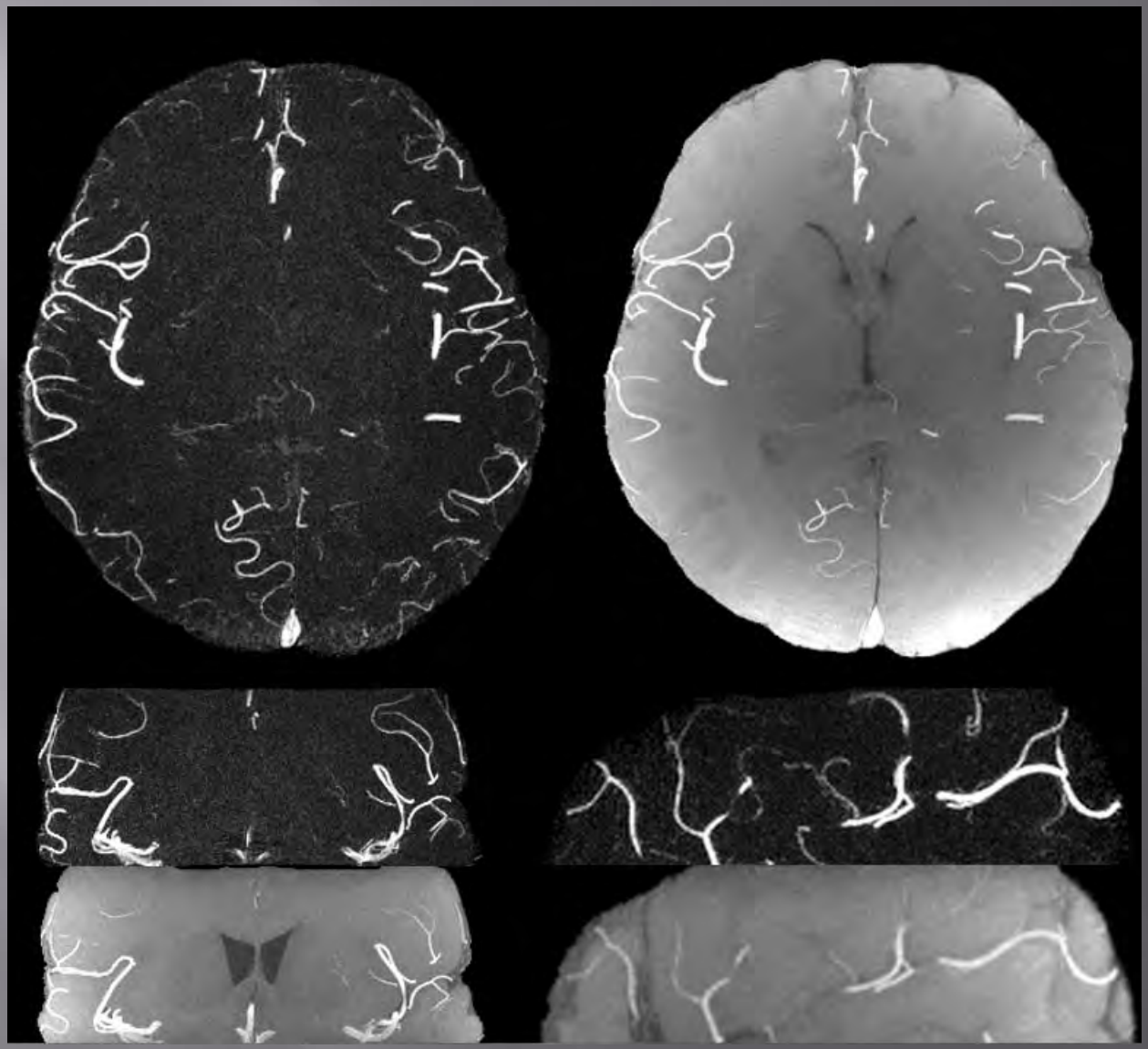
SWI only veins

RP-DP MRA

Simultaneous MRV and MRI using a double echo interleaved SWI rephased/dephased sequence[7]

At 3T, veins are more naturally suppressed because they have T2* = 25ms 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

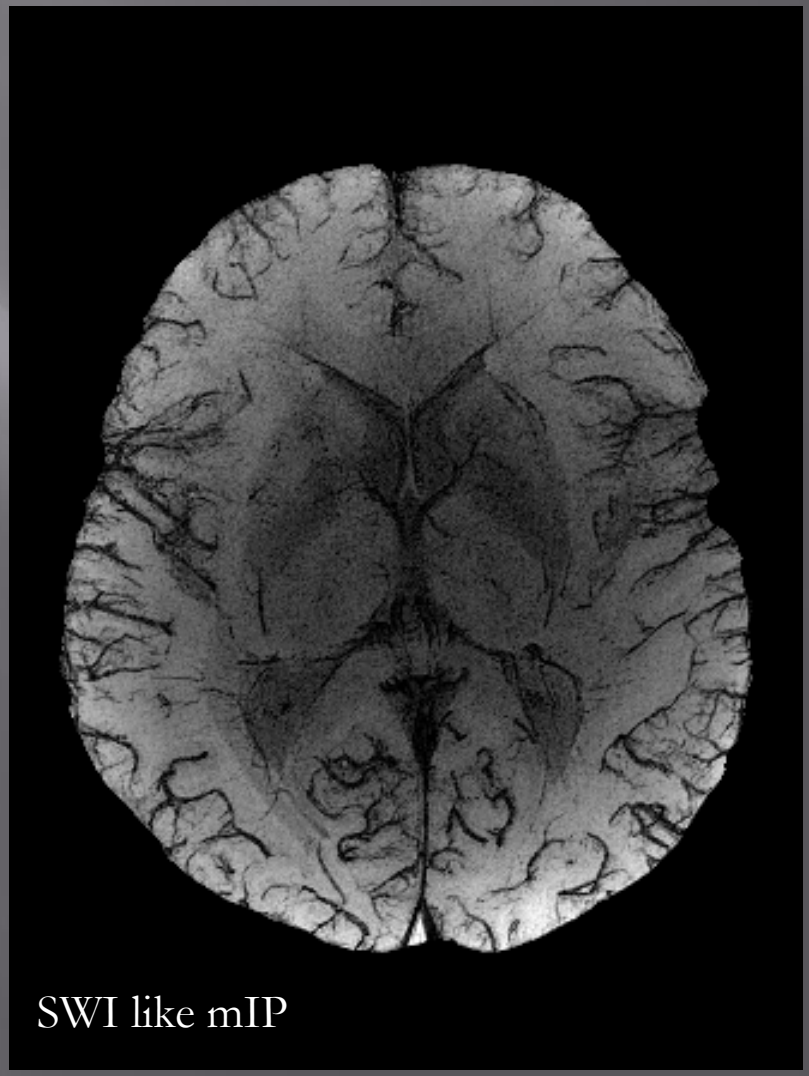


Comparison of 2nd TE (FR-FD) and 1st TE MRA

3D MRAV of the brain

Simultaneous MRV and MRA using a double echo interleaved SWI rephrased(FR)/ dephased(FD) sequence

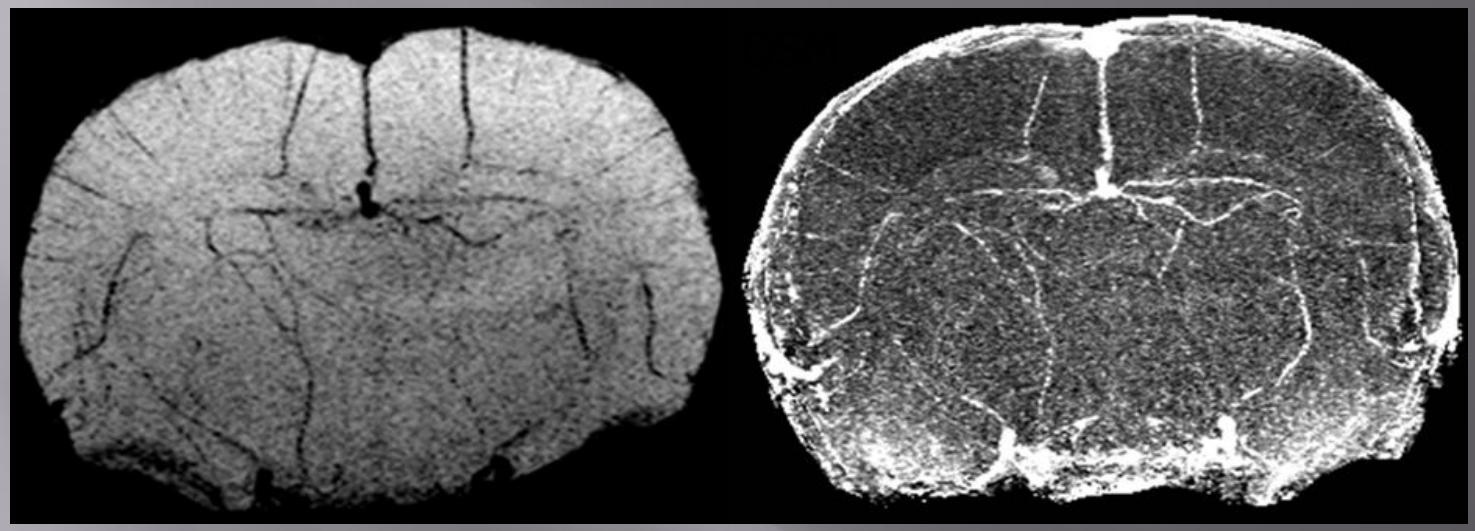
1st TE FR – 2nd TE FD



SWI like mIP

SWI: Future Directions

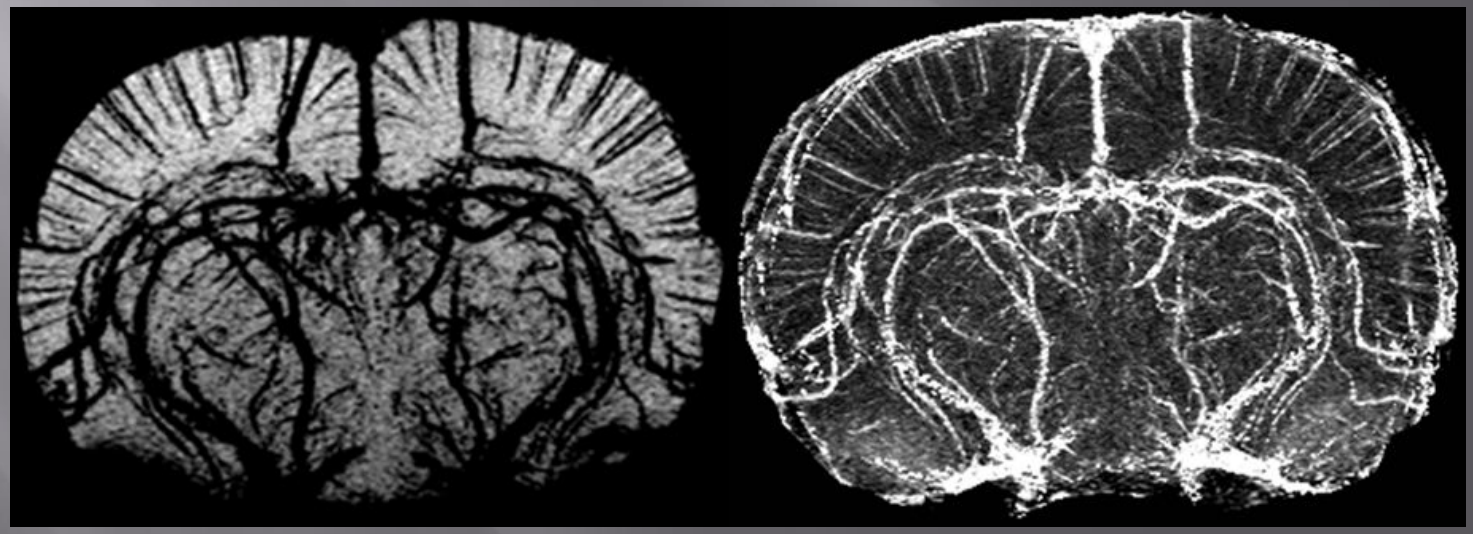
Past 20 Years



SWI of arteries with P904

QSM of arteries with P904

Future 20 Years



YM Shen et al, USPIO High Resolution Neurovascular Imaging: CJMR 2014: 31, 20-31

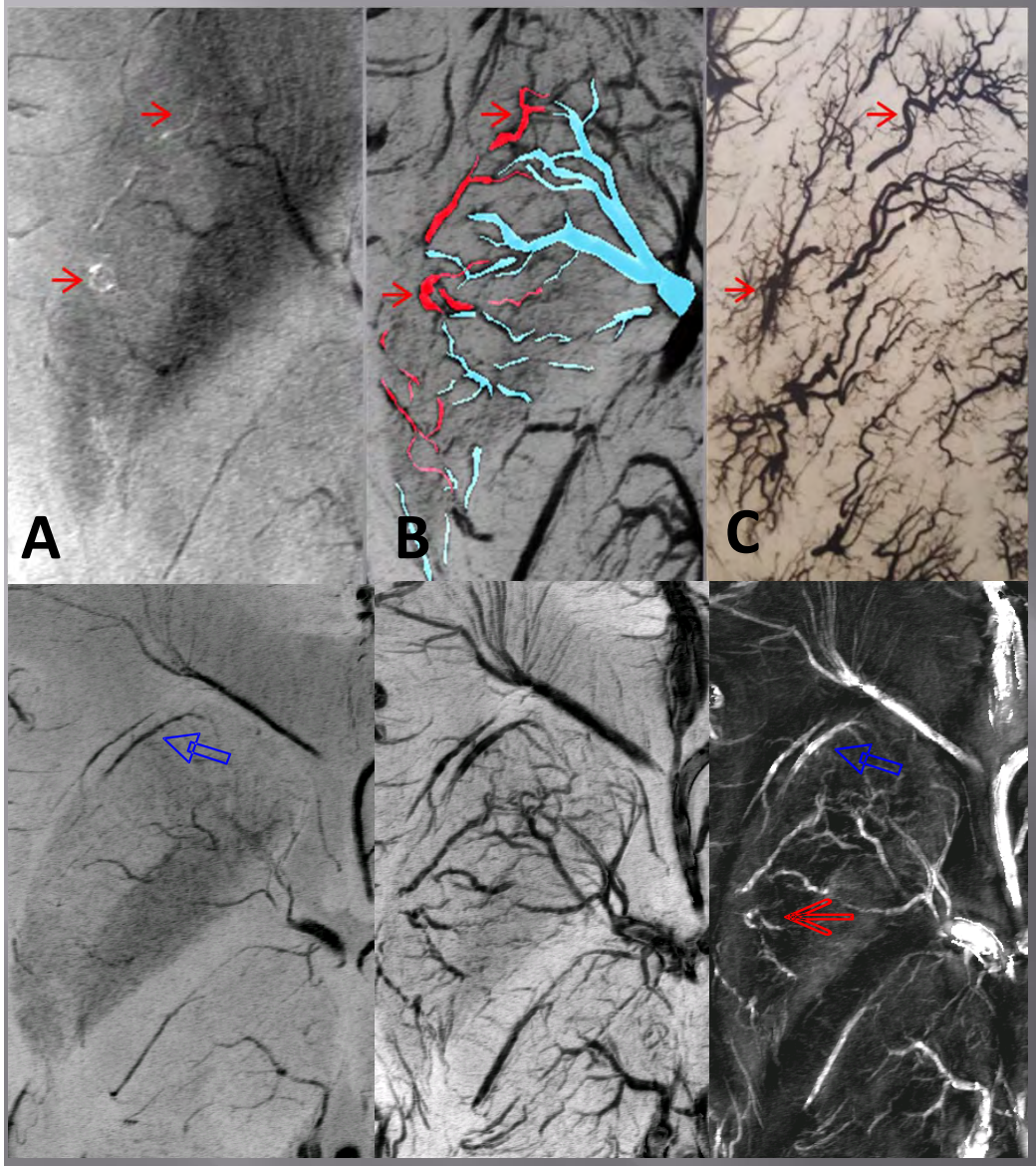


Figure 3. MICRO data acquired at 7T with TE = 8ms and a resolution of 100μm x 200μm x 1.25mm.

