Imaging the Microvasculature using MRI

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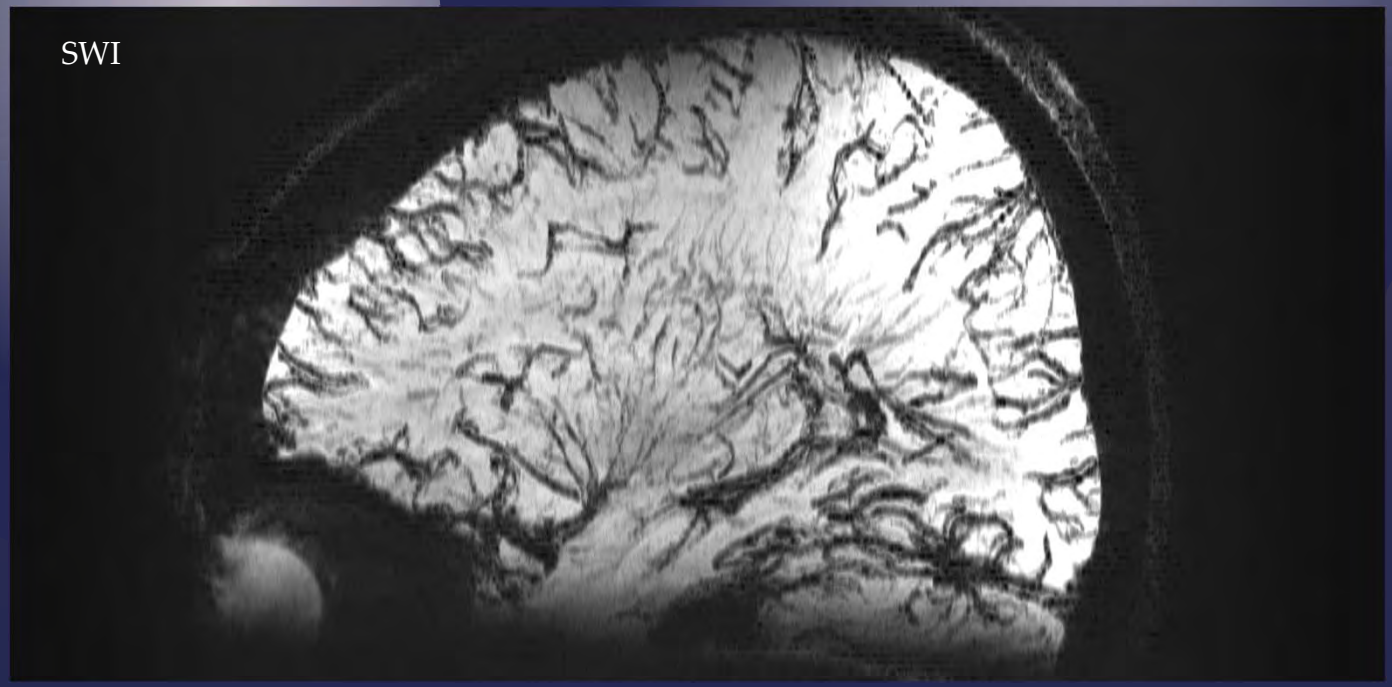


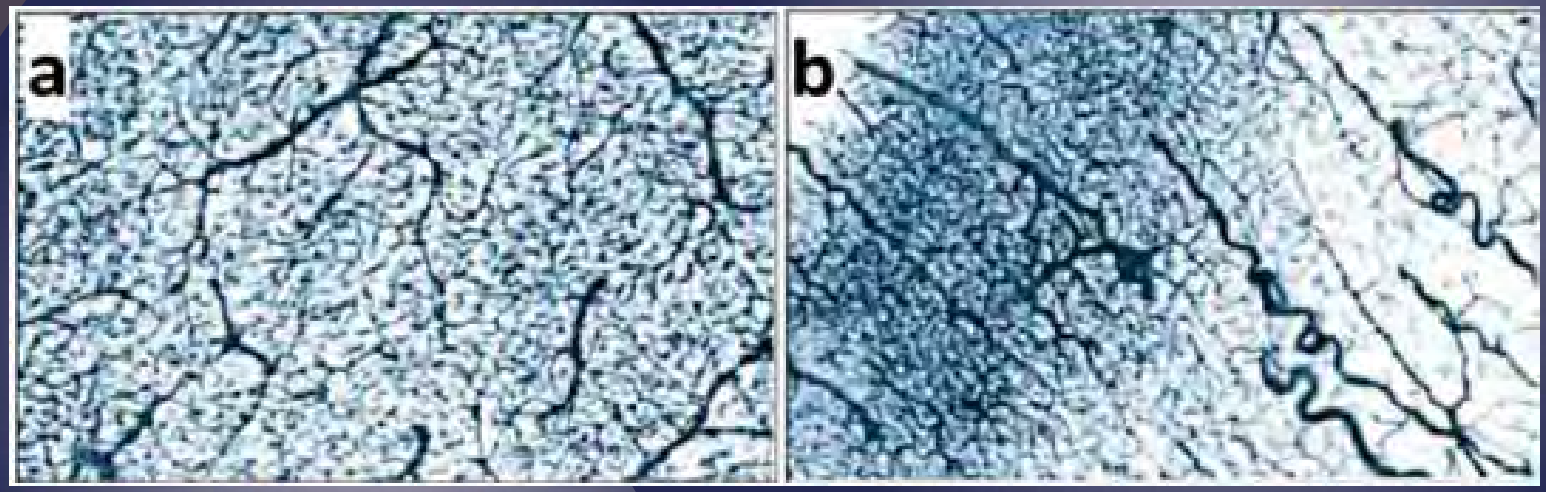
Conflicts of Interest

- Support from Siemens Medical Systems
- DoD grant on SWI and SWIM
- NIH grant on USPIO susceptibility
- President of MR Innovations, Inc.

