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Neuro-Microvascular Imaging at 1,5T Using the Flow Sensitive Black Blood Technique

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Introduction

Cerebral magnetic resonance angiography (MRA) at 1.5T is generally limited to the time-of-flight (TOF) technique which is most widely used for the visualization of macrovasculature in intracranial arterial diseases. The TOF technique at 1,5T has spatial and contrast resolution limitations for visualizing slow-flow arterial branches mainly because of spin saturation and relatively short T1.

Current neuro-imaging techniques based on computed tomographic angiography or digital subtraction angiography have been used to investigate vascular pathophysiology. However, the study of microvascular diseases in vivo has been restricted by their inherent invasiveness.

Lenticulostriate arteries (LSAs) are one of the most important microvascular structures in the human brain as they supply blood to the basal ganglia (Fig. 1) where ischemic and hemorrhagic cerebral strokes often occur. The LSAs are end arteries that have little or no collateral circulation.

LSA branches can be clearly observed using digital subtraction angiography, though this technique is invasive. Recently, LSA branches have been successfully visualized with 7T MR imaging by using time-of-flight MRA[1,3]. Some relationships between decreased LSA visualization and hypertension or infarction at the basal ganglia and/or its vicinity were demonstrated[3]. However, the availability of 7T MR imaging systems is very limited, and they are currently used for research purposes only.

There is a great need for imaging the microvasculature in the brain for the early detection of cerebrovascular strokes in routine clinical practice and for research purposes. However, the literature agreed

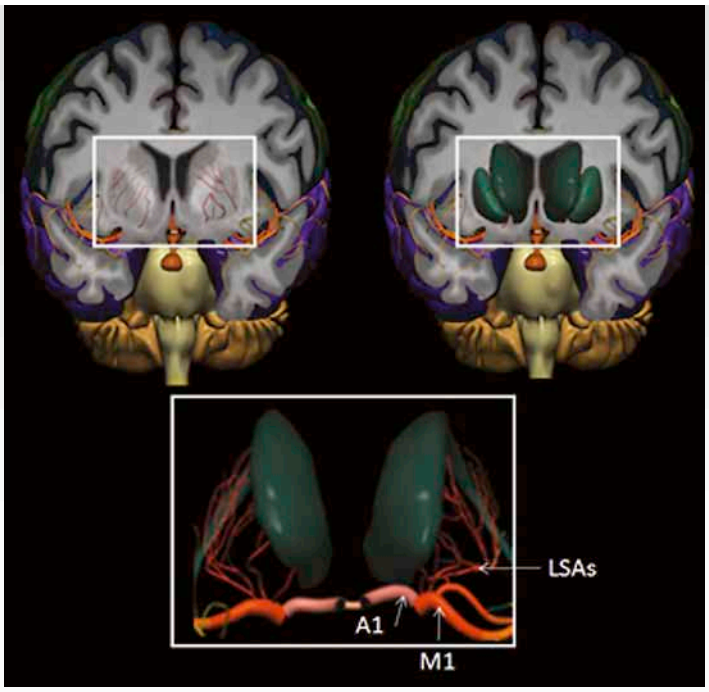

Fig. 1: Lenticulostriate Arteries anatomy. The horizontal M1 segment gives rise to the (lateral) lenticulostriate arteries which supply part of head and body of caudate, globus pallidus, putamen and the posterior limb of the internal capsule. Often the medial lenticulostriate arteries arise from the A1-segment of the anterior cerebral artery.

that non-invasive imaging of cerebral microvasculature such as the LSAs requires ultra-high MR field strength (7T) and could not be realized at lower field strengths (1,5T nor 3T)[1–3].

Flow sensitive black blood imaging

FSBB is a high resolution 3D gradient echo technique which, unlike Susceptibility Weighted Imaging (SWI), uses a weak Motion Probing Gradient (MPG) pulse that dephases the water signals of the flowing blood and has no effect on the water signal in stationary tissues[4, 5].

SWI is based on high resolution, three-dimensional (3D), fully velocity-compensated gradient-echo sequences using both magnitude and phase images. A phase mask obtained from the MR phase images is multiplied with magnitude images in order to increase the visualization of the smaller veins and other sources of susceptibility effects. The images are then displayed using the minimal intensity projection (minIP). Because the image contrast in SWI is mainly based on the susceptibility effect SWI is more successful at high (3T) and ultra-high (7T) field strengths. Furthermore, phase disturbance is observed mainly in the vein and therefore not suitable for arterial microvasculature imaging.

With FSBB the signal from rapidly flowing blood is attenuated by applying a very weak MPG for signal dephasing, which mainly attenuates the signal from rapidly flowing blood in the artery, while the signal from stationary or slow-moving components is not or much less affected. Since this technique does not rely only on susceptibility effect only, it can be successfully used at standard (1,5T) field strength (see Fig. 2).