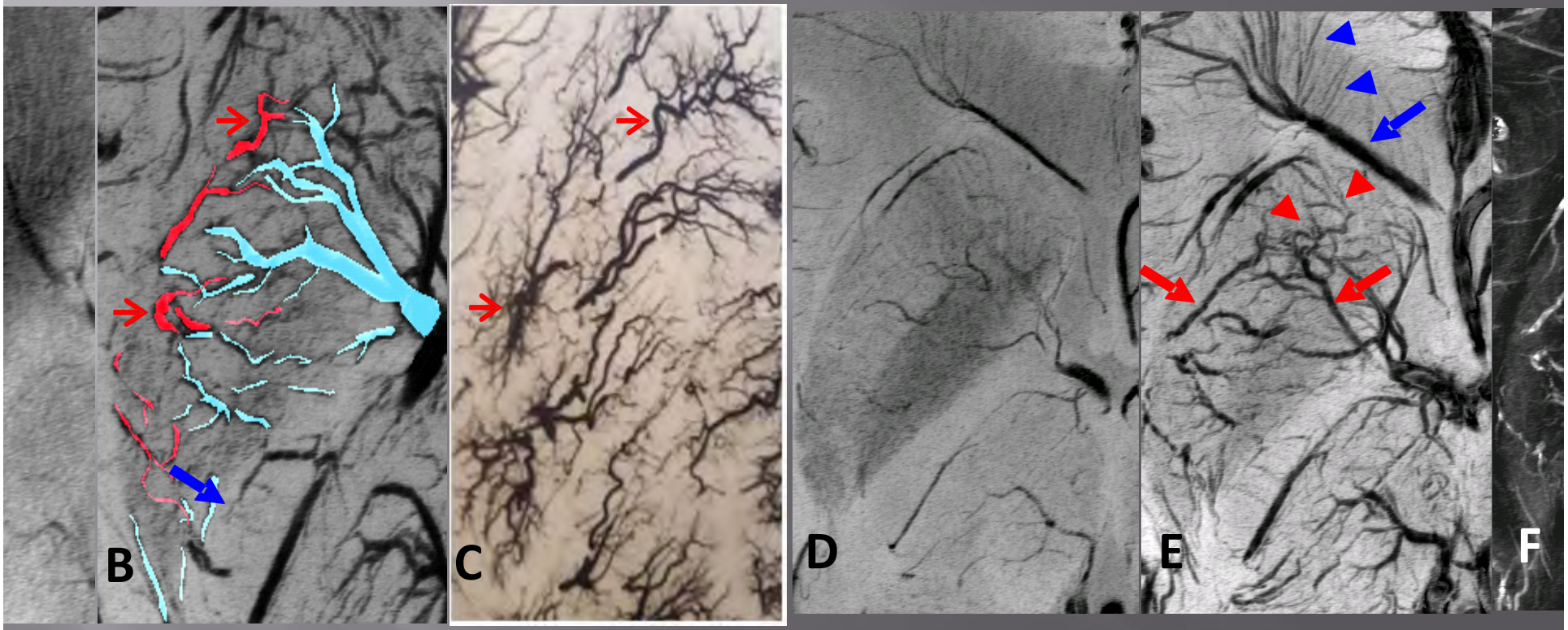
(A) MIP of pre-contrast original magnitude image (1st echo) showing the arterial signal (red).
(B) Post 4mg/kg Ferumoxytol MICRO image.
(C) Basal ganglia arteries from the cadaver brain work of Georges Salamon (1971).
(D) mIP of pre-contrast SWI shows veins only.
(E) Post-Ferumoxytol SWI (2mg/kg) showing both veins and arteries including small arterioles (red arrowheads) and venules (blue arrowheads).
(F) Post-contrast QSM showing higher susceptibility values in veins than in arteries.

Our goal is to track both arteries and veins, and use this to study microvascular disease at 3T.

Arteries, arterioles and venules are now visible thanks to the susceptibility contrast and blooming effect from Feuromxytol.

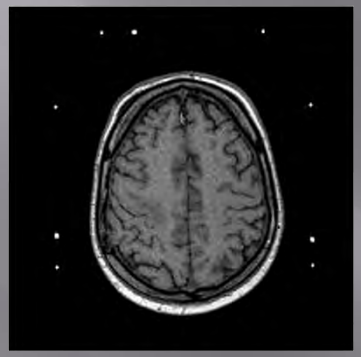
The process of separating arteries from veins from pre/post Ferumoxytol images.

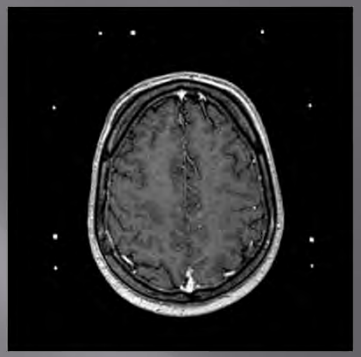
The process of separating arteries from veins from pre/post Ferumoxytol images.



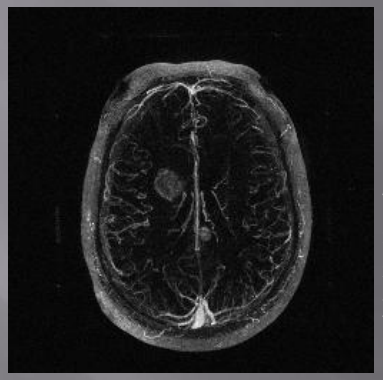
CONTRAST ENHANCED TUMOR IMAGING 3D T_1 WEIGHTED

Flash 3D T_1 weighted pre-Gadolinium series

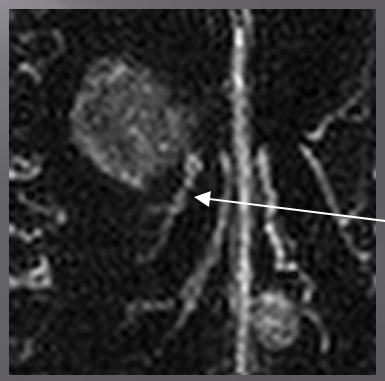




Flash 3D T_1 weighted post-Gadolinium series



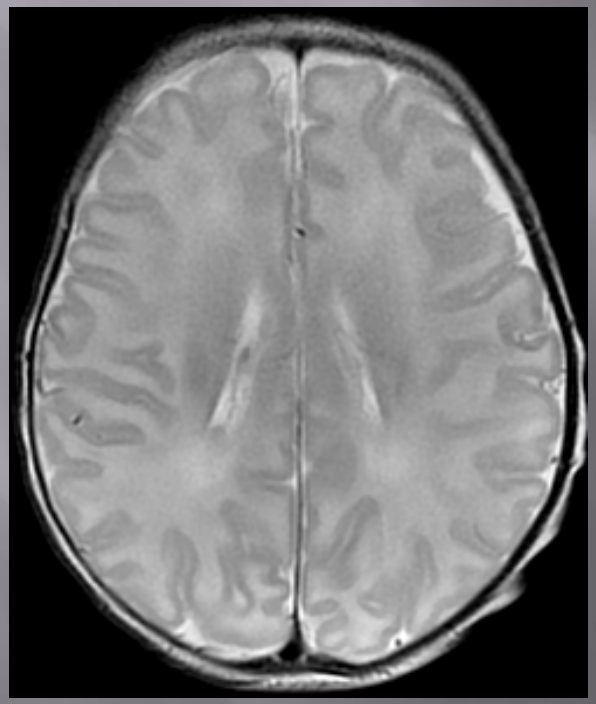
T_1 subtraction maximum intensity projection image



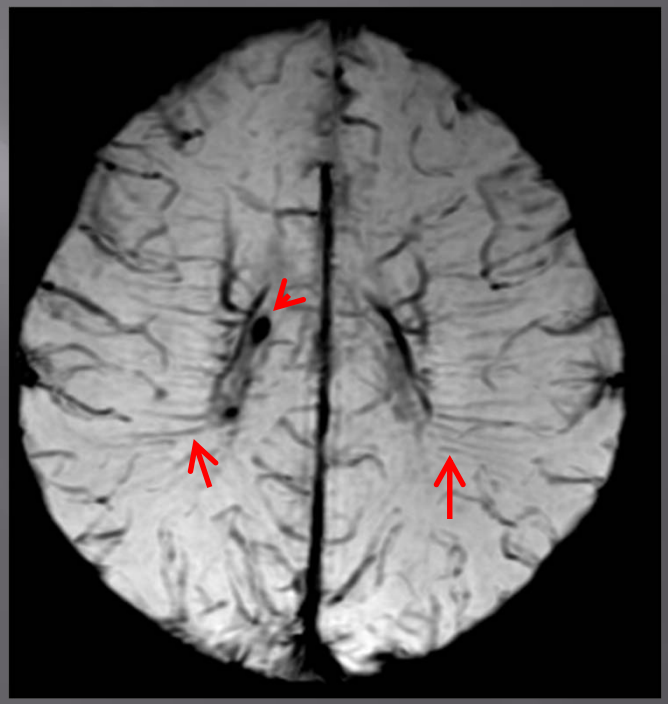
The 3D sequence allows better coverage of the tumor volume and pre-post contrast imaging allows exact subtraction revealing enhanced regions and in some cases even feeding/draining vessels.