Small vessel morphological changes

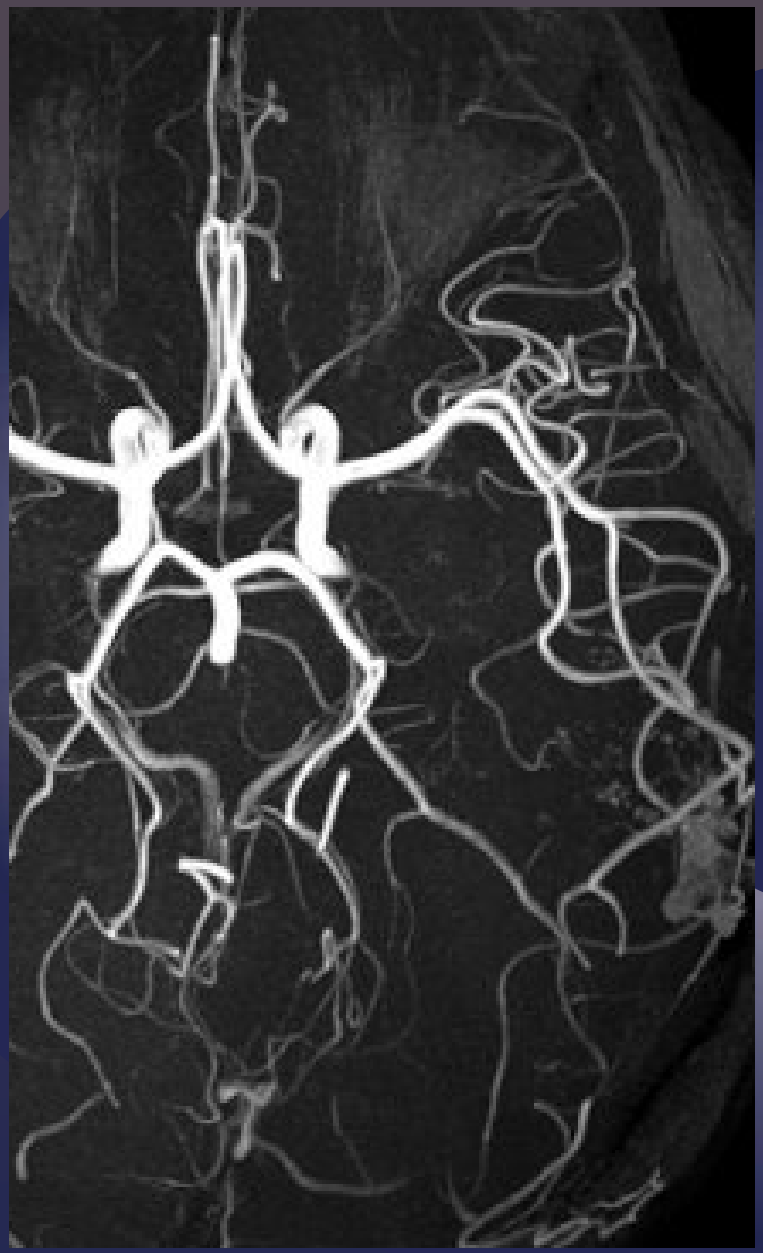
Control

Alzheimer's Disease

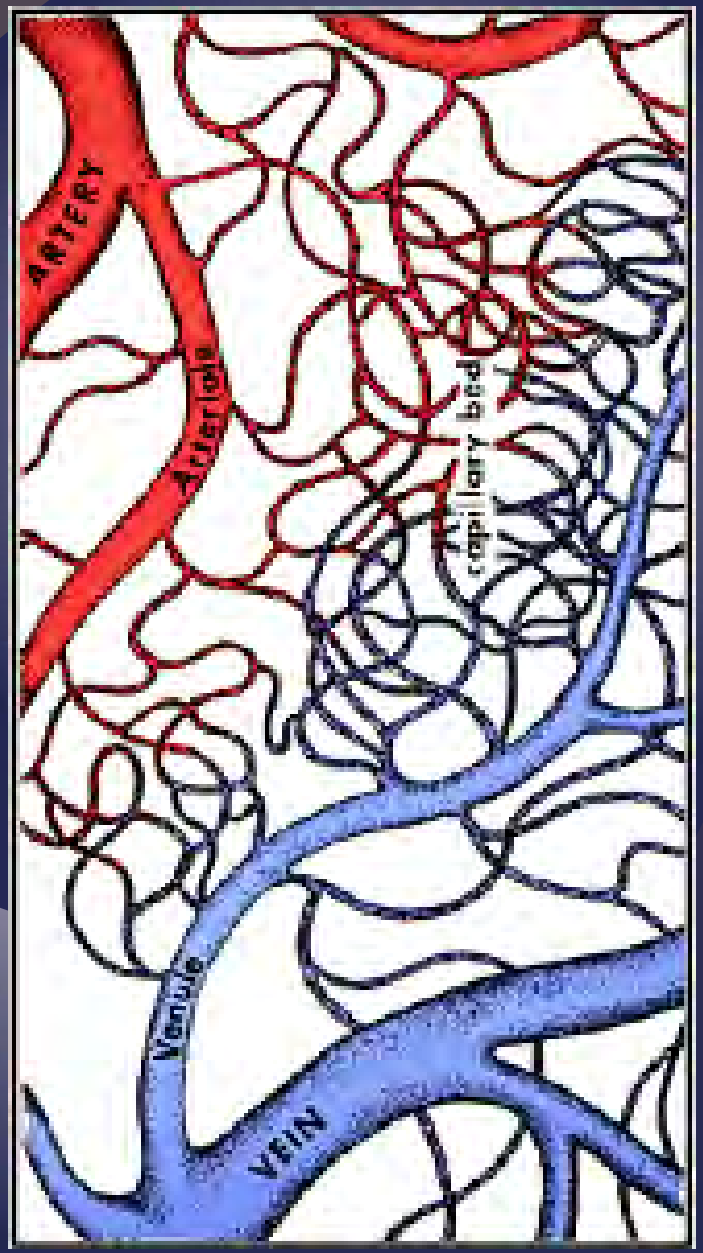


Tortuous vessels have decreased pulse pressure that compromise the flow and oxygen delivery.

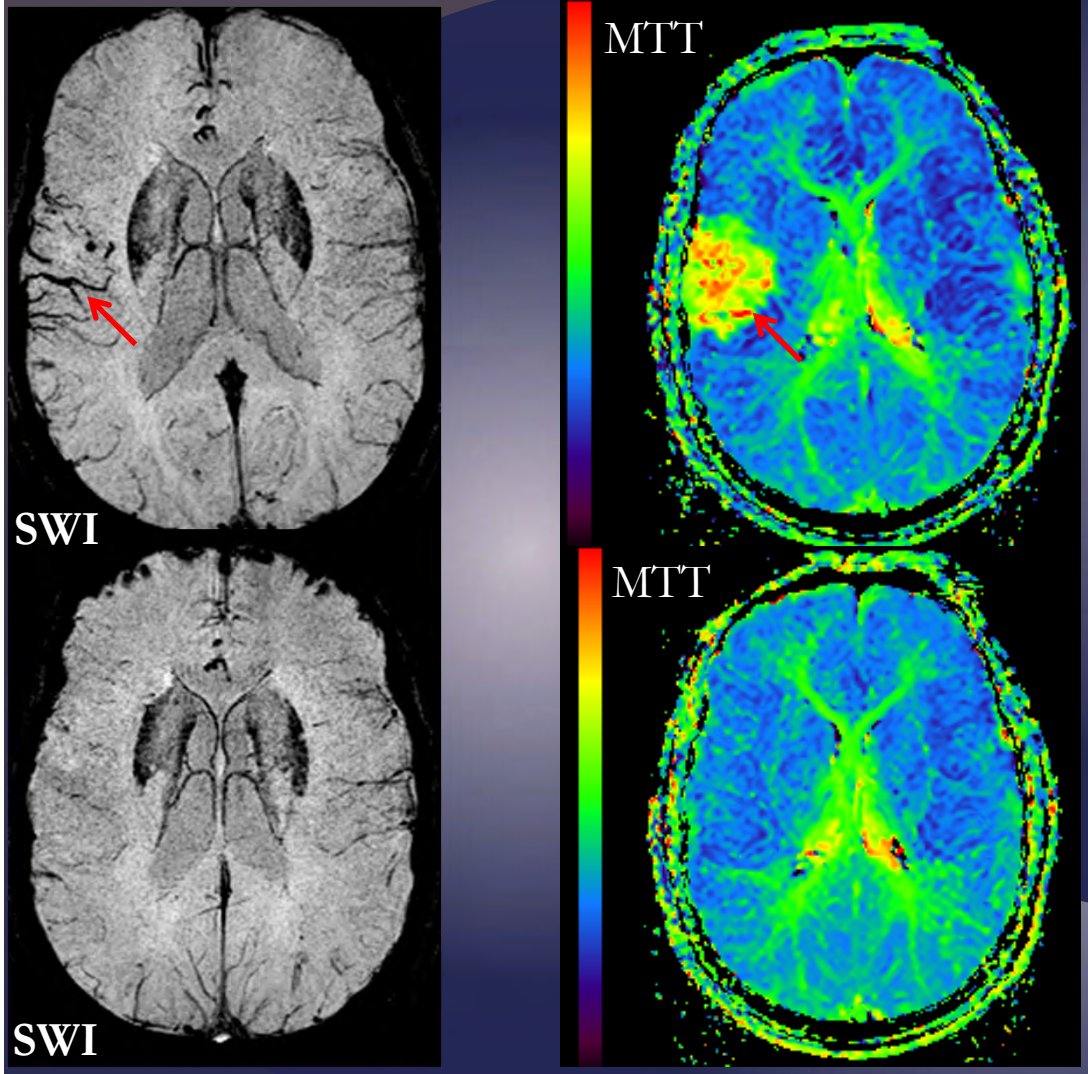
Current Macro MRA



Microcirculation



MRI scan date: 2013.01.04



MRI scan date: 2013.01.11

Images from Dr. Yu Luo, Shanghai First Hospital.

Imaging stroke patients with SWI and PWI[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.

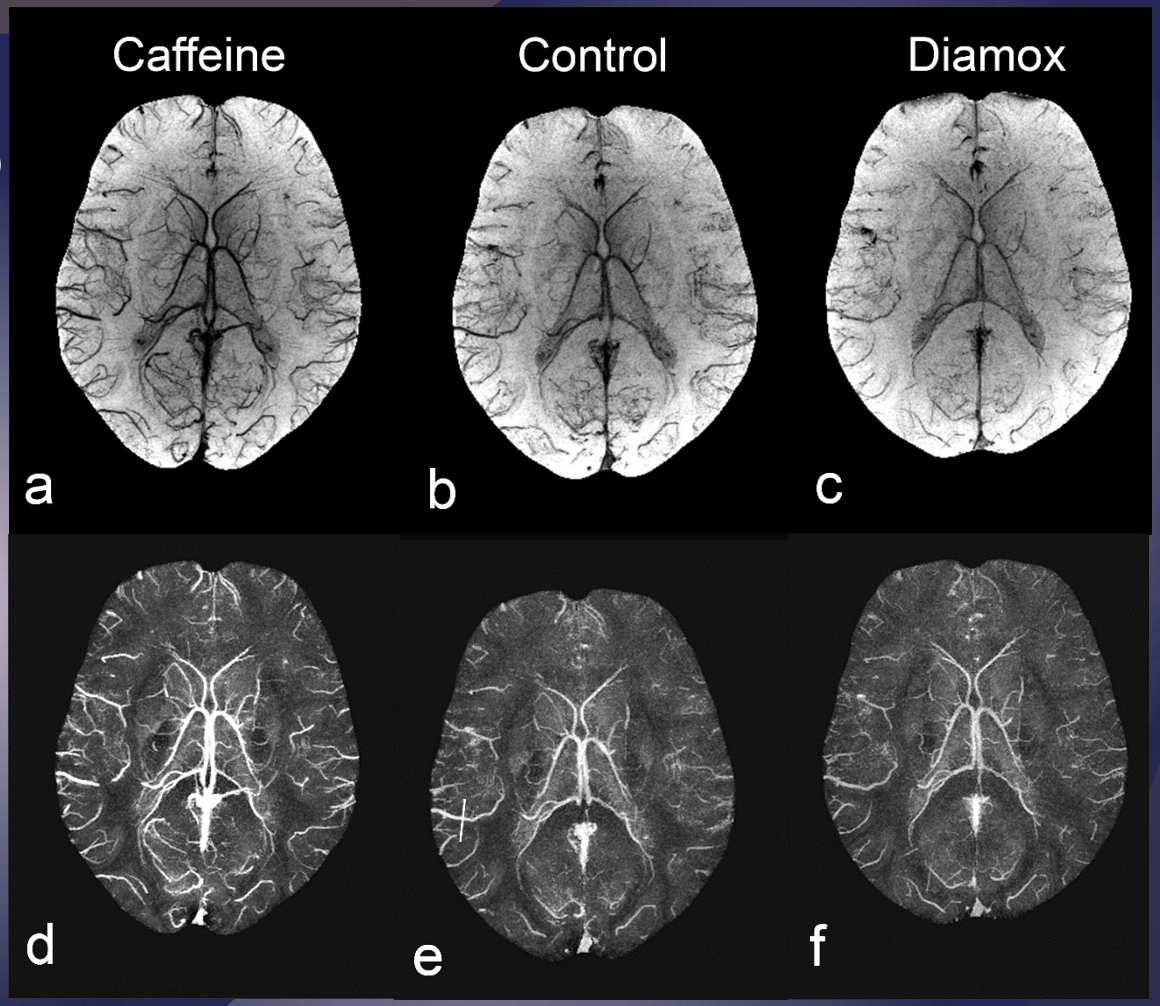
After treatment the increases in MTT and the evidence of the asymmetrically prominent cortical veins disappears.