Being a 3D gradient echo technique, FSBB can, like SWI, benefit from the susceptibility effect useful for venous signal visualization. When a long TE value is used (~40 ms) the T2* effect is increased and the venous signal is attenuated which allows a good contrast with the parenchyma. The typical parameters for susceptibility oriented FSBB are: TE: 40 ms, TR: 50 ms, FA: 20, MPG pulse b-factor = 4 s/mm^2 acquisition matrix size = 256 x 224, FOV 205 x 179 mm in one axial 3D slab of 160 slices. The scan resolution is 0.8 x 0.8 x 0.8 mm (reconstructed into 0.4 x 0.4 x 0.4 mm in order to increase apparent resolution) for a scan time of ~6,5 minutes.
A shorter TE value (~20 ms) and a lower b-factor would minimize the T2* effect and be more favorable to arterial imaging while minimizing the venous/parenchyma contrast allowing a better artery/veins discrimination (see Fig. 3). The common imaging parameters are TR = 29 msec, TE = 20 ms, flip angle = 20°, MPG pulse b-factor = 2 s/mm^2 acquisition matrix size = 256 x 224, FOV 205 x 179 mm in one axial 3D slab of 160 slices. The scan resolution was 0.8 x 0.8 x 0.8 mm (reconstructed into 0.4 x 0.4 x 0.4 mm in order to increase apparent resolution) for a scan time of ~6,5 minutes.

Clinical evaluations

T. Kodama and co-authors[6] from the university of Miyazaki (Japan) compared FSBB to SWI in the visualization of venous malformation (VM), arteriovenous malformation (AVM) and dural arteriovenus festulas (dAVF) using a 1.5T Vantage ZGV Atlas. They showed that VMs were more clearly visualized on FSBB images than SWI. They found that small VMs could be missed on SWI images. In some

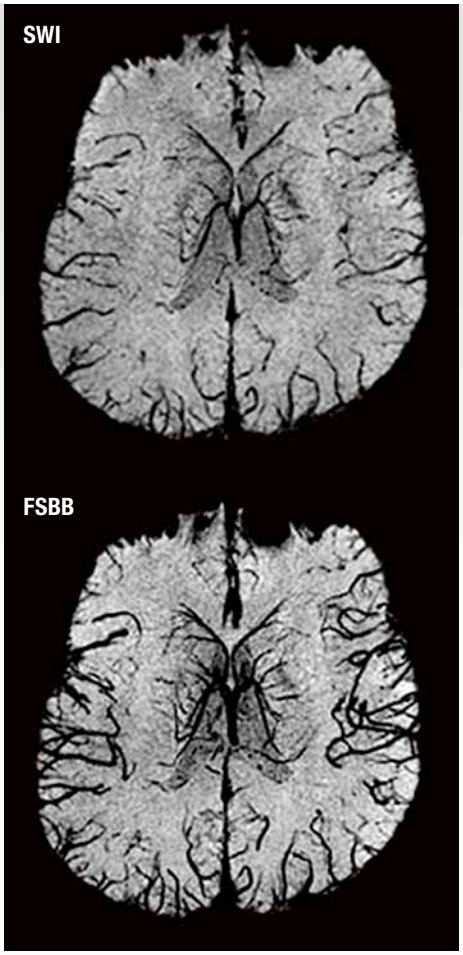

Fig. 2: Comparison between minIP SWI image (left) and minIP FSBB image (right) in a healthy volunteer scanned at 1.5T. Note the increased vessel/parenchyma contrast in FSBB.

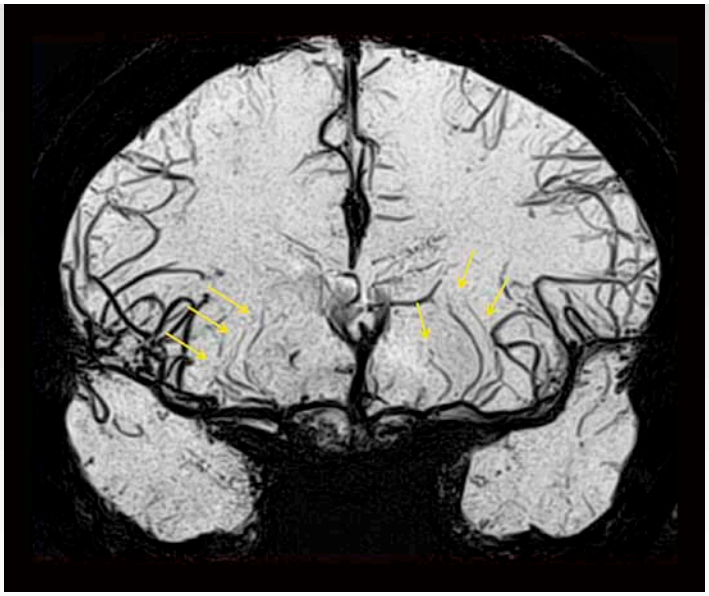

Fig. 3: FSBB image (minIP) clearly showing the LSAs (yellow arrows) at 1,5T field strength in a healthy volunteer.