SWI- Venography in Pediatric Population

2 day old infant

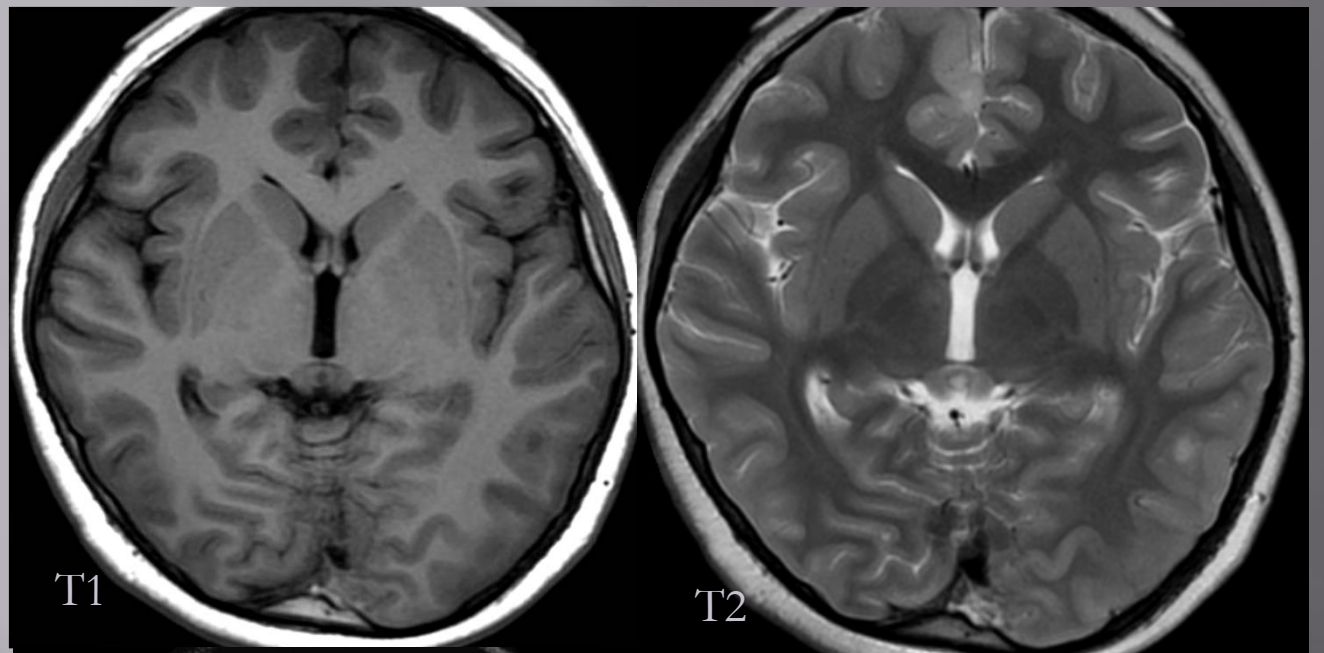


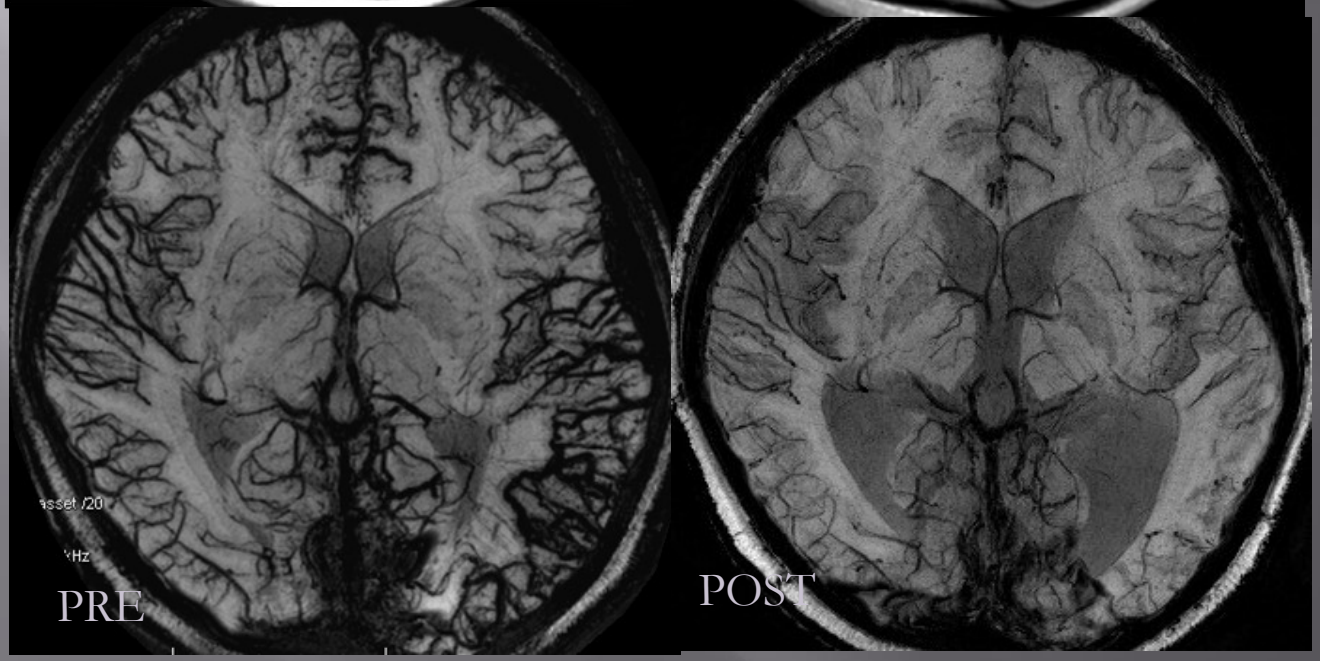
T2



SWI

Neonatal encephalopathy

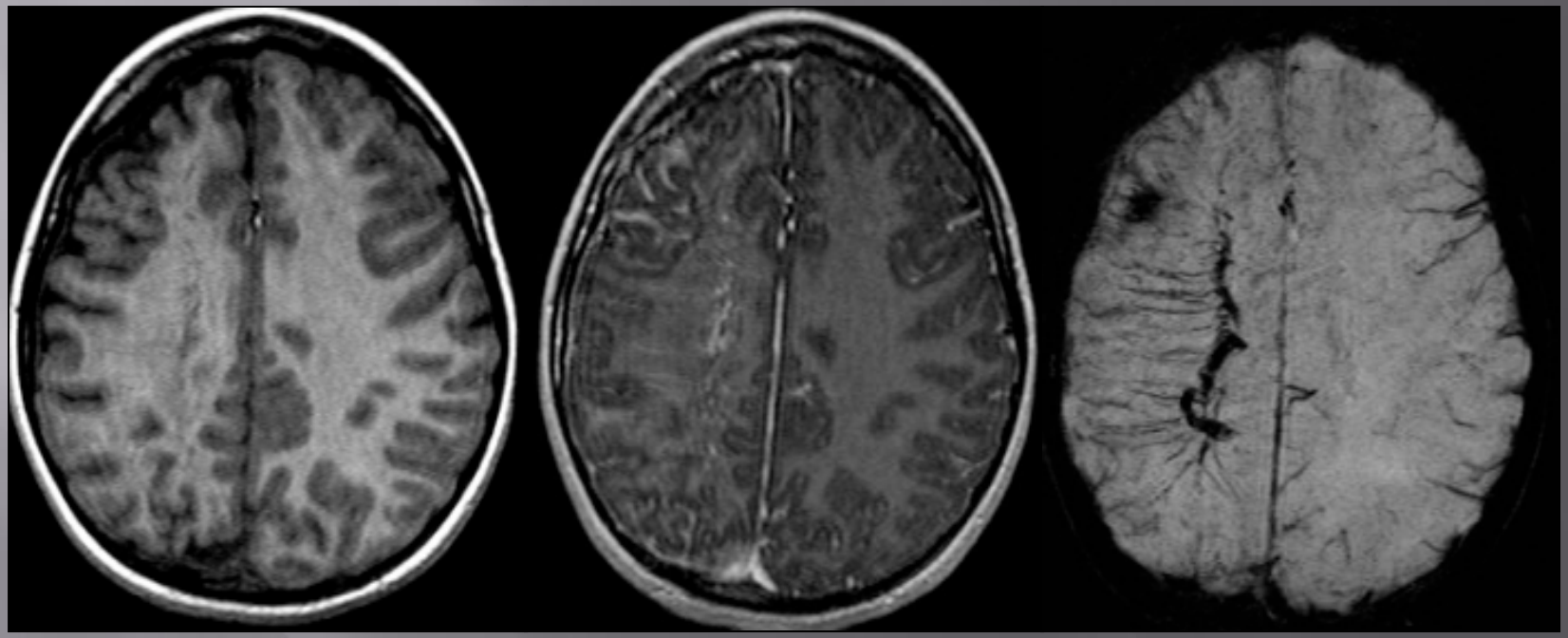




Venous Thrombosis: before treatment and after thrombolysis

Guangbin Wang M.D.
Shandong Medical Imaging Research Institute

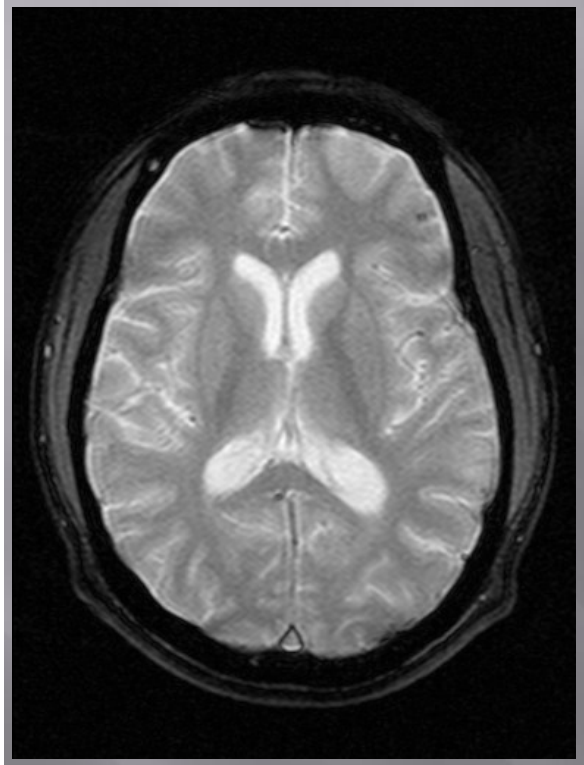
Sturge Weber Syndrome

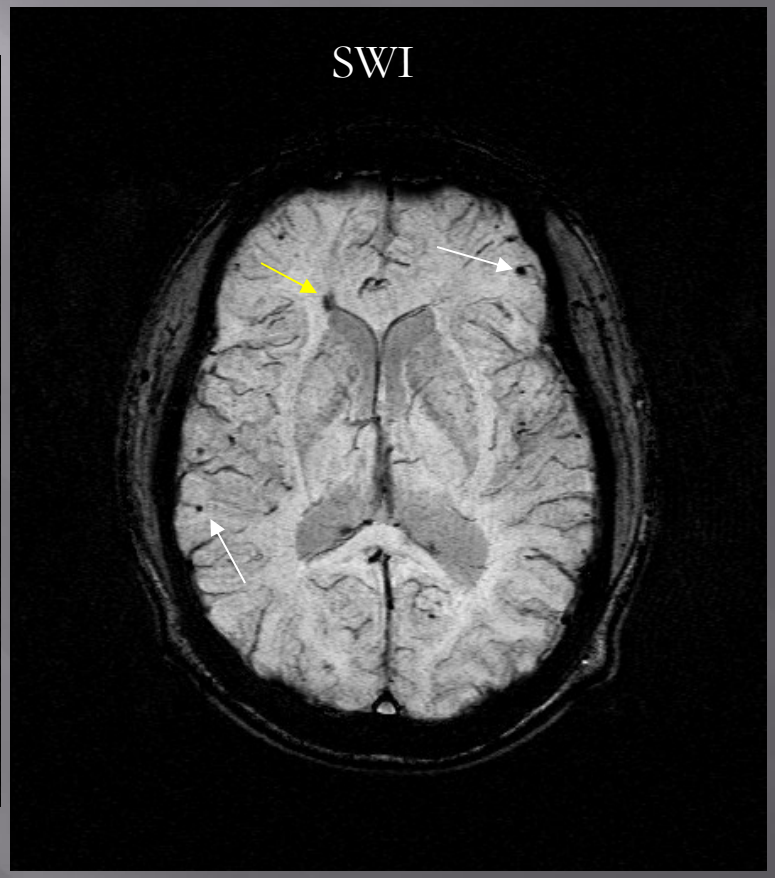


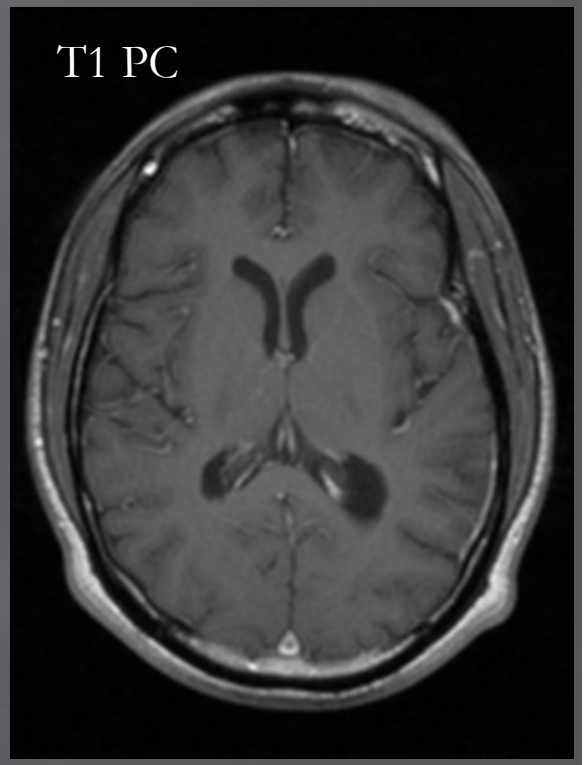
3D-T1 Post Gd 3D T1 SWI (no contrast agent)

Czabo Juhasz, Yang Xuan and Dr. E. Haacke, Wayne State University

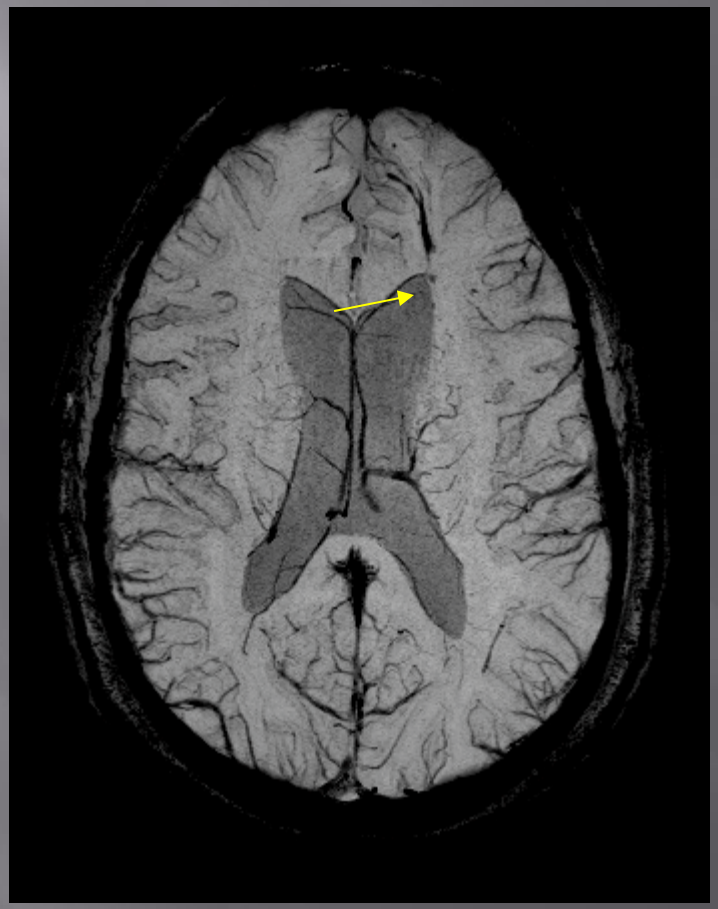
Motorcycle trauma: medullary vein involvement



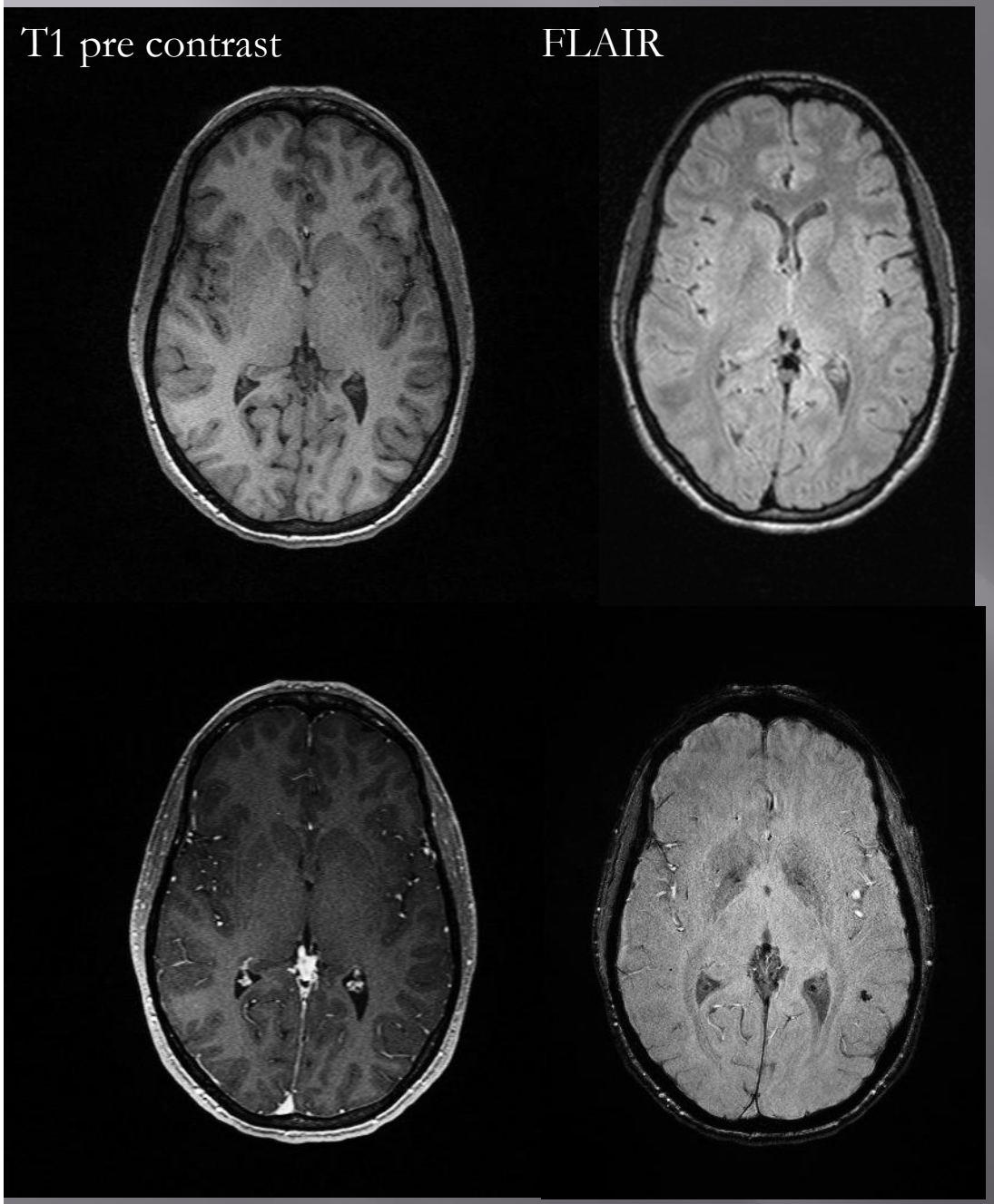




Medullary vein involvement

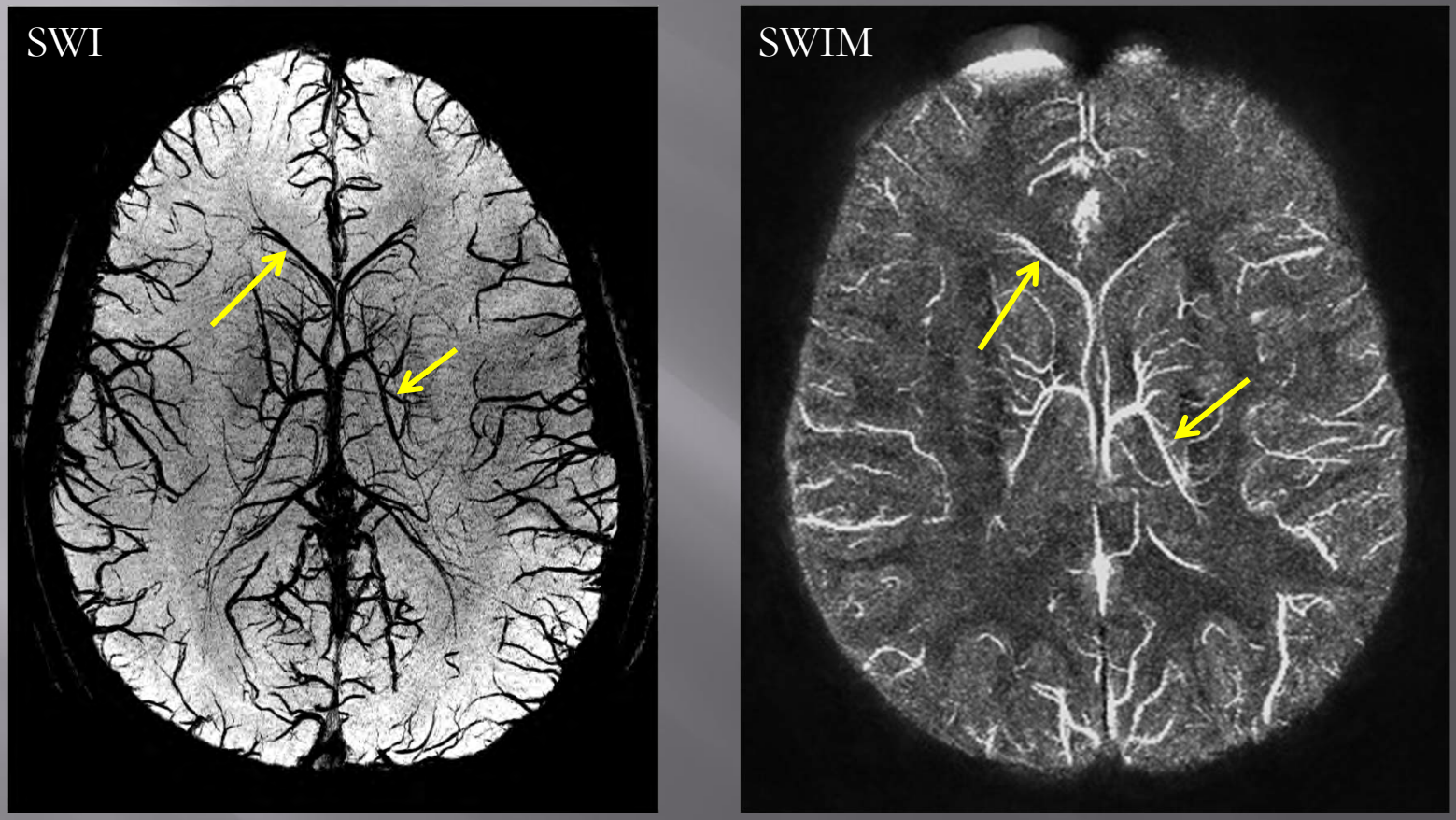


Z. Kou et al. The Role of Advanced MR Imaging Findings as Biomarkers of Traumatic Brain Injury (TBI). J. Head Trauma Rehabil. 2010 - 25:267-282.