Qualitative SWI versus quantitative susceptibility mapping (QSM) or SWIM
0.5mm isotropic resolution, TE = 20ms, 3T

Cerebral Vascular Reserve: Challenging the neurovascular system

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.



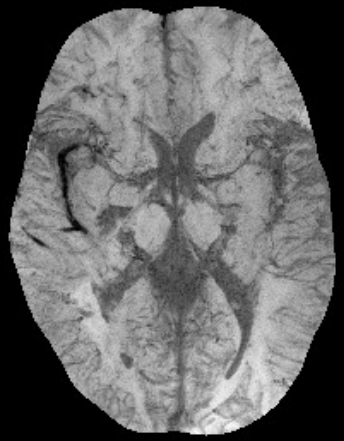
Caffeine: flow change = − 27% ± 9% and ΔY = − 0.09 ± 0.02
Diamox: flow change = +40% ± 7% and ΔY = +0.10 ± 0.01

Buch S, Ye Y, Haacke EM. Quantifying the changes in oxygen extraction fraction and cerebral activity caused by caffeine and acetazolamide. J Cereb Blood Flow Metab. 2016.

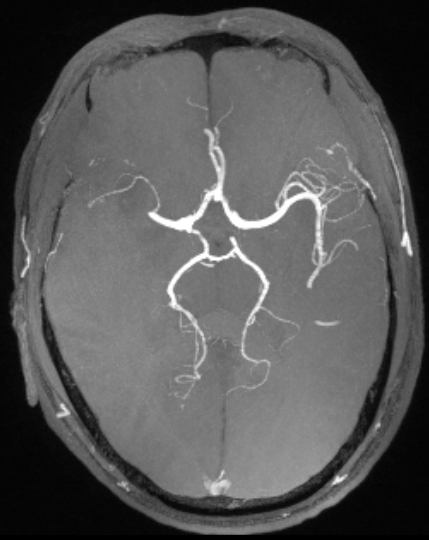
Imaging veins and arteries using double echo SWI[5]

Images courtesy of Meiyun Wang, Zhengzhou

Thrombus dominates the SWI image (TE = 7.5ms)

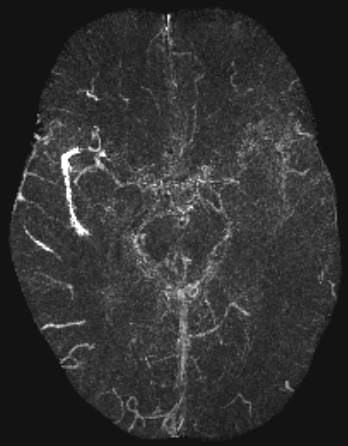


First echo MIP

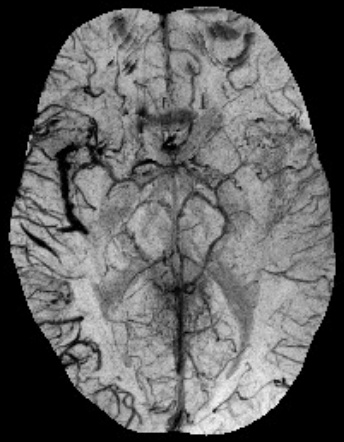


First echo MRA like signal

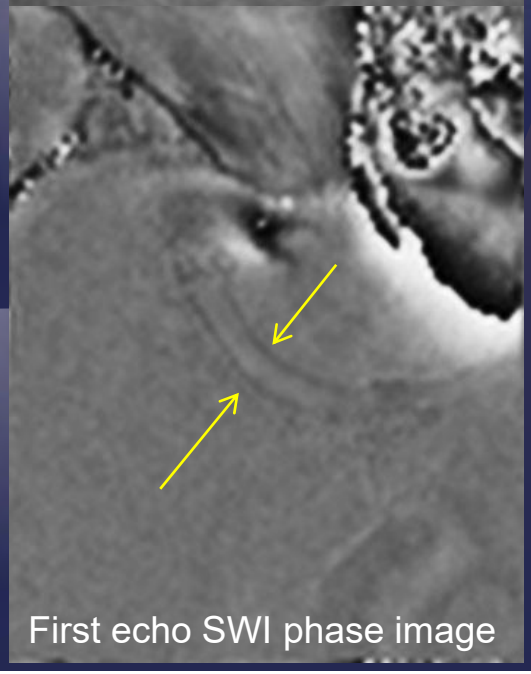
Thrombus dominates the SWIM image (TE = 7.5ms)



Second echo (17.5ms) true SWI

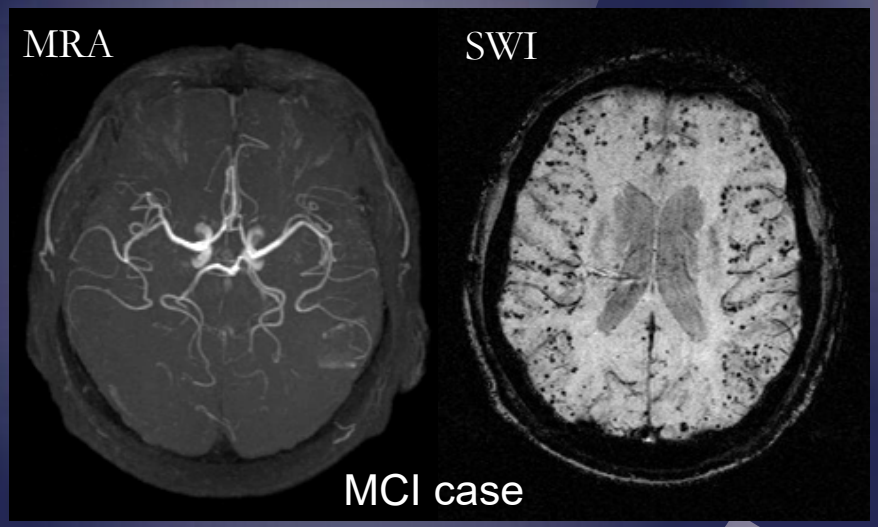


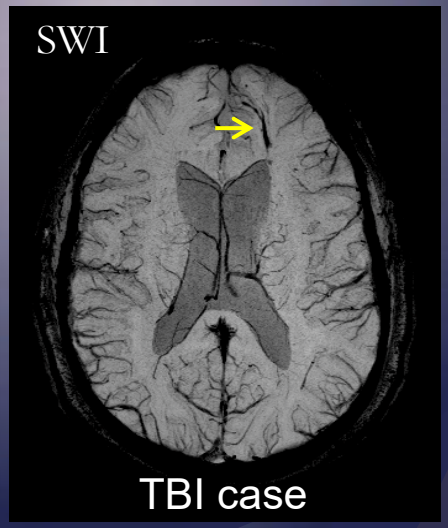
Note the asymmetrically prominent cortical veins