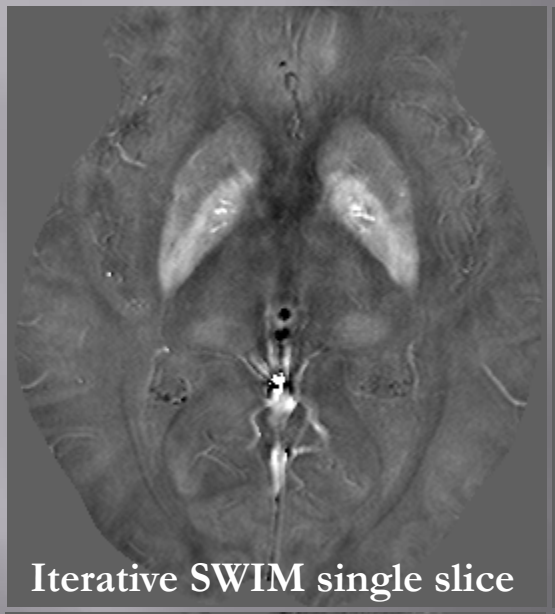
SEIZURE CASE

SWI vs. SWIM



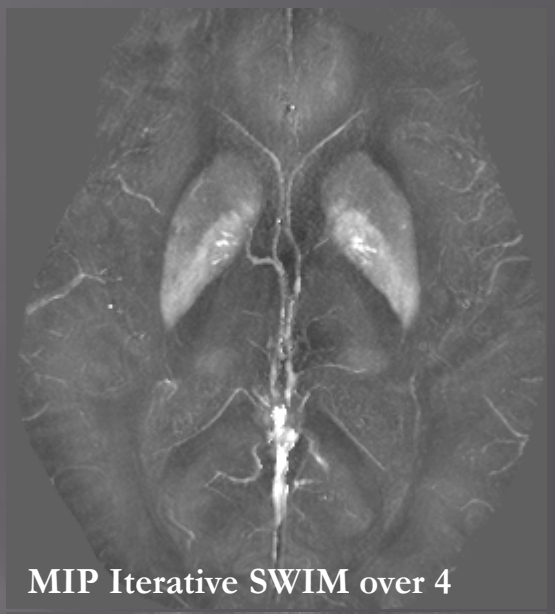
- SWI enhances the presence of ferritin, hemosiderin and deoxyhemoglobin
- Exquisite images to diagnose microbleeds and abnormal oxygenation levels

Normal volunteer

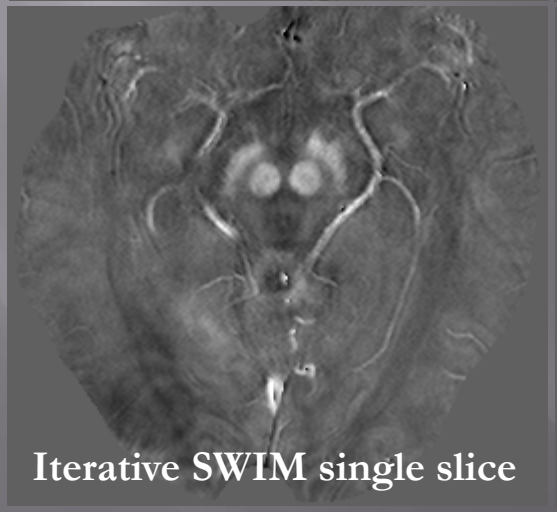


Iterative SWIM single slice

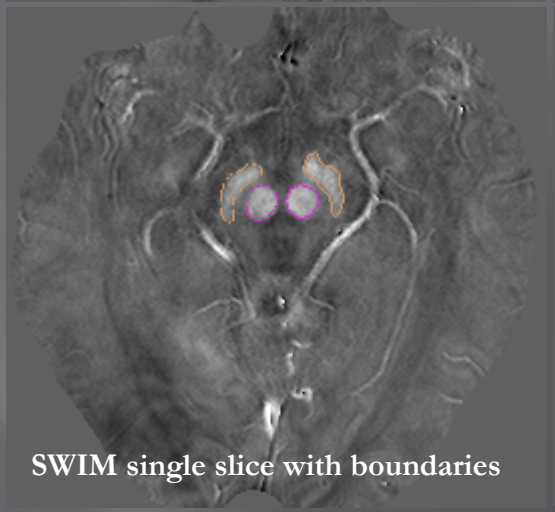
SWIM single slice with boundaries



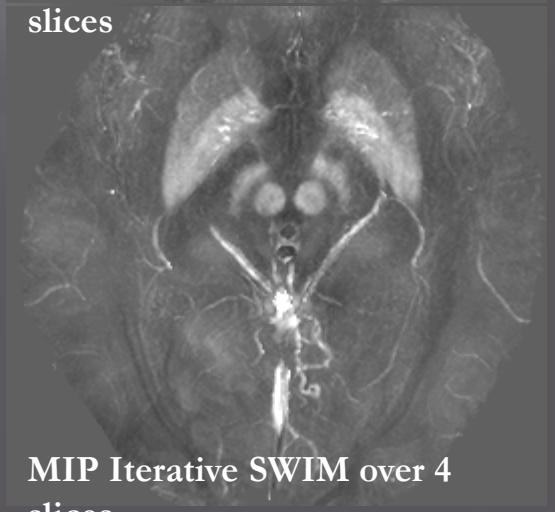
MIP Iterative SWIM over 4 slices



Iterative SWIM single slice

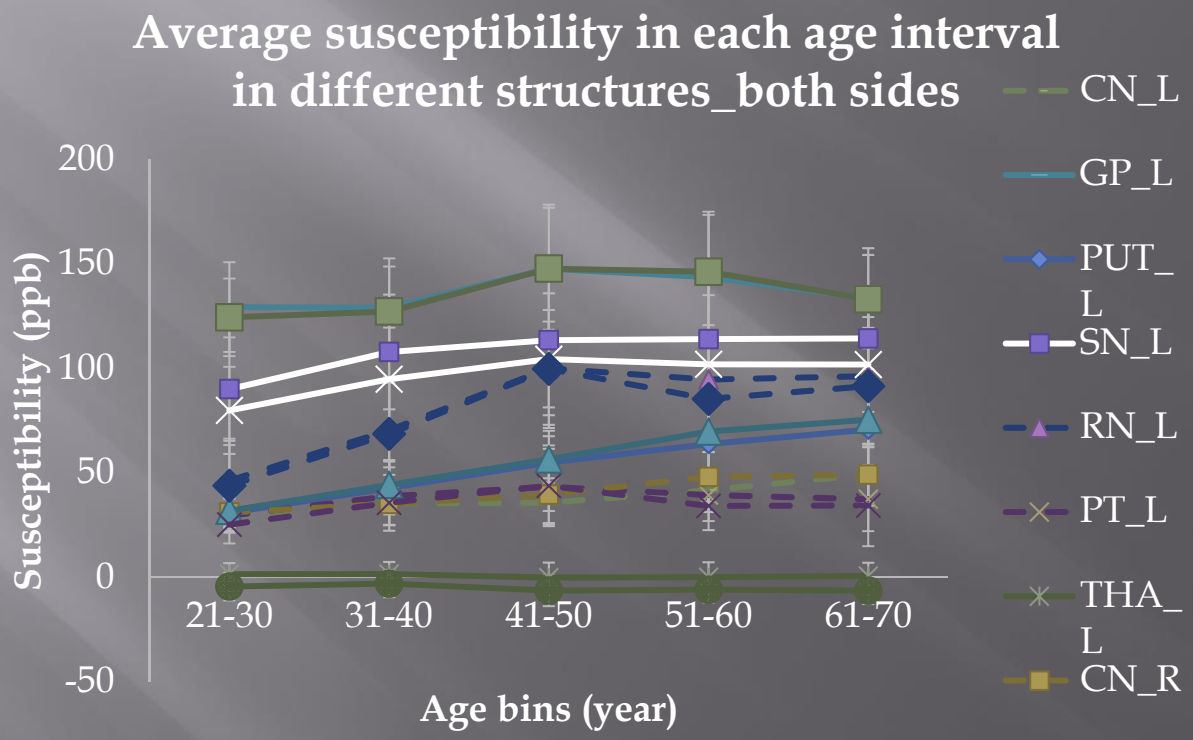


SWIM single slice with boundaries



MIP Iterative SWIM over 4 slices

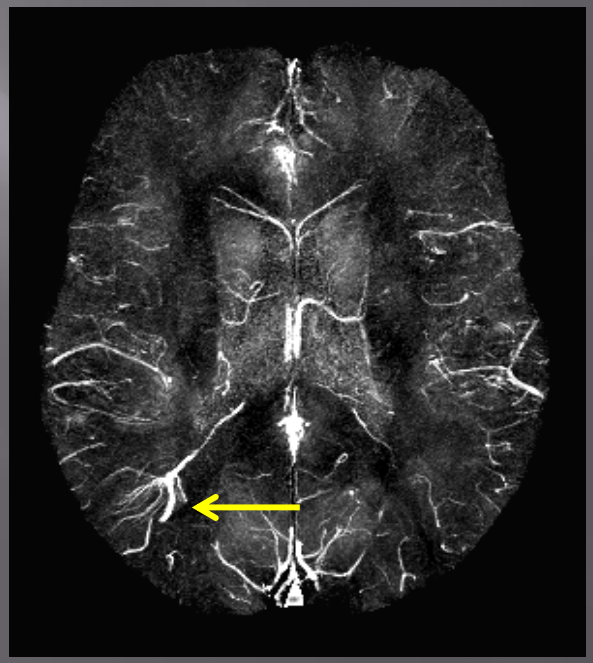
We all rust as we get older



Deep venous anomaly in a healthy control

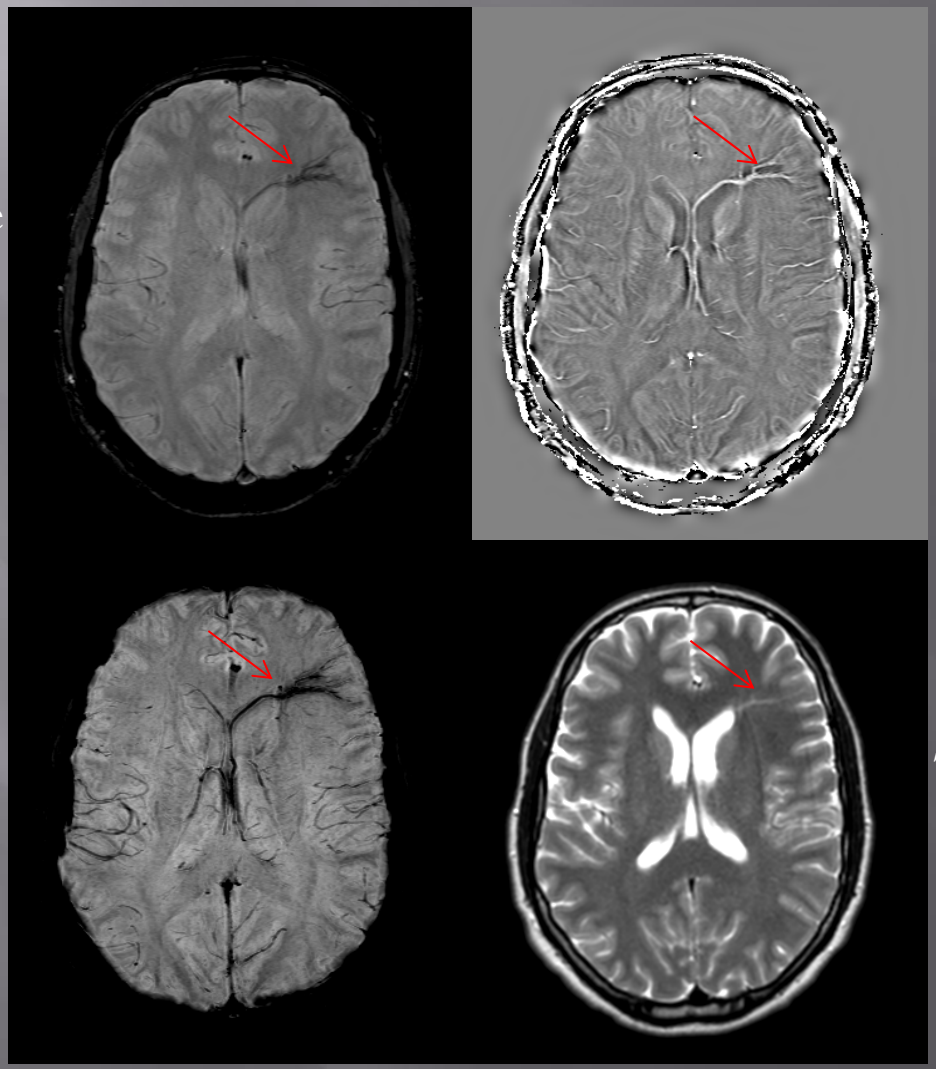
SWI

SWIM



SWI reveals MVD

SWI-Magnitude

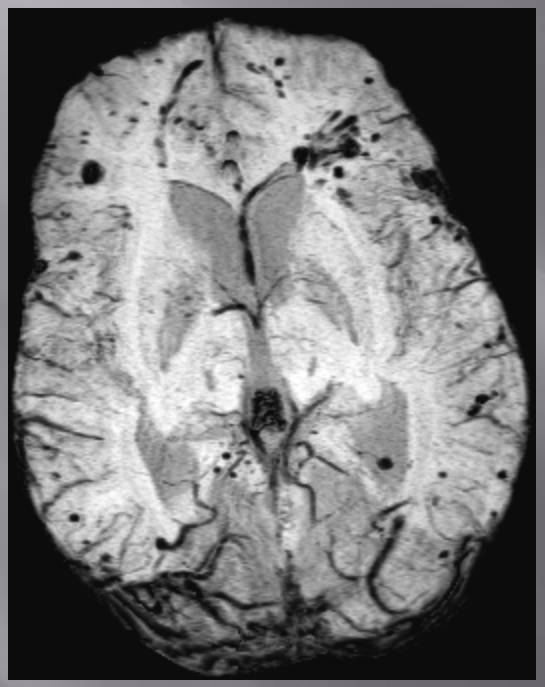


SWI-Phase

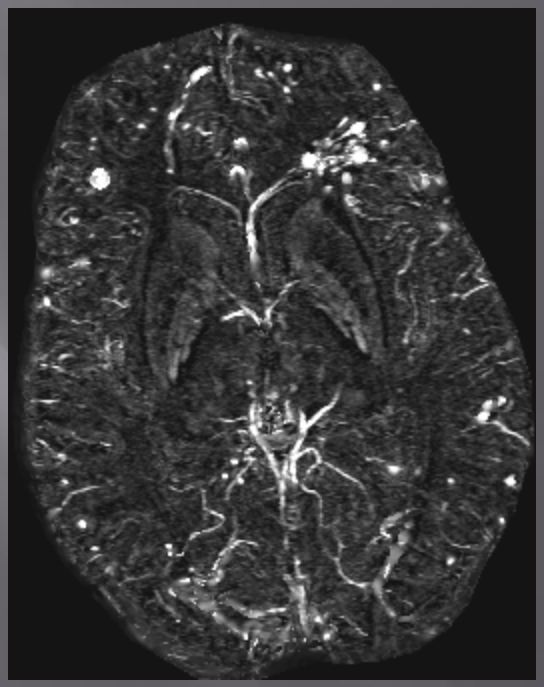
SWI-mIP

T2

The First Clinical Applications of SWIM in Traumatic Brain Injury (TBI)



SWI minIP image projected over 16mm



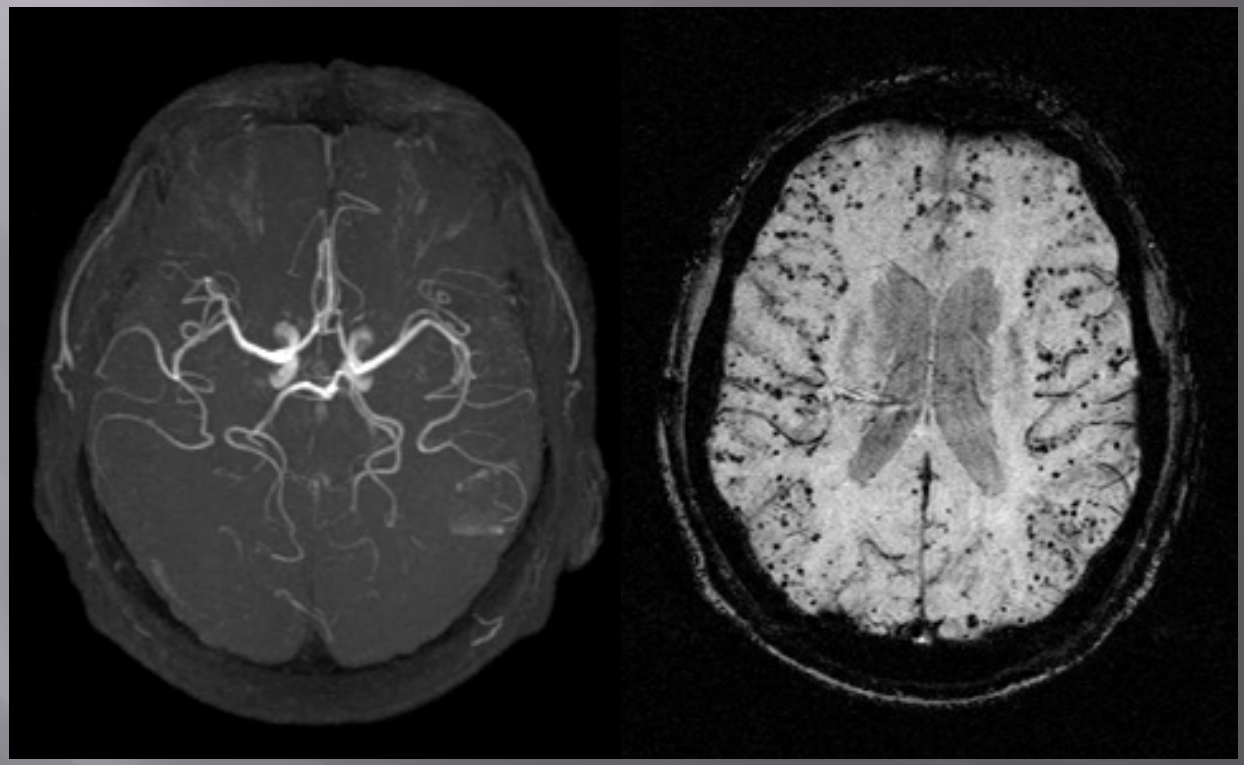
Corresponding MaxIP susceptibility map image projected over 16mm

Cerebral Microbleeds: Pathophysiology to Clinical Practice (Cambridge Medicine) Editor, David J. Werring, 2011, ISBN-13: 9780521198455

Imaging Aging

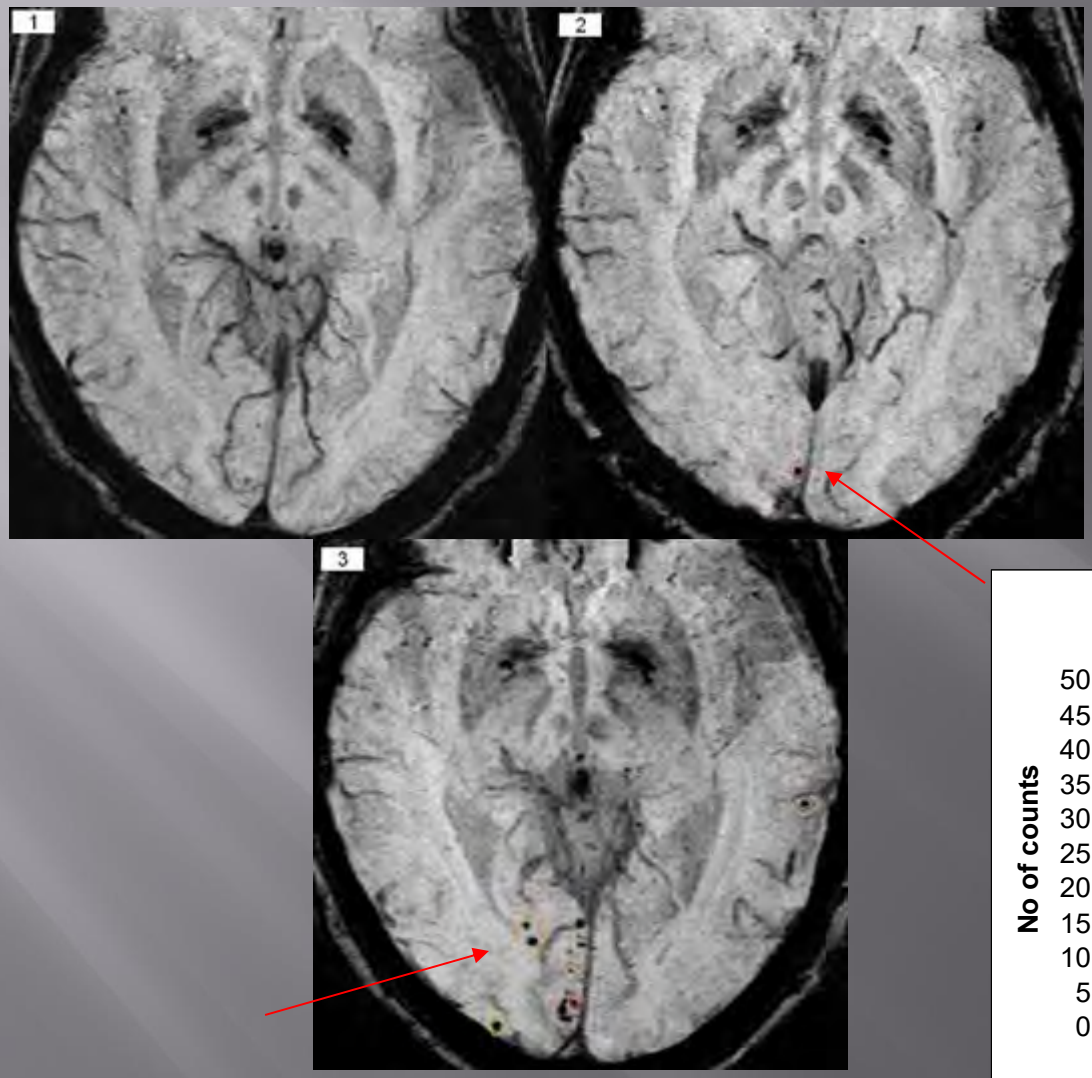
- It is now believed that up to 35% of dementia cases may be caused by vascular dementia.
- We see microhemorrhages as a means to predict who will get Alzheimer's disease.
- These may lead to "cognitive strokes".
- Hopefully this work will lead to collaborations with the pharmaceutical industry to come up with neuroprotective drugs that will strengthen the vessel wall or help to prevent its degeneration.

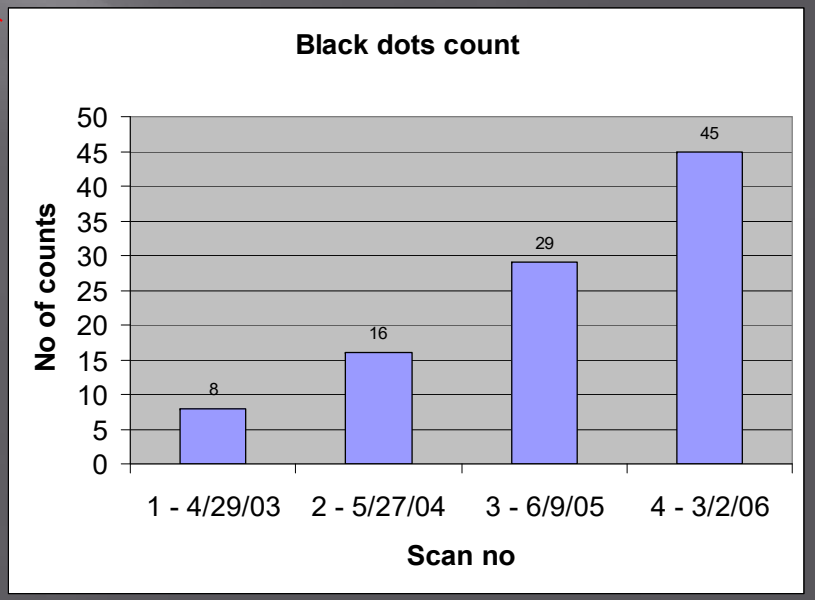
Cerebral amyloid angiopathy



50μ objects can manifest as $1mm^3$ objects

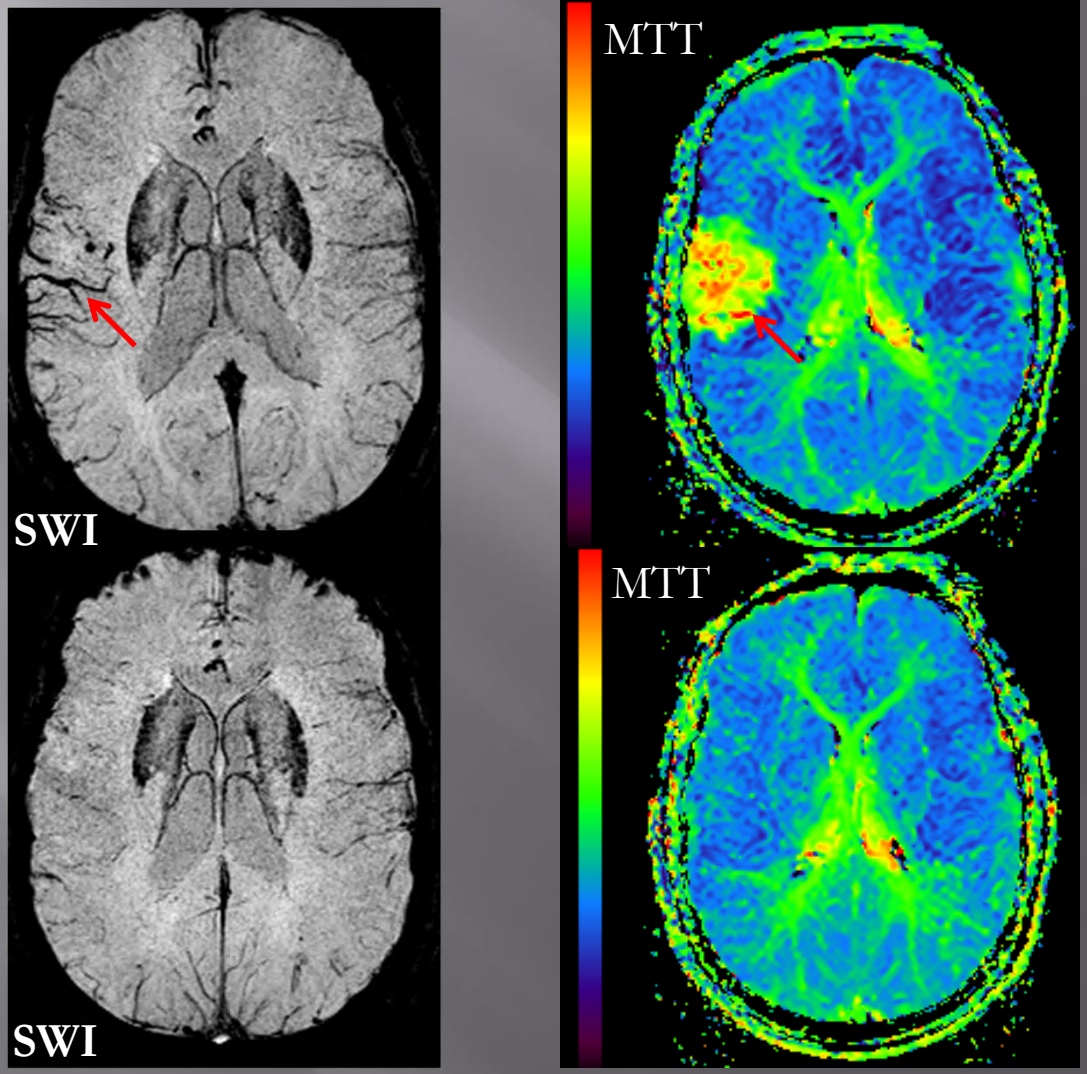
time to go sailing





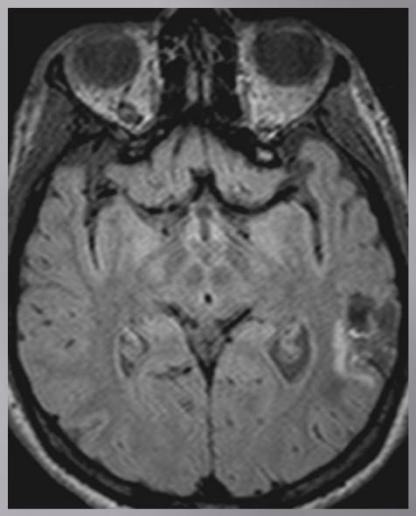
Two scans from same stroke patient

MRI scan date: 2013.01.04

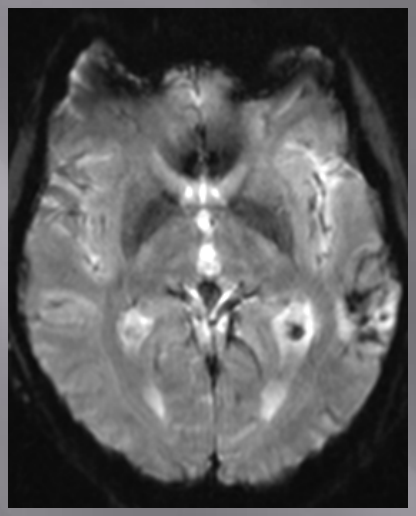


MRI scan date: 2013.01.11

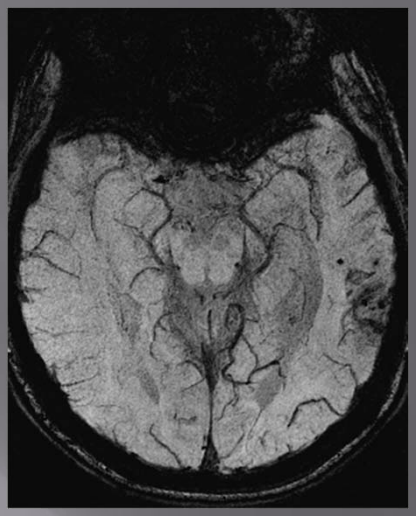
Stroke case for a young woman in her mid 30s



FLAIR

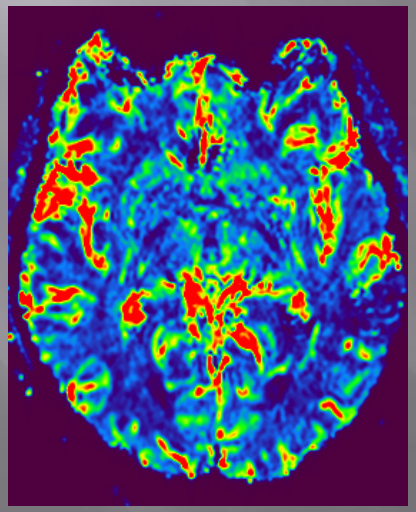


PWI (1st)

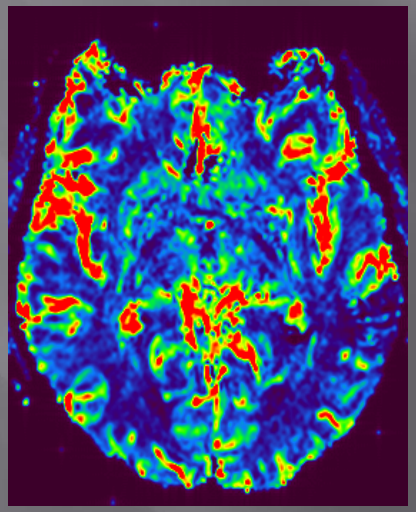


SWI mIP

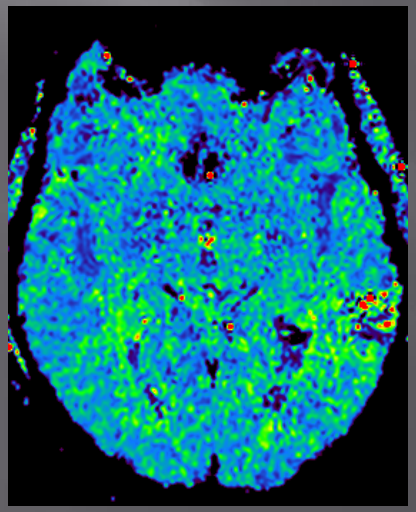
MRA



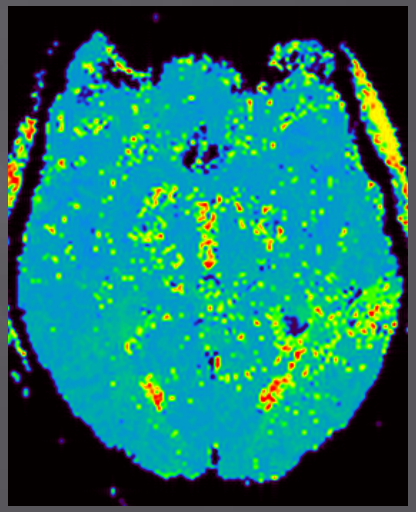
CBV



CBF



MTT

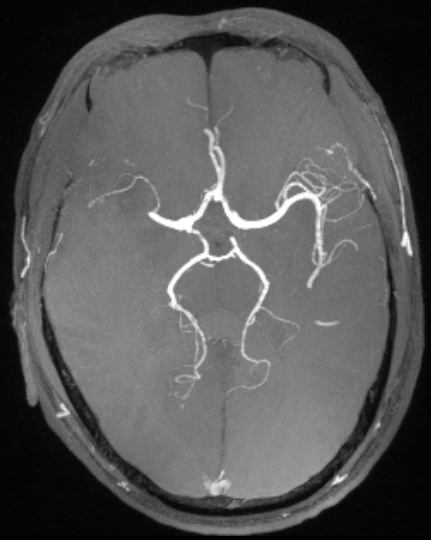


TTP

Imaging veins and arteries using double echo SWI[5] Images courtesy of Meiyun Wang, Zhengzhou