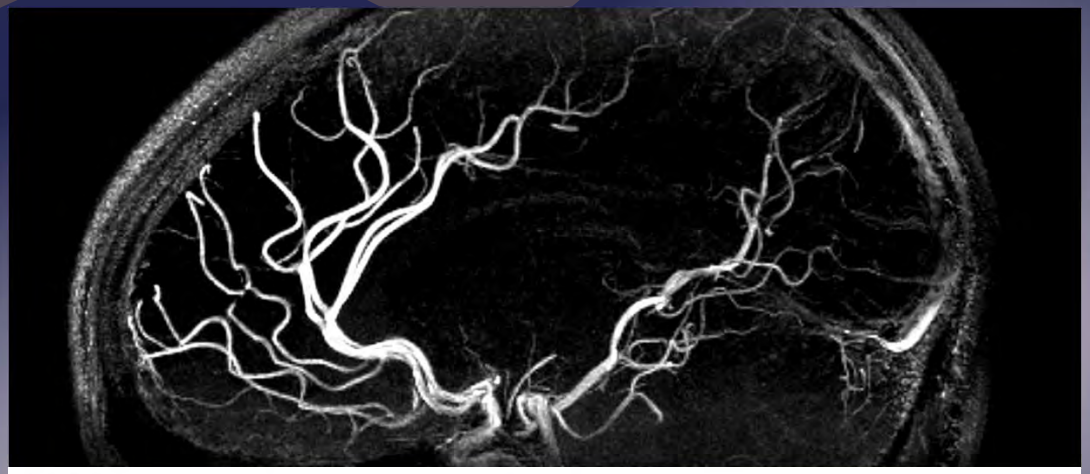
First echo SWI phase image

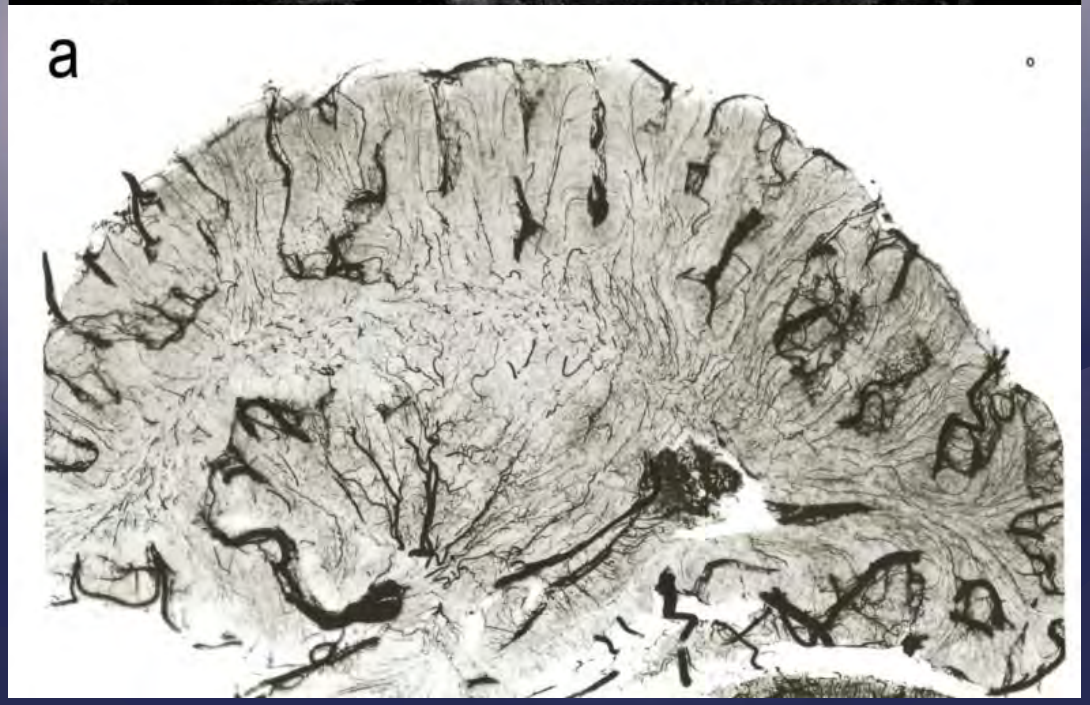
Imaging veins and blood products using SWI and SWIM[1-3]