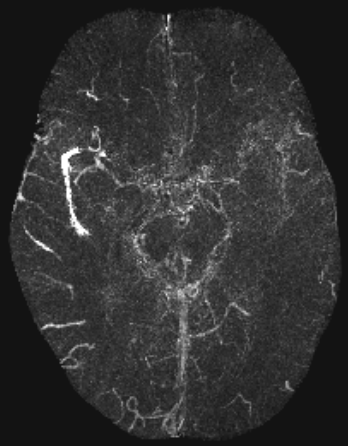
Thrombus dominates the SWI image (TE = 7.5ms)

First echo MIP

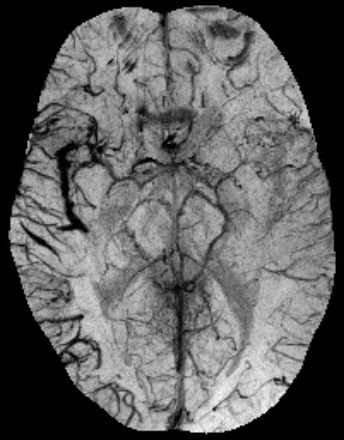


First echo MRA like signal

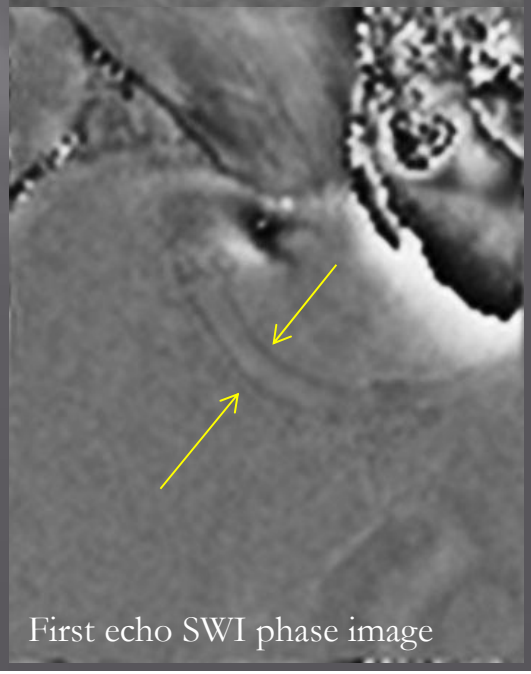
Thrombus dominates the SWIM image (TE = 7.5ms)



Second echo (17.5ms) true SWI



Note the asymmetrically prominent cortical veins



First echo SWI phase image

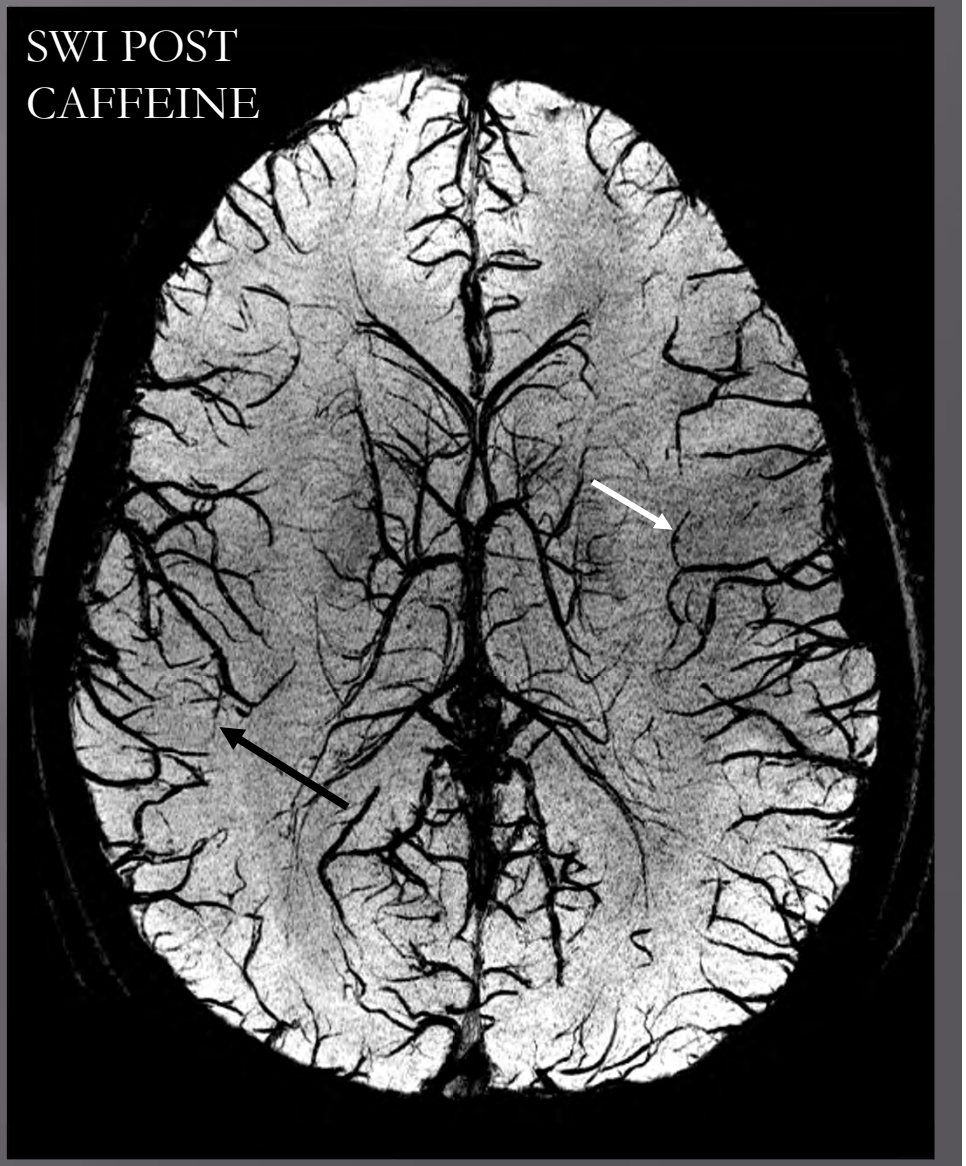
Using caffeine decreases blood flow to the brain

two cups of coffee and you will have a major change of blood flow to the brain

maybe we should approach Starbucks for funding

at least it is a relatively harmless contrast agent to use to study the brain and a heck of a lot cheaper

SWI as a high resolution BOLD imaging method

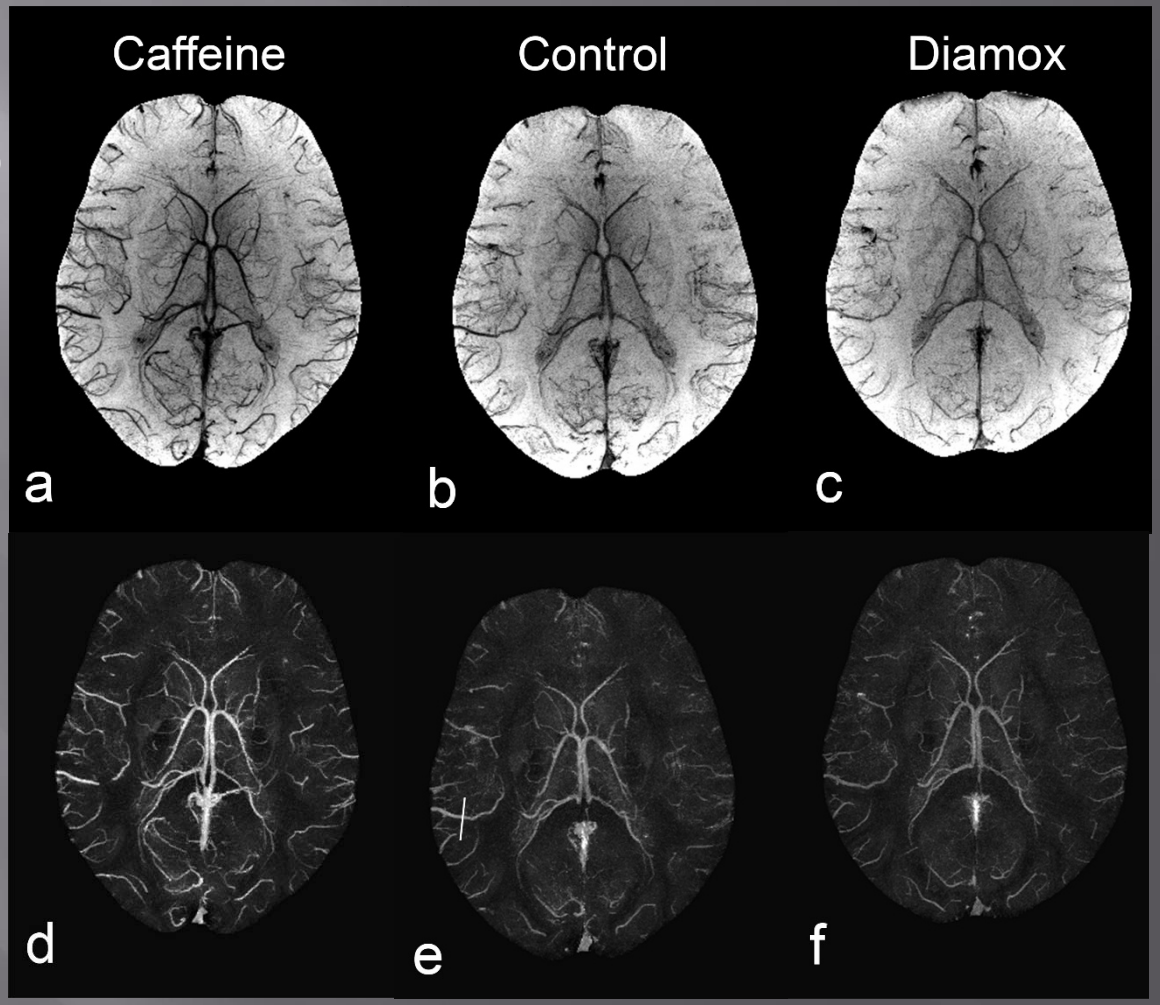


MinIP of caffeine/Gd over 28 slices with 4 phase multiplications

Imaging veins and blood products using SWI and SWIM: Challenging the neurovascular system[4]

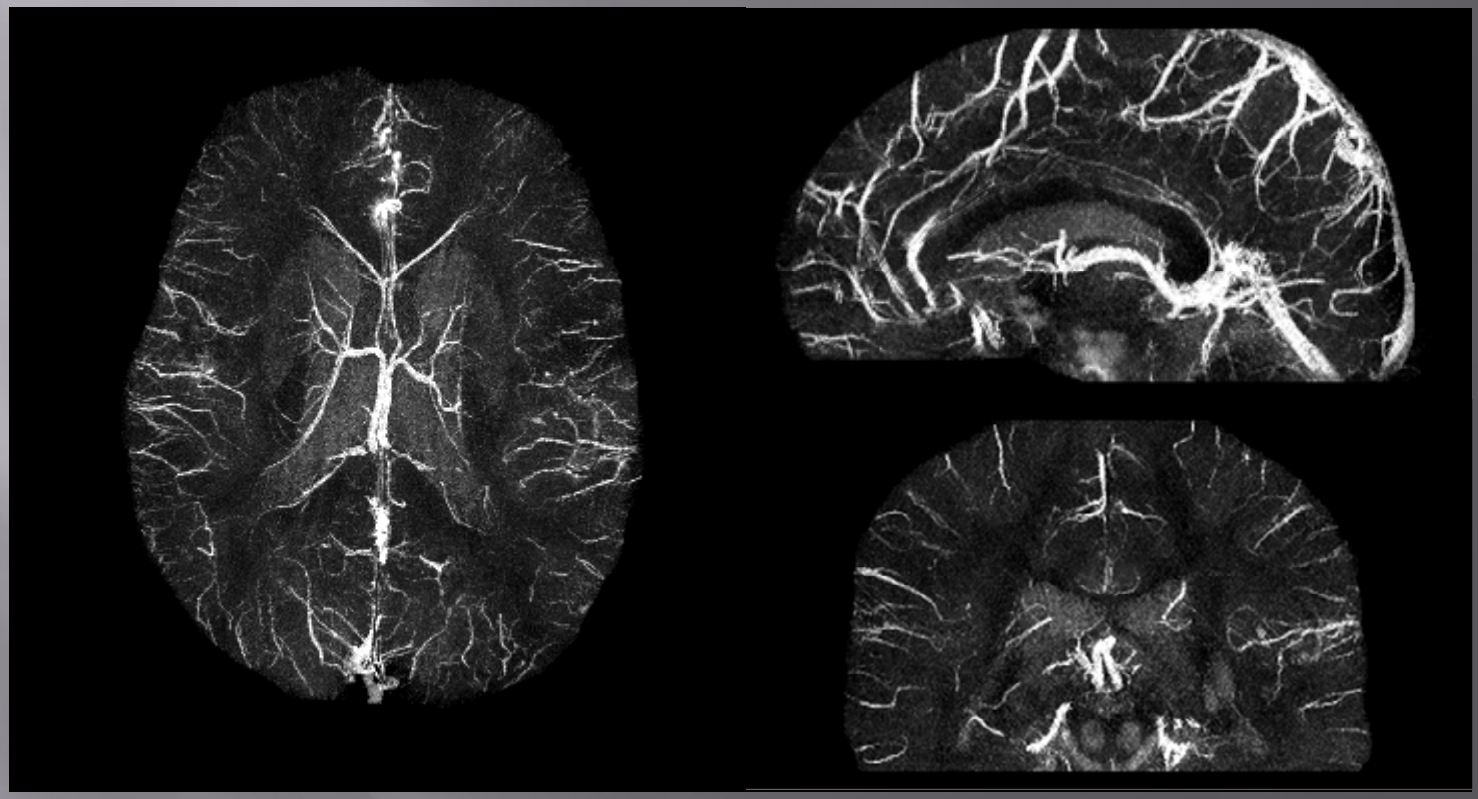
200mg caffeine pills (a, d) or 1000mg diamox IV injection (c, f).

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



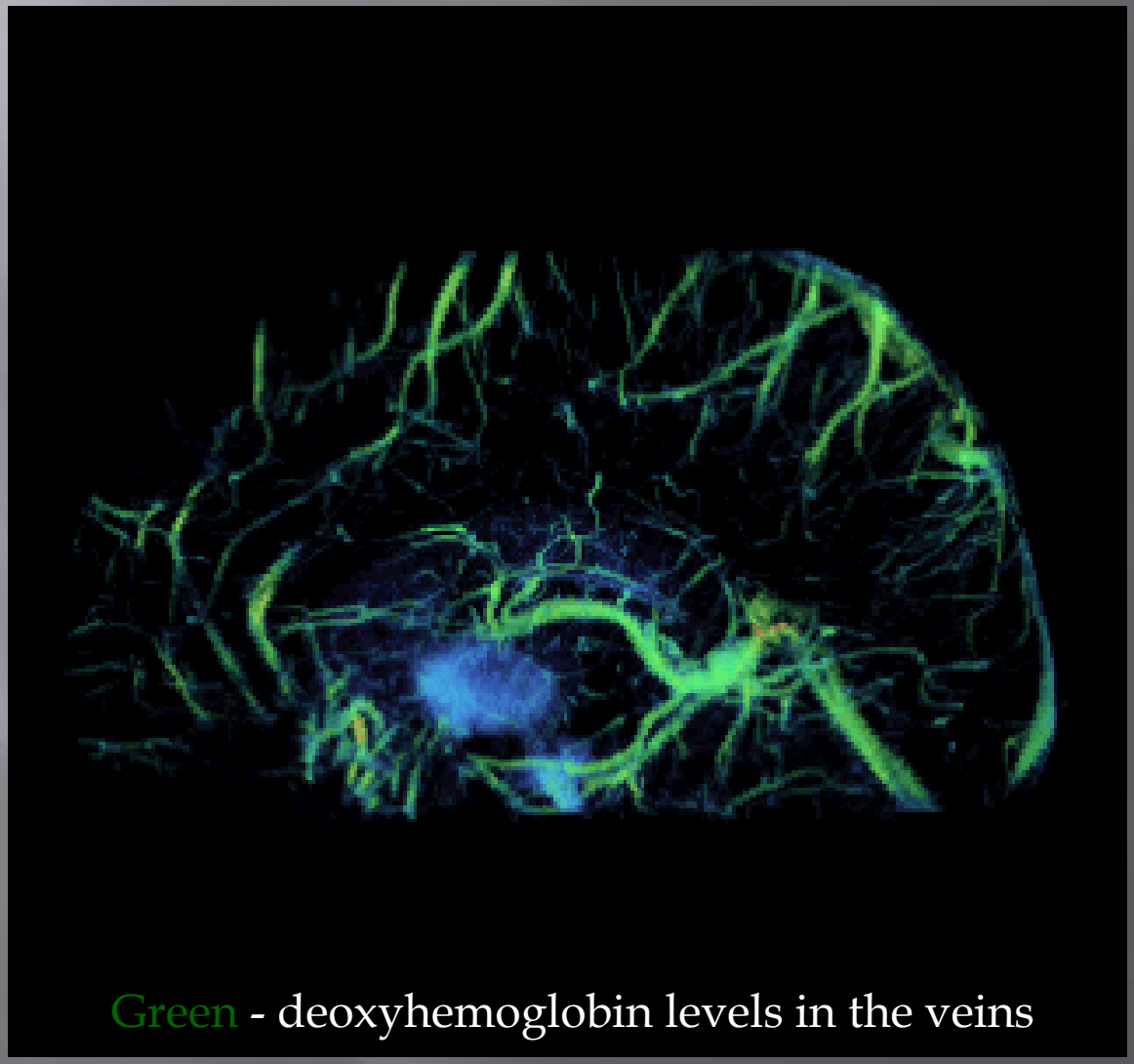
Caffeine: flow change = − 27% ± 9% and ΔY = − 0.09 ± 0.02
Diamox: flow change = +40% ± 7% and ΔY = +0.10 ± 0.01

Future Directions:
OXYGEN EXTRACTION FRACTION



MIPs of SWIM data over 8mm. The data where collected at 3T with TE=14.3ms and a voxel size $0.5x0.5x0.5mm^3$.

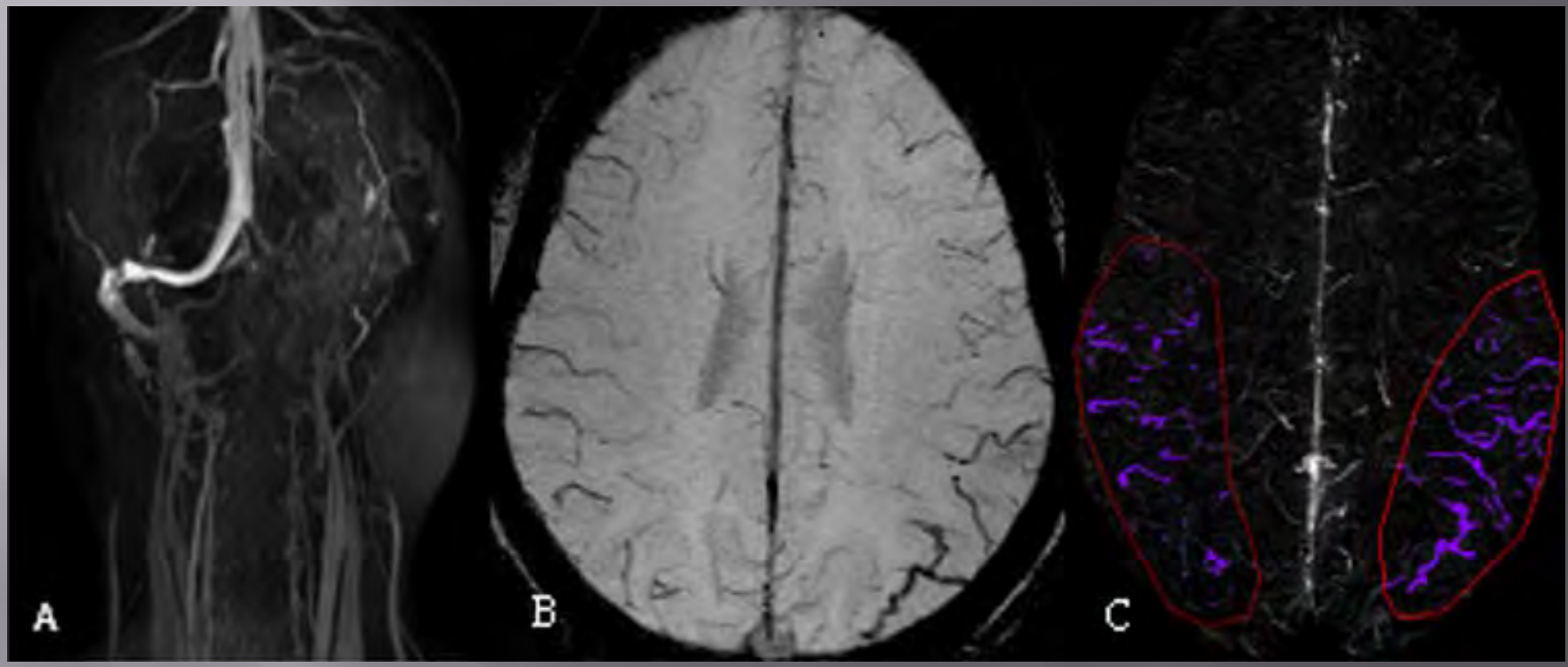
Whole brain iron oxygen extraction fraction



Green - deoxyhemoglobin levels in the veins

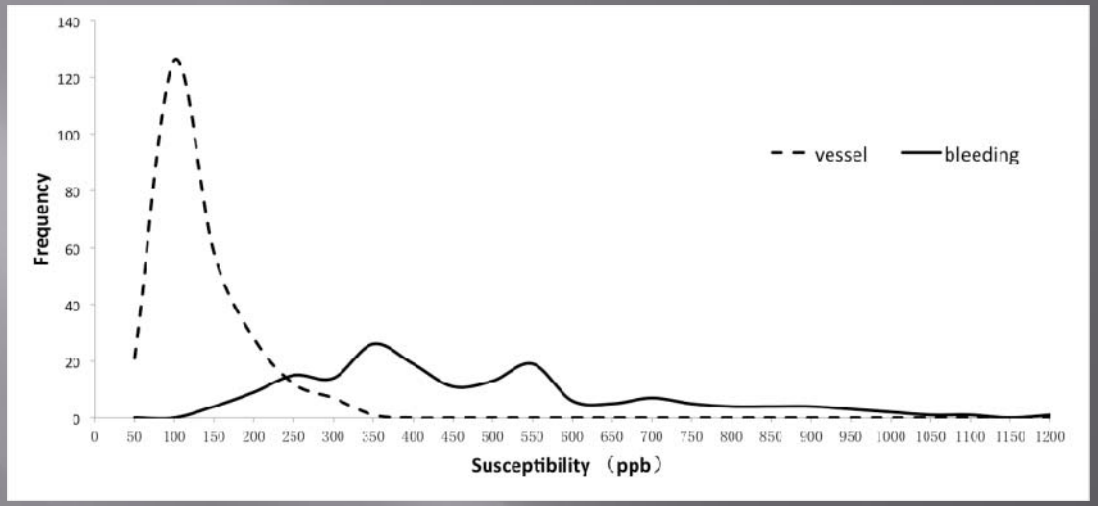
Blue represents iron in the basal ganglia and midbrain

Headache can be associated with bad venous vasculature



A 32-year-old female with headache and intracranial hypertension. Occlusion of the left transverse sinus (CE MRAV, A) and APCVs on the mIPped-SWI images (B). The susceptibility value of the ipsilateral pial veins measured 159±60 ppb and the contralateral measured only (131±43) ppb.

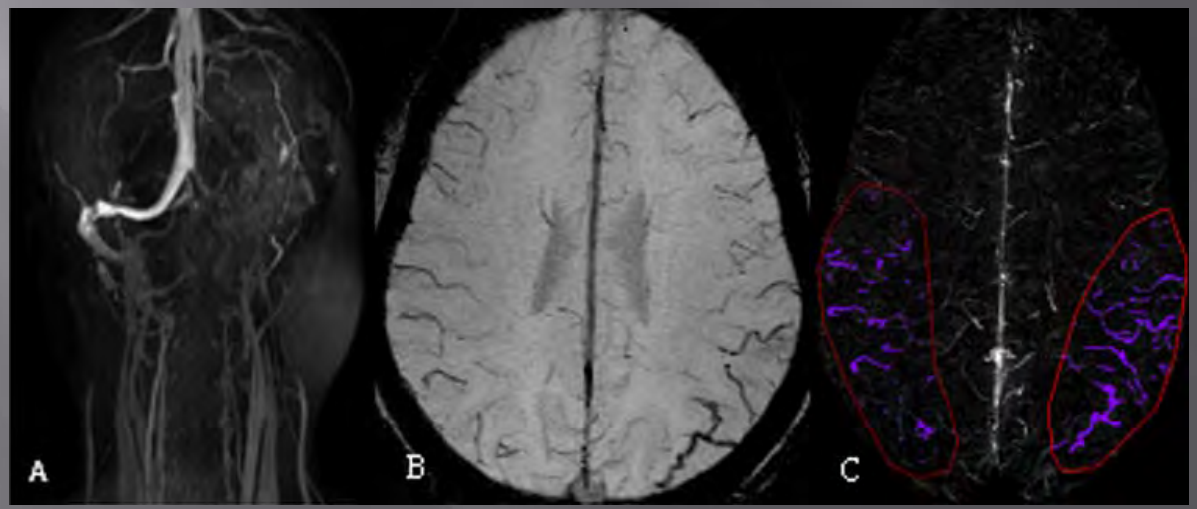
Stroke: Isolating poor flow using a threshold in SWIM[9,10]



Imaging headache and idiopathic intracranial hypertension

Asymmetrically prominent cortical veins are seen bilaterally

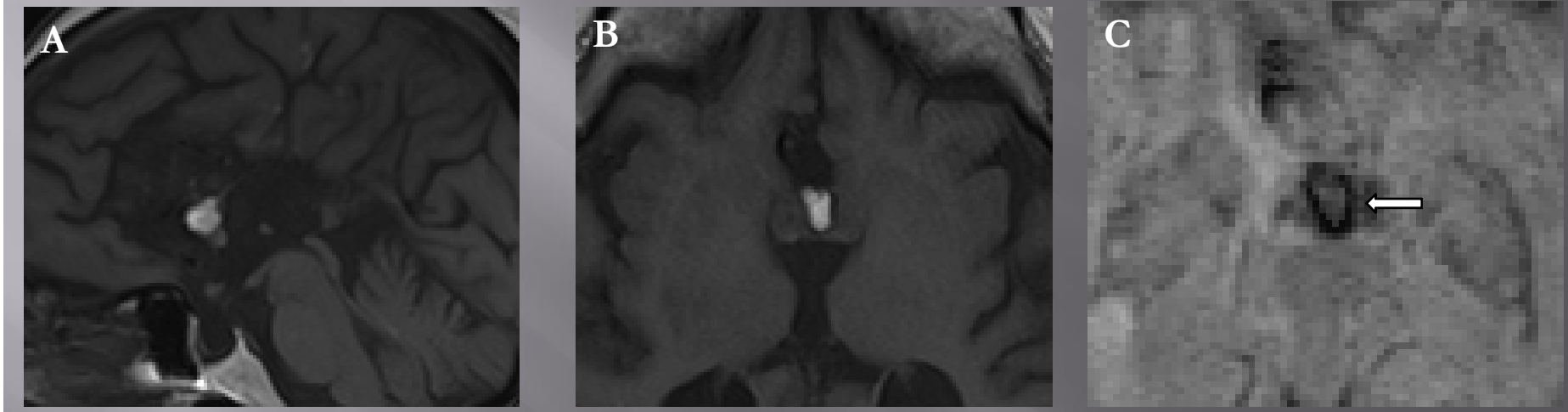
Abnormal dural sinuses and jugular vein



Fat containing intracranial lesions

- Congenital lesions
- Lipoma
- Dermoid
- Tumor
- Teratoma
- Craniophrayngioma
- Lipomatous meningioma
- Lipomatous differentiation/transformation of PNETs, ependymoma and glioma.
- Cerebellar liponeurocytoma
- Acquired
- Dissemination of fat in CSF after skull base/fat graft surgery.

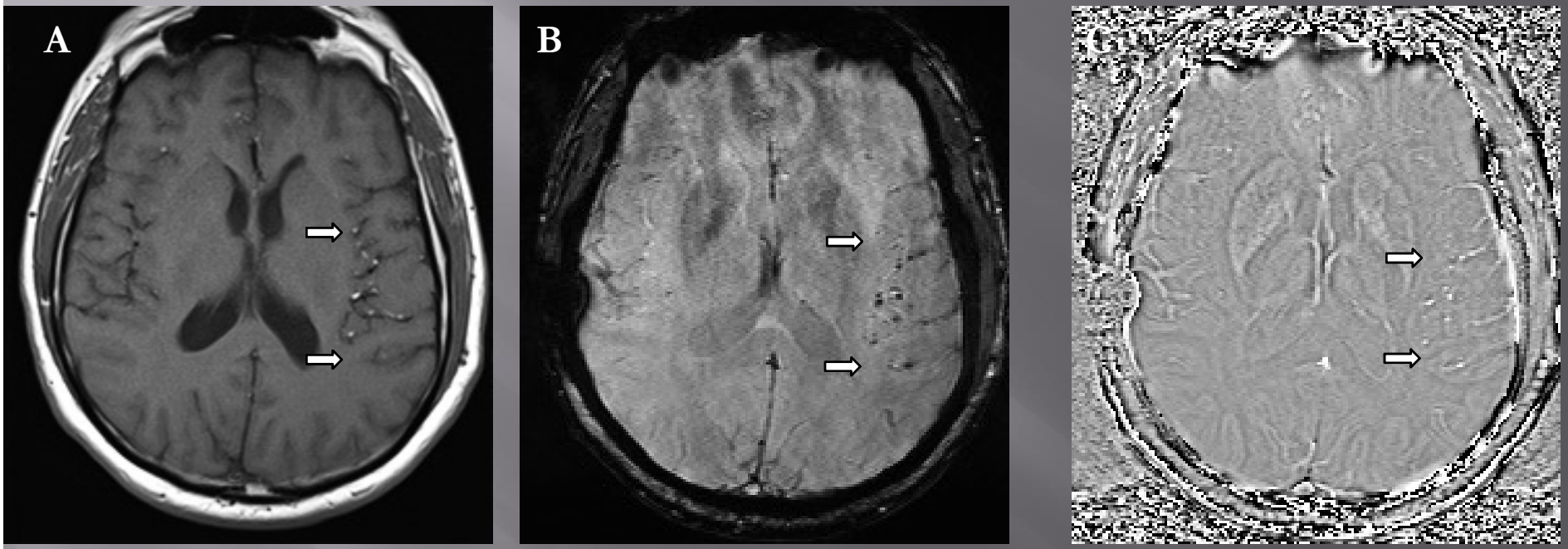
Callosal Lipoma



35-year-old male with an anterior interhemispheric lipoma in association with corpus callosum agenesis. MRI brain sagittal (A) and axial (B) T1WI depict the lipoma as a T1 hyperintense lesion located in the anterior interhemispheric fissure. SWI (C) shows a hypointense rim (arrow) surrounding the lipoma which represents the chemical artifact at the fat-CSF interface.

Images courtesy of Charles Hsu
AJR Am J Roentgenol 2013;201:902-7

Ruptured Dermoid Cyst



42-year-old man with ruptured intracranial dermoid. MRI brain T1WI (A) shows multiple small T1 hyperintense tiny fat droplets in the subarachnoid space of the left Sylvian fissure. On SWI (B) the fat droplets appear hypointense. Phase image (C) depicts the tiny fat droplets as hyperintense foci. Left handed MRI system, Siemens.

Neuroradiol J 2014; 27: 677–684

Lipomatous meningioma

78-year-old male with a left sphenoid ridge lipomatous meningioma. CT head (A) shows a fat containing extra-axial mass (arrows) with central area of soft tissue density. MRI brain SWI (B) depicts the peripheral areas of fat attenuation as hypointense. T1WI (C) confirms high signal intensity in areas of intralesional fat. Post gadolinium enhanced T1WI (D) shows homogenous enhancement pattern.