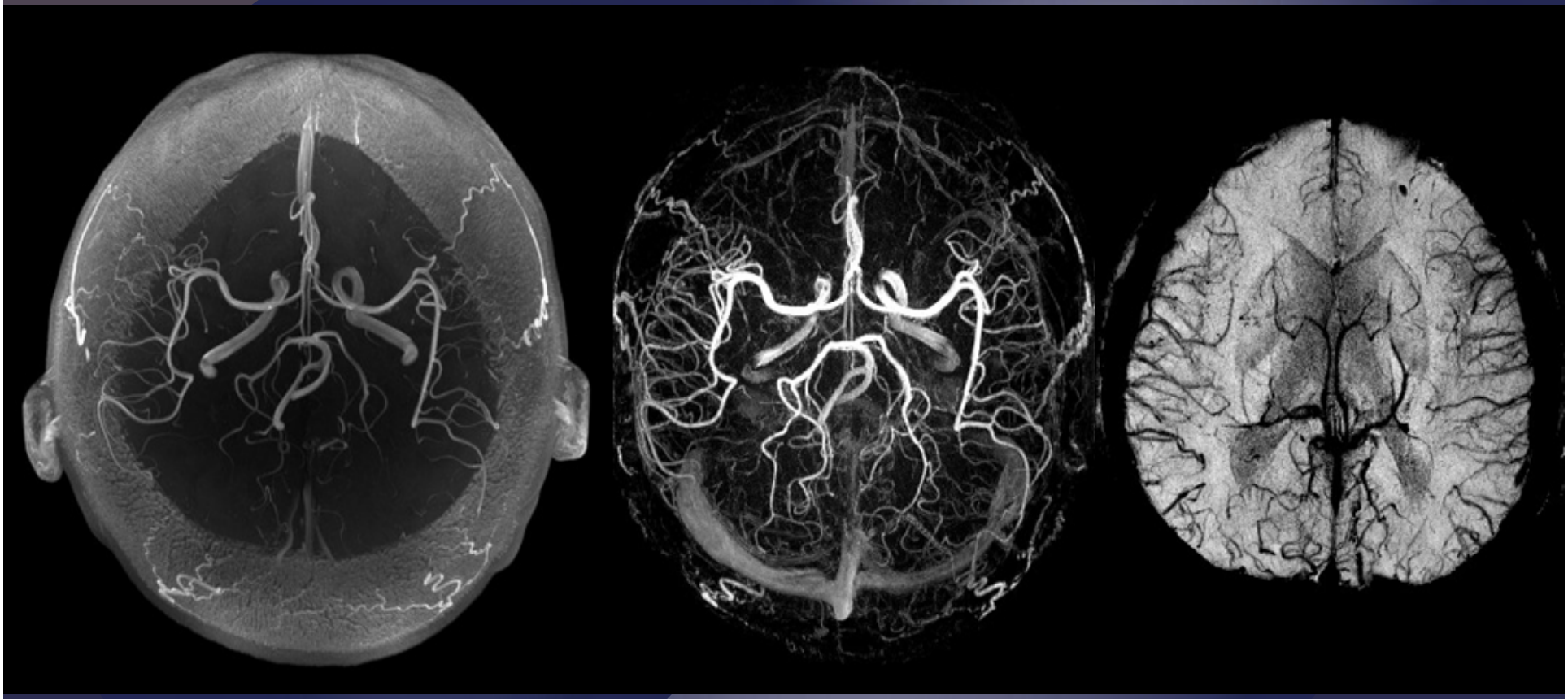


MRA of major, intermediate and microvessels



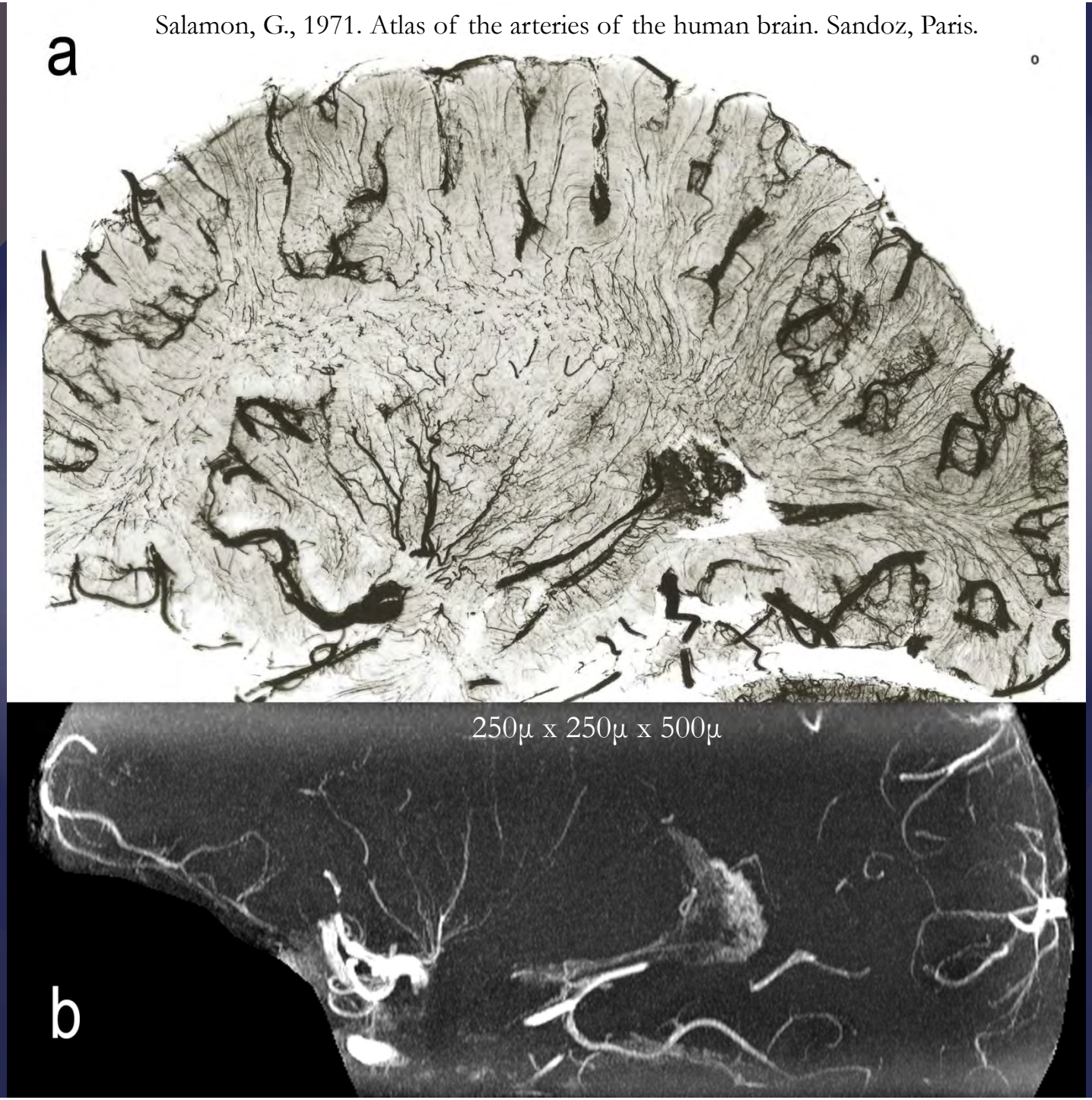


High resolution conventional MRA



We can certainly see small vessels here on the order of 0.5mm, but nature is hiding the cerebral arteries at the level of 100 microns in diameter.
This central image took 16minutes to acquire. To get 250μ resolution would take 32 minutes and would have limited signal-to-noise.

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

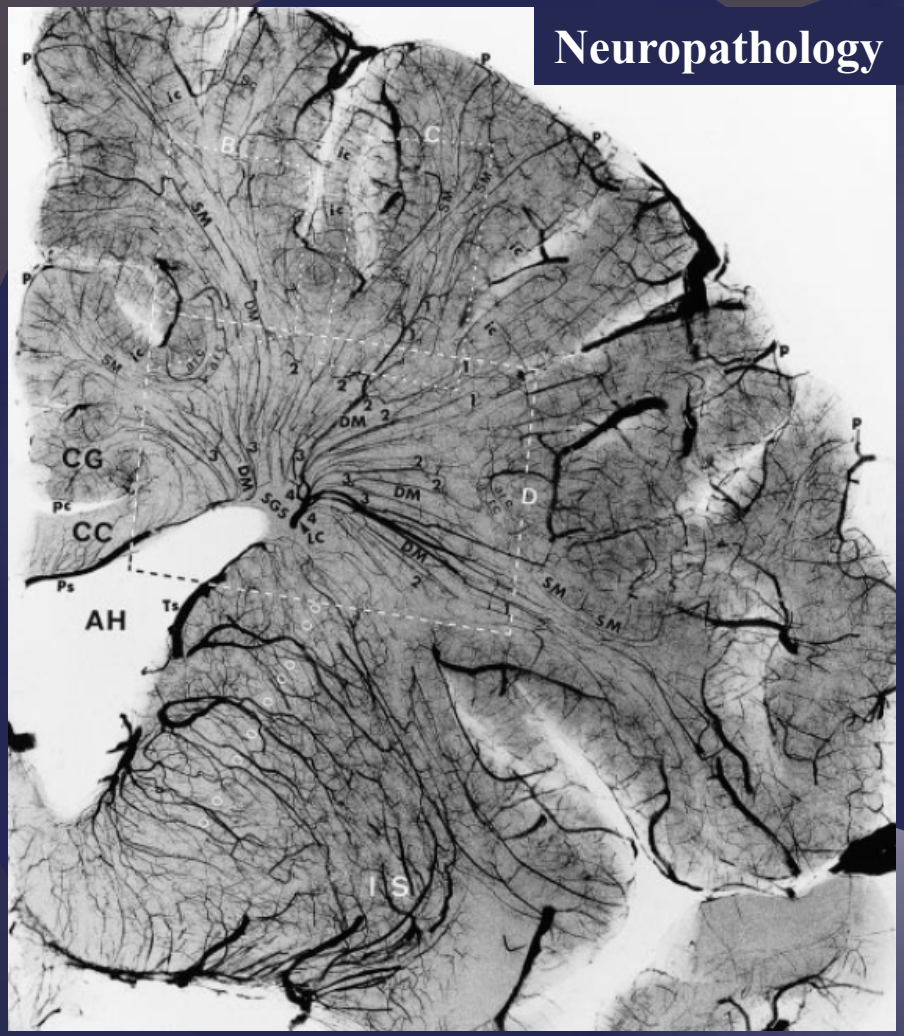


Microvascular Arterial and Venous Imaging

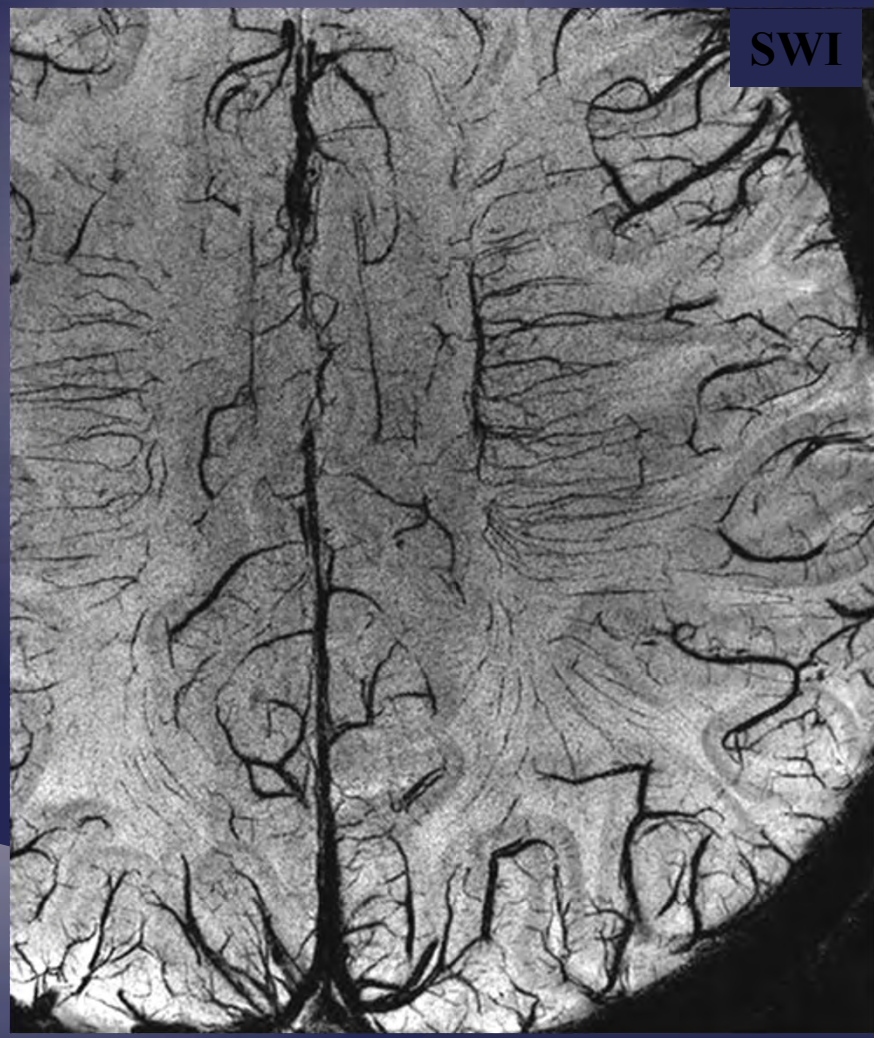
We propose to overcome the obstacles of long acquisition times, visibility of small arteries and a loss of signal-to-noise when high resolution data are collected using the next generation of microvascular imaging, which we call ***MICRO*** which stands for:

"Microvascular In-vivo Contrast Revealed Origins".