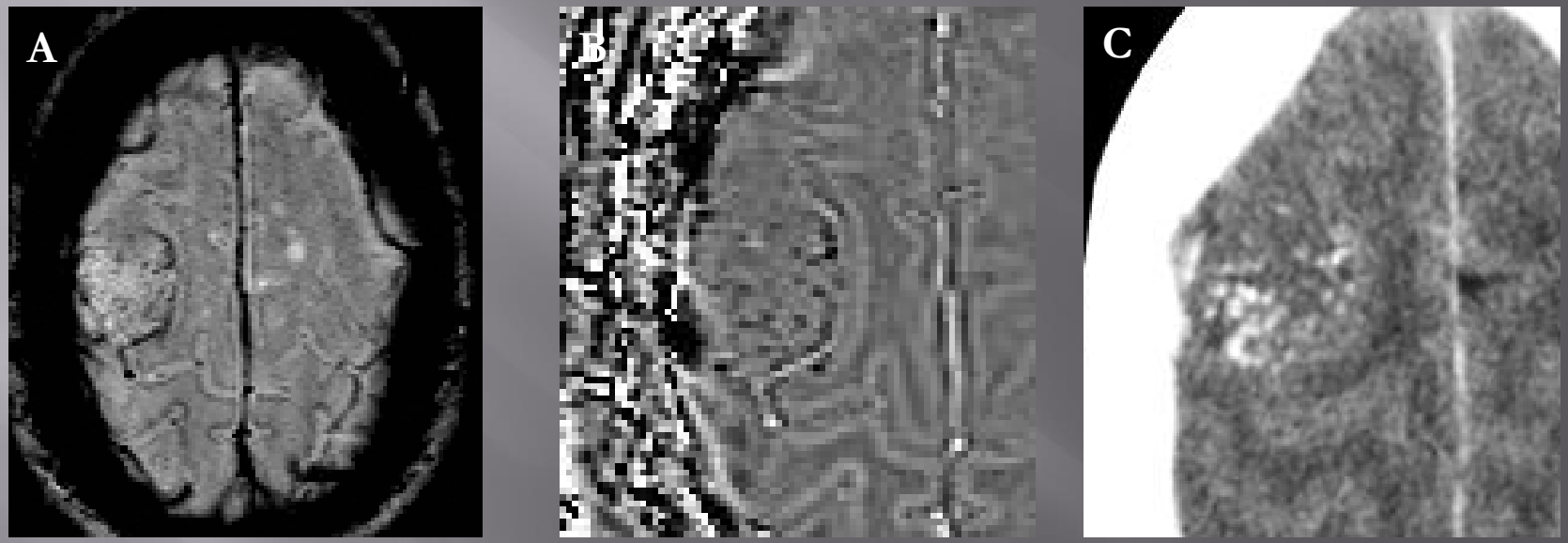
Intratumoral Susceptibility Signal

Intratumoral Susceptibility Signal describes the intratumoral susceptibility signal characteristics, which may be due to microhaemorrhage, neoangiogenesis or calcification.

Phase shift in calcified intracranial neoplasm

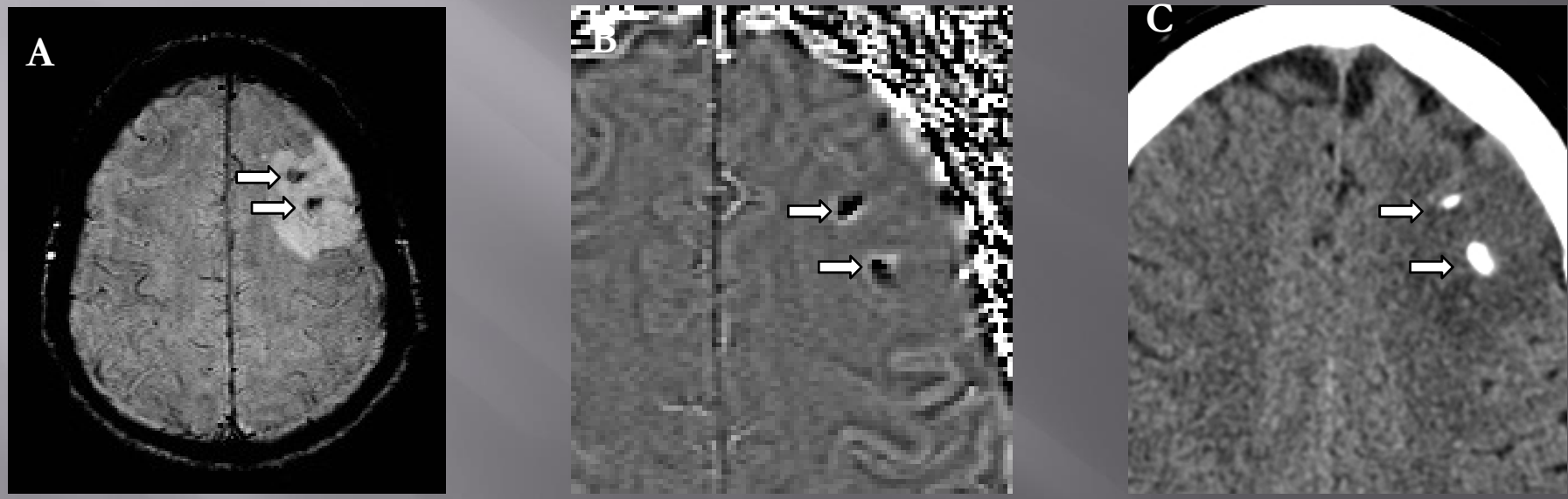
- Heme iron and calcium generate opposing phase shift values on the SWI phase image.
- Diamagnetic substances such as calcium demonstrate negative shift on phase imaging, however, paramagnetic substances such as deoxyhemoglobin, hemosiderin and ferritin demonstrate positive shift on phase imaging for a left handed system.

Meningioma



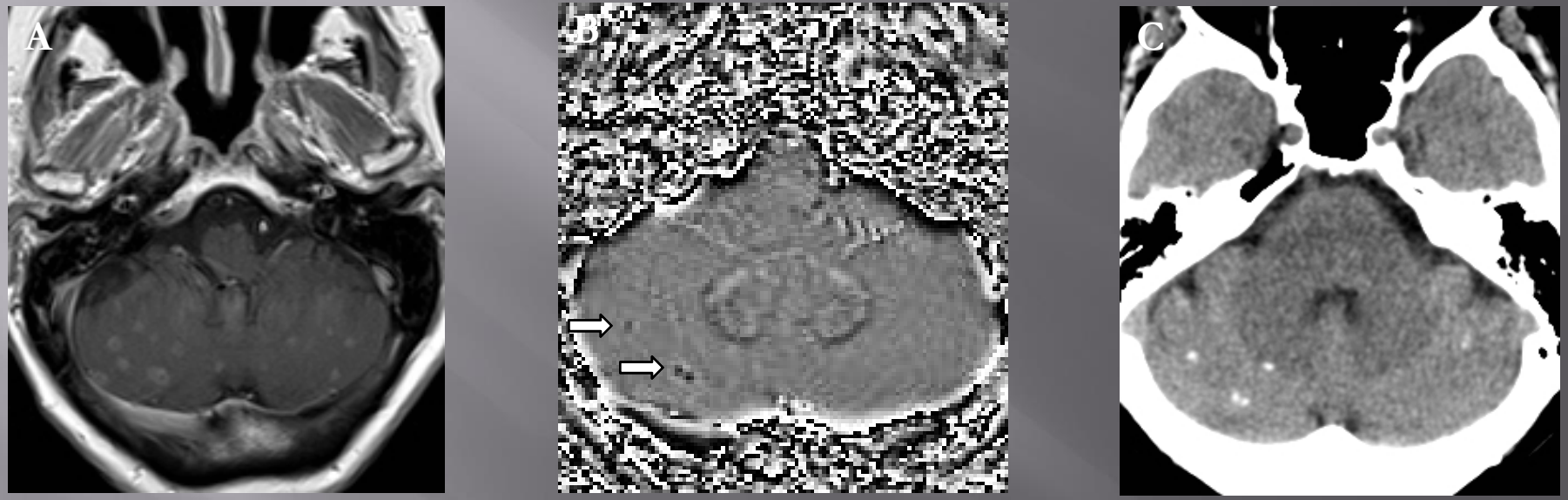
42-year-old female with a right frontal meningioma. MRI brain SWI (A) depicts an extra-axial mass with hypointense intralesional foci. On the phase image (B) these intralesional foci appear hypointense suggestive of intralesional calcifications. CT head (C) confirms punctate intralesional calcifications. Left handed MRI system, Siemens.

Oligodendroglioma (WHOII)



40-year-old female patient with a left frontal oligodendroglioma. SWI image (A) shows two punctate hypointense foci (arrows) which are also hypointense on the phase image (B) confirming intratumoral calcifications. Corresponding non-contrast CT (C) confirms the presence of intratumoral calcifications. Left handed MRI system, Siemens.

Calcified Metastases

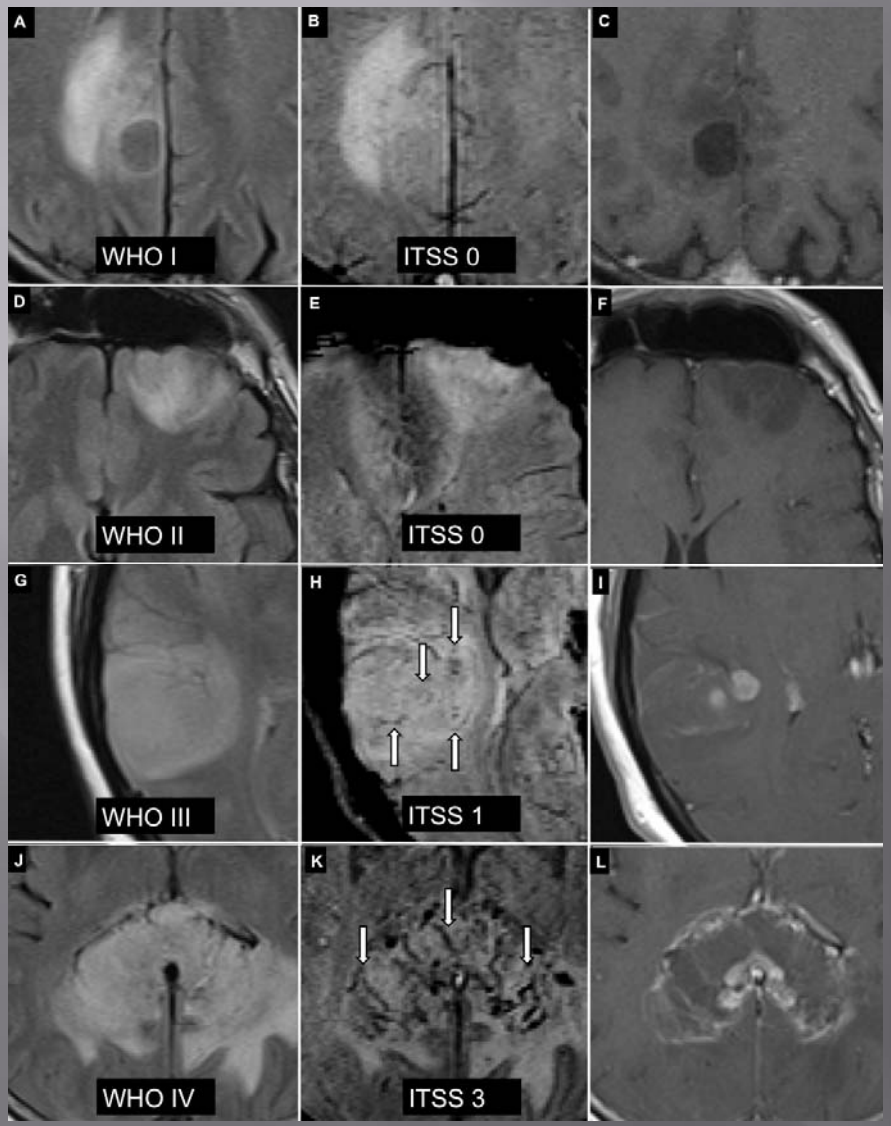


50 year-old female with calcified cerebral metastases from breast cancer. Post contrast T1WI (A) shows multiple enhancing lesions in the cerebellum. Phase image (B) show some of the lesion as hypointense (arrows). Corresponding non-contrast CT (C) confirms multiple calcified lesions which were underestimated on the phase image. (Images acquired on the left handed MRI system, Siemens).

Intratumoral Susceptibility Signal

Intratumoral Susceptibility Signal describes the intratumoral susceptibility signal characteristics, which may be due to microhaemorrhage, neoangiogenesis or calcification.

ITSS and Histological Grading of Glioma



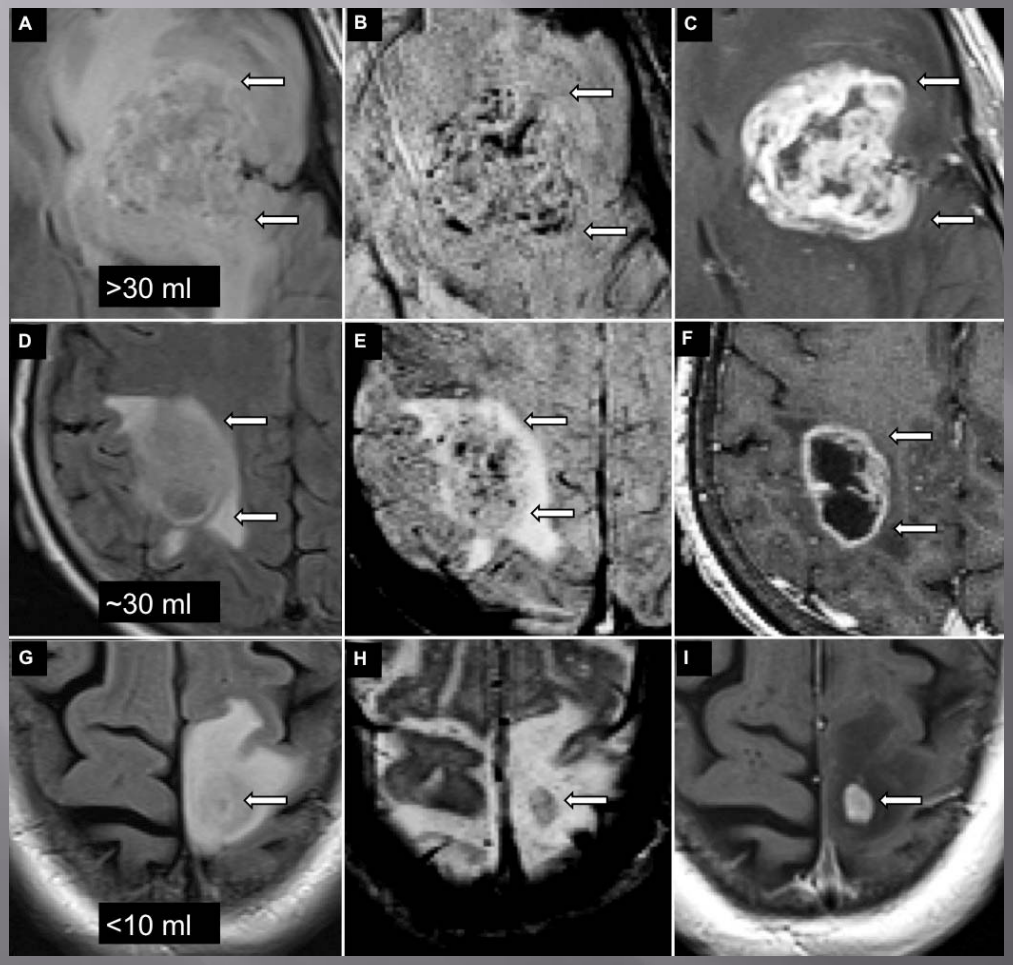
Research has shown a reliable correlation of ITSS with tumoral vascularity on dynamic susceptibility-weighted contrast-enhanced (DSC) perfusion-weighted MRI (PWI) and histological grade (WHO).

The ITSS grading scheme is as follows:

Grade 0: no ITSS
Grade 1: 1–5 dot-like or fine linear ITSSs
Grade 2: 6–10 dot-like or fine linear ITSSs
Grade 3: 11 dot-like or fine linear ITSSs

J Magn Reson Imaging 2014 ;39:1569-74

ITSS and Volume of Glioblastoma



Example of relationship between tumoral volume of glioblastoma and ITSS grade. Glioblastomas with > 30 ml volume (A-C) demonstrate greater ITSS in comparison with moderate volume ~30 ml glioblastomas (D-F). Smaller glioblastomas < 10 ml volume (G-I) demonstrate minimal ITSS. (Images acquired on the left handed MRI system, Siemens).

Conclusions

MR can provide information on:

- Arteries and Veins separately
- Microvasculature
- Oxygen saturation

Can this capability be used to better image tumors?