Periventricular WM Medullary Veins

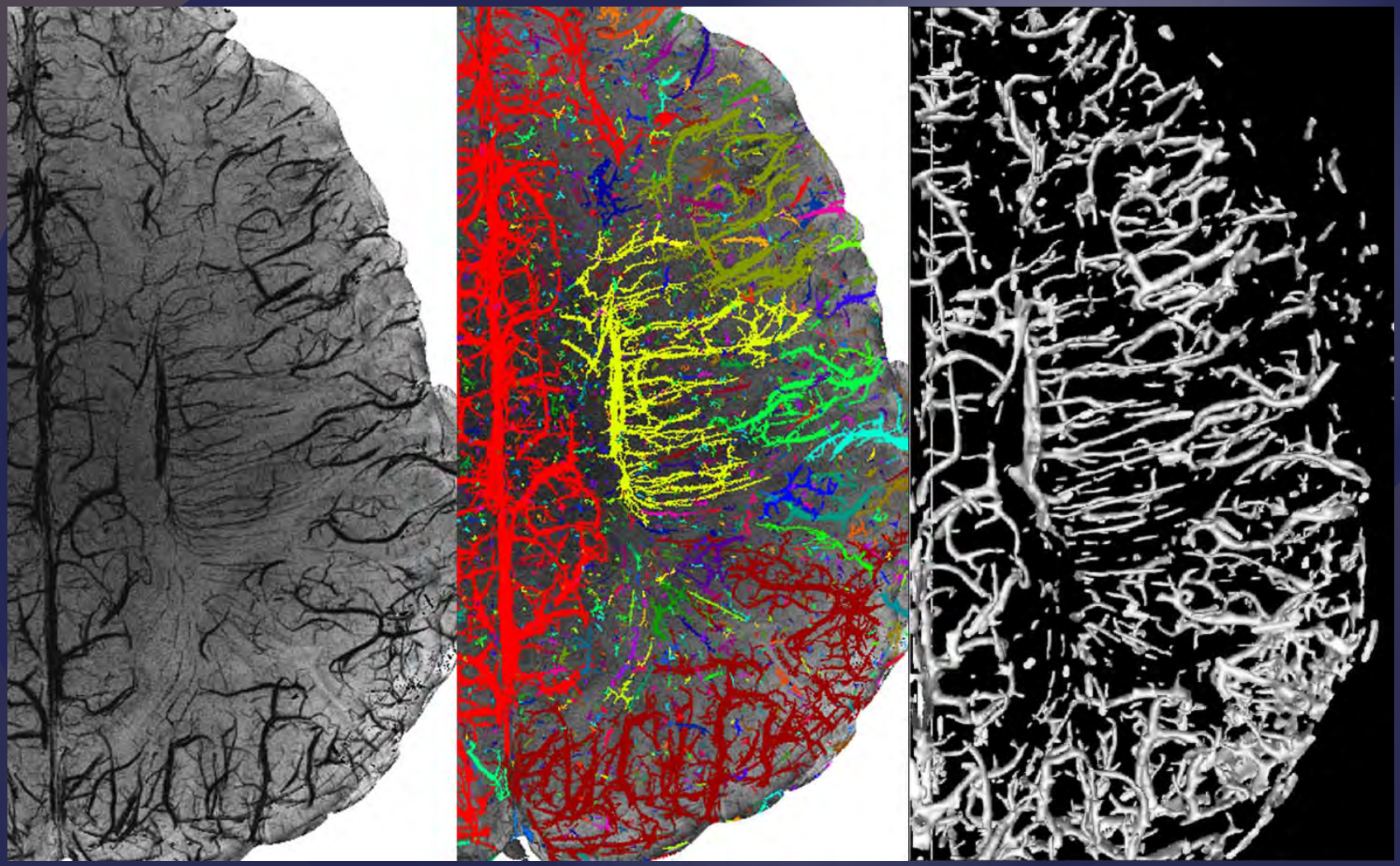


Okudera et al Neuropathology 1999



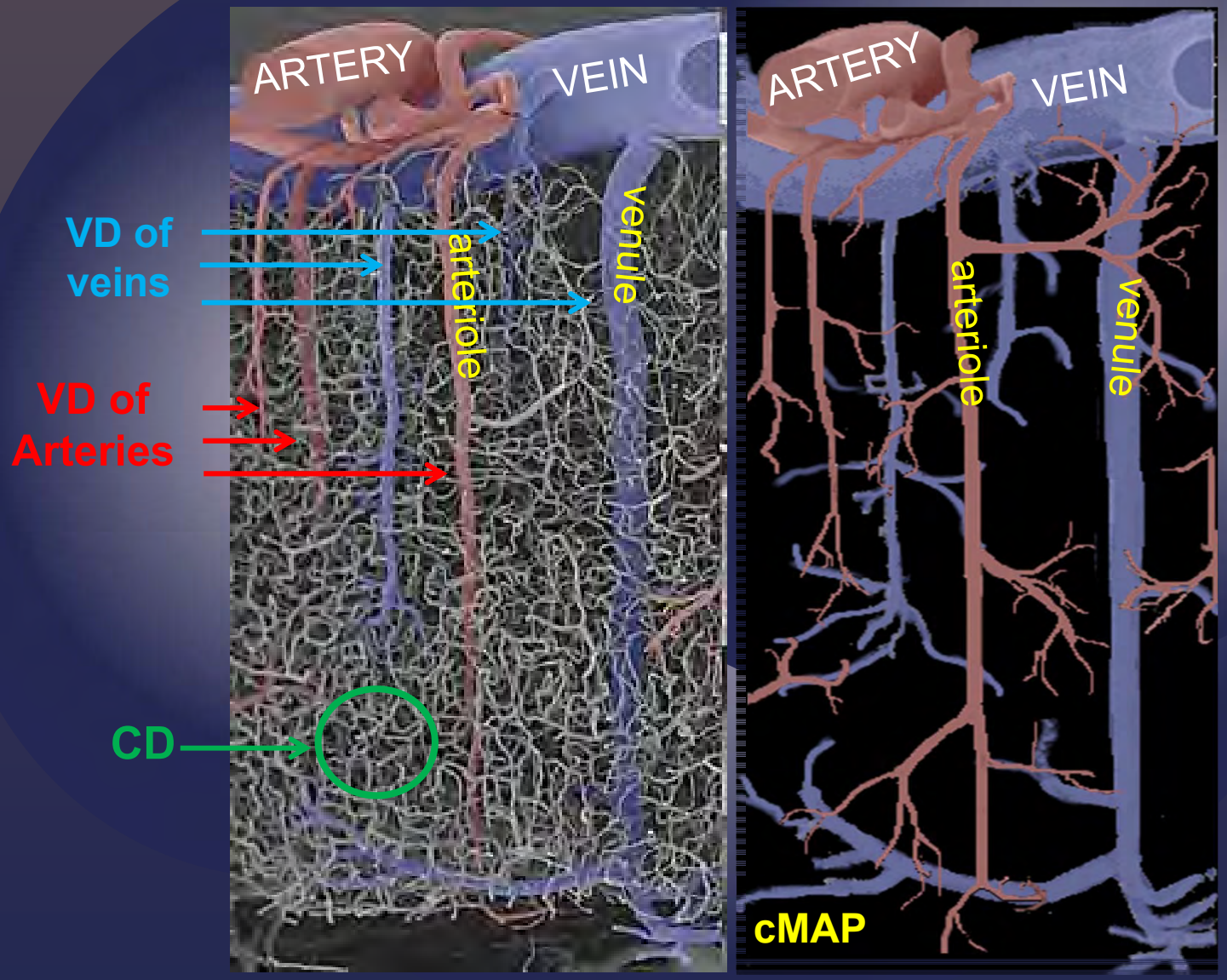
7T SWI courtesy of Yulin Ge

Quantification of SWI venous blood



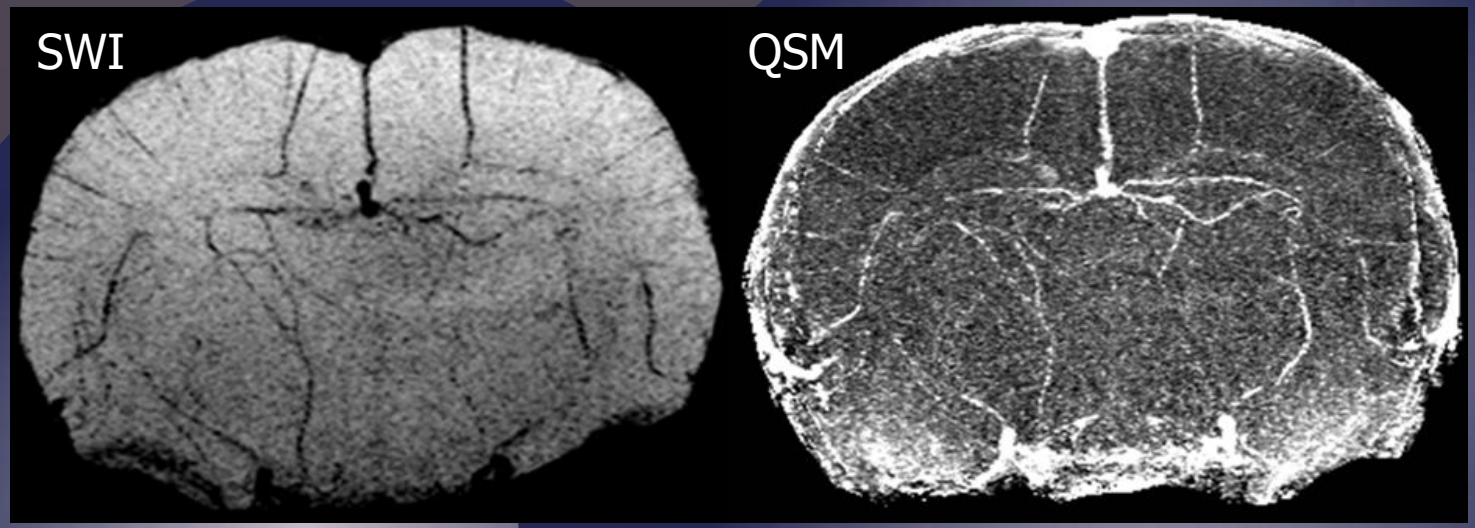
Images from SPIN software courtesy of Sam Barnes and Yulin Ge

We wish to use MICRO imaging to generate a cerebral microvascular architecture print **(cMAP)**



IMAGING ARTERIES WITH SWI USING P904[21]

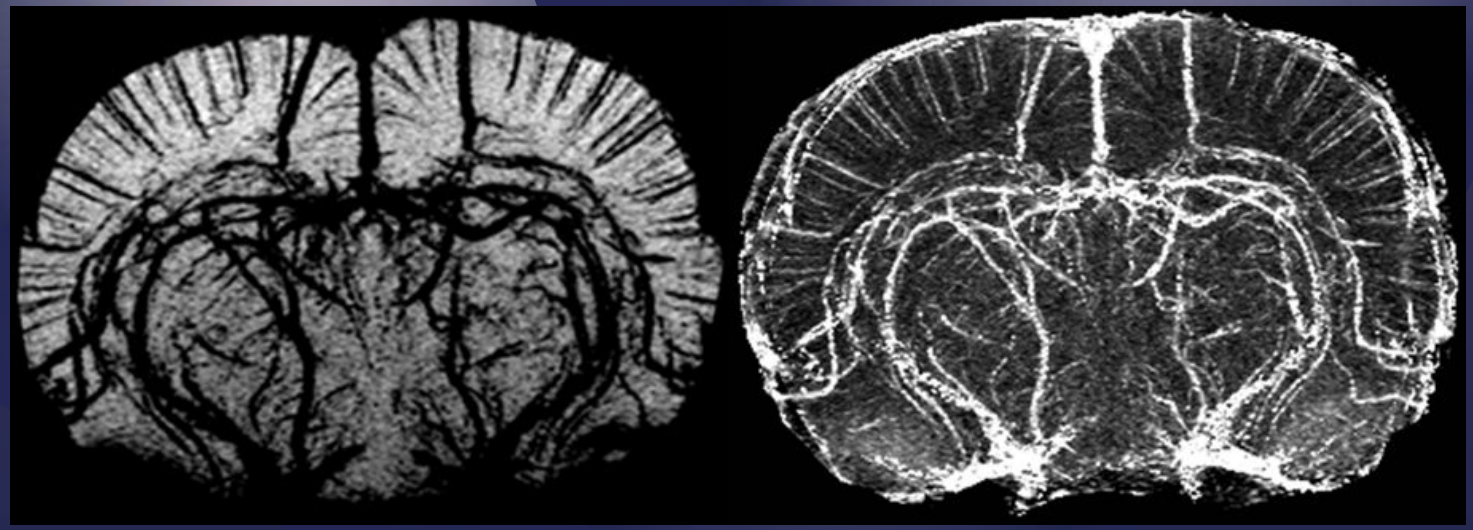
Past 20 Years



SWI of arteries with P904

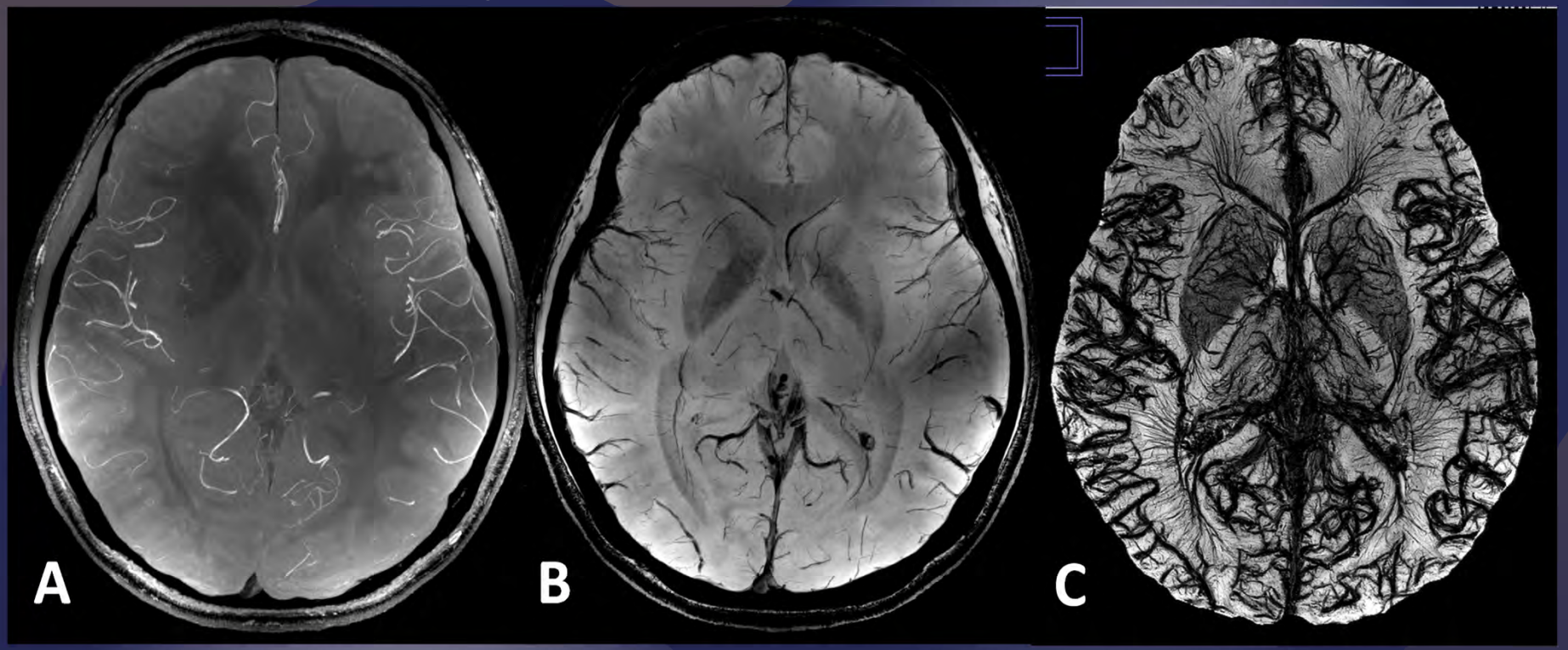
QSM of arteries with P904

Future 20 Years



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

Ferumoxytol enhanced MRAV



MICRO MRI was performed in a healthy volunteer at 7T. For TE = 8ms,16ms, the resolution is 0.11mm x 0.11mm x 1.25mm and 0.22mm x 0.22mm x 2.0mm. Pre-contrast magnitude (MIP) **(A)** showing arteries and pre-contrast SWI (TE=8ms) showing veins **(B)** and post-contrast 4mg/kg Ferumoxytol SWI (TE=16ms) (C).

Data collected in collaboration with Yulin Ge and NYU.

Ferumoxytol enhanced MRAV

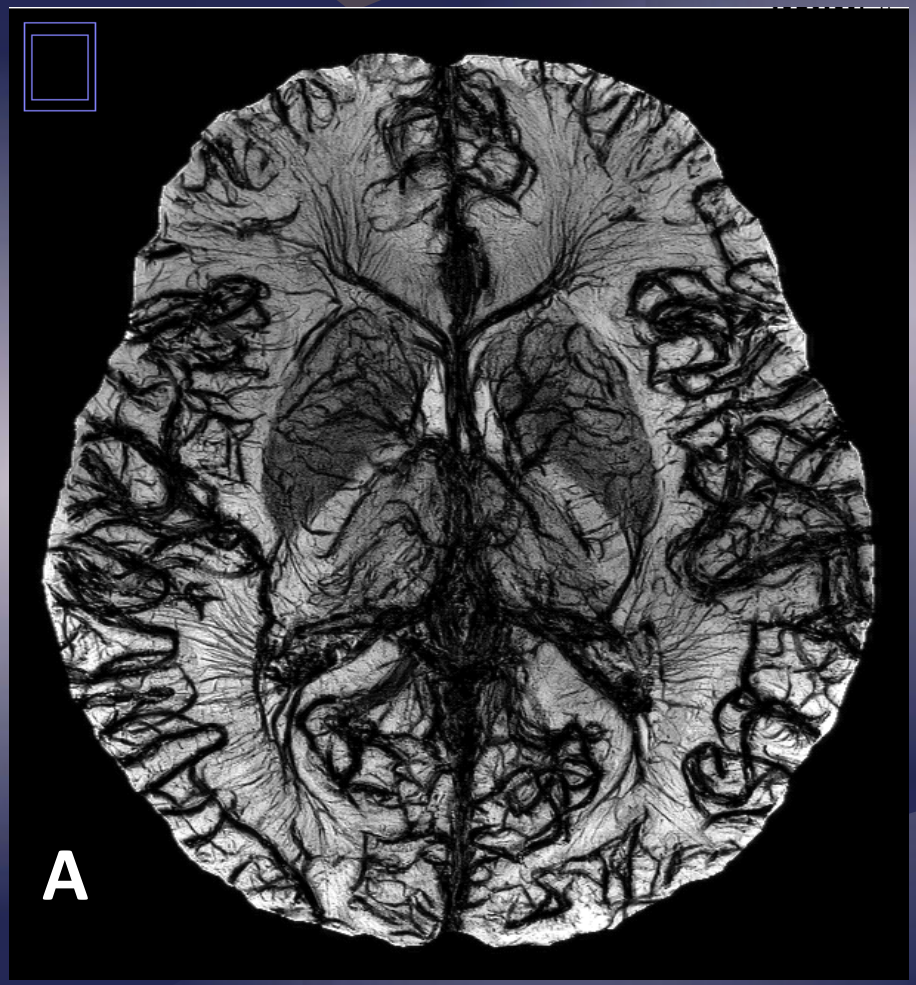
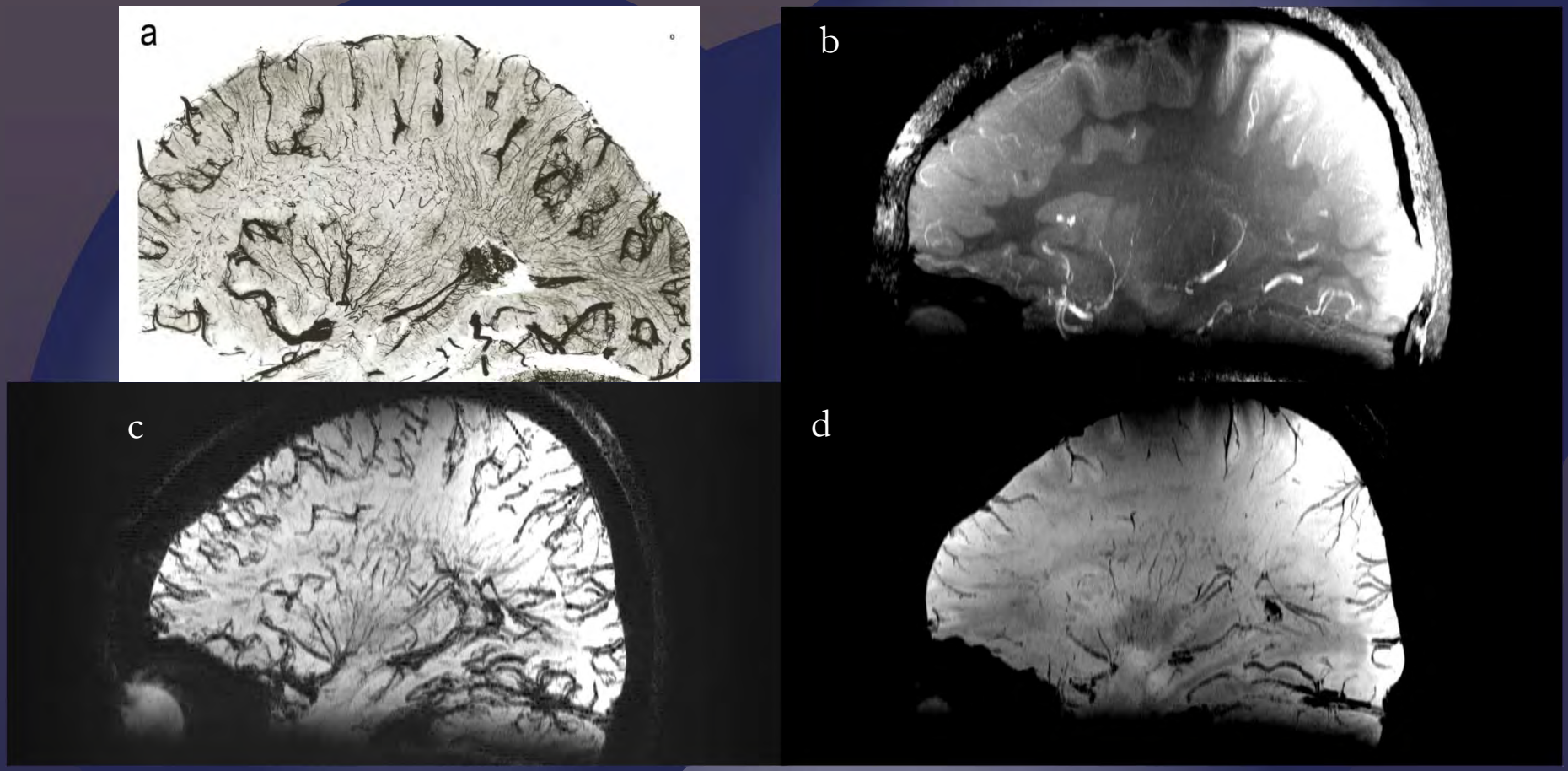


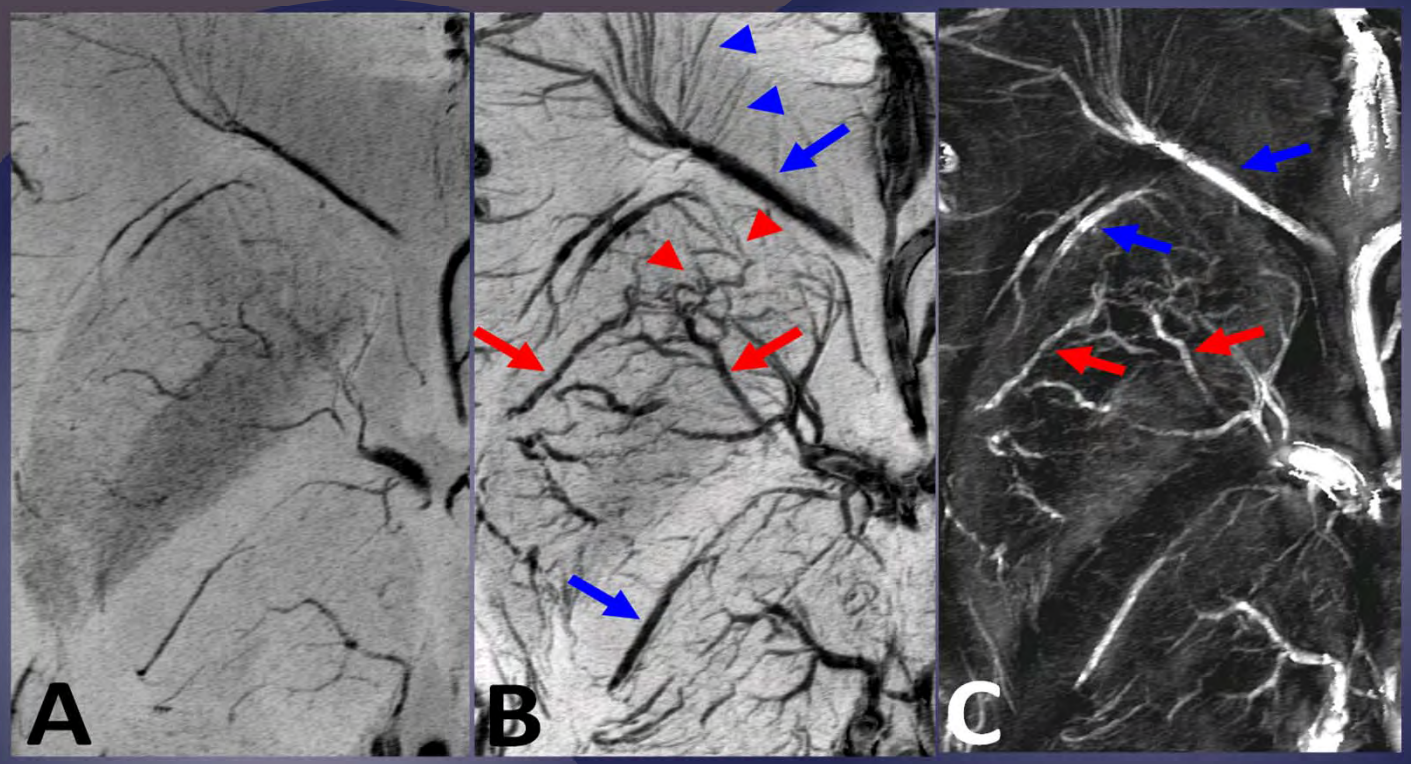
Image courtesy of Yulin Ge and NYU.

Comparison of MRAV using SWI and cadaver brain dye injection.



a) Georges Salamon's image of arteries in the human brain. b,c,d) Data from TE = 8ms with 0.1mm x 0.2mm x 1.25mm at 7T. b) MRA pre-contrast, c) mIP post-contrast SWI for 4mg ferumoxytol and d) mIP pre-contrast. Note that c) is a mixture of arteries and veins. However, the thalamic arteries are clearly highlighted in the post-contrast image. Image d) can be used as a guide as to where the veins are since it is a pre-contrast SWI.

Ferumoxytol enhanced MRAV



Pre-contrast SWI (TE=8ms at 7T) **(A)** only shows veins. Post-Ferumoxytol (2mg/kg) SWI **(B)** shows both veins (blue arrows) and arteries (red arrows) including small arterioles (red arrowhead) and venules (blue arrowhead). Post-contrast QSM **(C)** shows higher susceptibility values (blue) in veins than arteries (red). MICRO MRI was performed at TE = 8ms with a resolution of 110 μm x 110 μm x 1.25 mm.

Data collected in collaboration with Yulin Ge and NYU.

R2* (blooming) changes in the smallest of vessels in the putamen (from the subtraction of pre-post images)