cases, portions of draining veins could not be clearly visualized on SWI images. Their findings suggested that direction of vessels in respect to that of the magnetic field affected their visualization on SWI images. Furthermore, they found that drainage veins of AVMs and dAVFs can be hyperintense on SWI images probably because of their arterialization due to the arteriovenous shunt. Even though SWI has flow compensation, feeding arteries sometimes showed signal loss. On FSBB images, all of arteries, niduses, veins, and hemorrhagic lesions appeared as "black" structures. In five patients with AVM or dAVF, prominent venous structures other than drainage veins were clearly noted on FSBB images. These veins seemed to reflect hemodynamic changes such as venous congestion, collateral circulation, and steal phenomenon associated with the AVM and dAVF.
V. Sawlani and co-authors[7] from Morriston and Singleton hospitals ABM university NHS trust (UK), showed the potential of the FSBB technique on a 1.5T Vantage XGV Atlas system in several cerebral vascular diseases: FSBB was found a useful tool in imaging hemorrhages from trauma, visualizing blood products, venous sinus thrombosis but also in neuro-oncology (see Fig. 4). The microvasculature and hemorrhage of the tumor could be depicted with FSBB. These findings demonstrate the potential of FSBB in tumor grading and in therapy monitoring.

K. Gotoh and co-authors from Kyoto University Graduate School of Medicine, Kyoto (Japan), compared FSBB to TOF in the visualization of the LSAs in 21 healthy subjects (age range 19–44 years)[8, 9]. They found in[9] a total of 145 LSA branches visualized with FSBB while only 66 branches were visualized with TOF. All the LSAs visualized with TOF were also visualized with FSBB. The images were evaluated in terms of number, length, and image quality at origins and distal areas of visualized LSA branches. In all evaluated terms, FSBB was significantly better than TOF.

In a very recent study S. Okuchi and co-authors[10] from Kyoto University Graduate School of Medicine, Kyoto (Japan), examined the correlation of LSA imaging findings using FSBB in patients with lacunar infarction compared with age matched controls. They prospectively enrolled fifteen patients (9 men, 6 women, mean age 73 years) with infarction at the basal ganglia and/or its vicinity, and 12 age-matched control subjects (6 men, 6 women; mean age, 68 years). The authors found that patients with stroke had significantly fewer LSA branches (average 6.3; 95 % CI, 5.4–7.1) than controls (8.7; 95 % CI, 7.8–9.5) (P = .0003). The total LSA lengths were 117 mm (95 % CI, 96–138 mm) for patients with stroke and 162 mm (95 % CI, 133–91 mm) for control subjects (P = .01). Only the LSA branch numbers were significantly related to infarction while only hypertension was significantly related to total LSA length.

Discussion and future work

Microvascular brain damage is mainly assessed by imaging the microbleeds (MB) and not by studying the microvasculature itself as this was not possible in-vivo at clinical MR field strength (≤3T). However, at ultra-high field strength (≥7T) it has recently become possible. Therefore, there is a growing interest in studying the microvasculature in small vessel disease and neuro-degenerative disease, during life, at ultra-high field. Unfortunately,

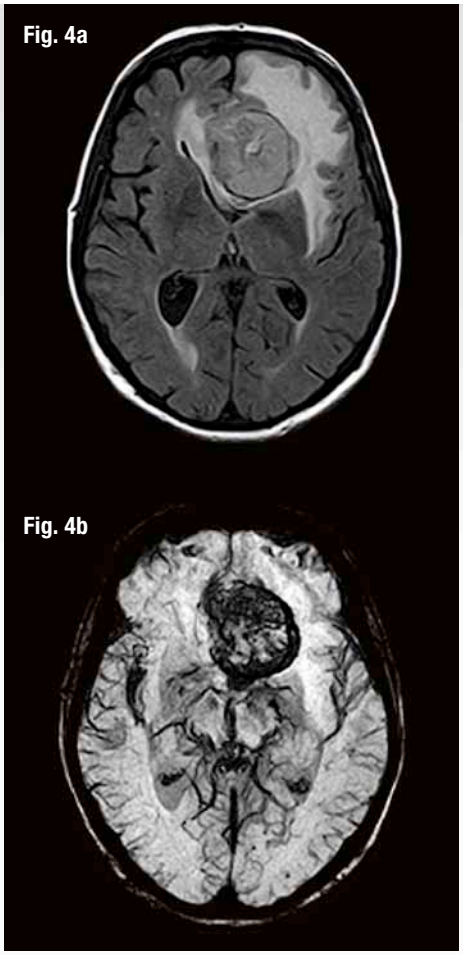

Fig. 4: Primary glioma with hemorrhage
a) Flair image
b) minIP FSBB image showing complex microvasculature of the tumor

(Courtesy of Dr V. Sawlani, Morriston and Singleton hospitals ABM University NHS trust)

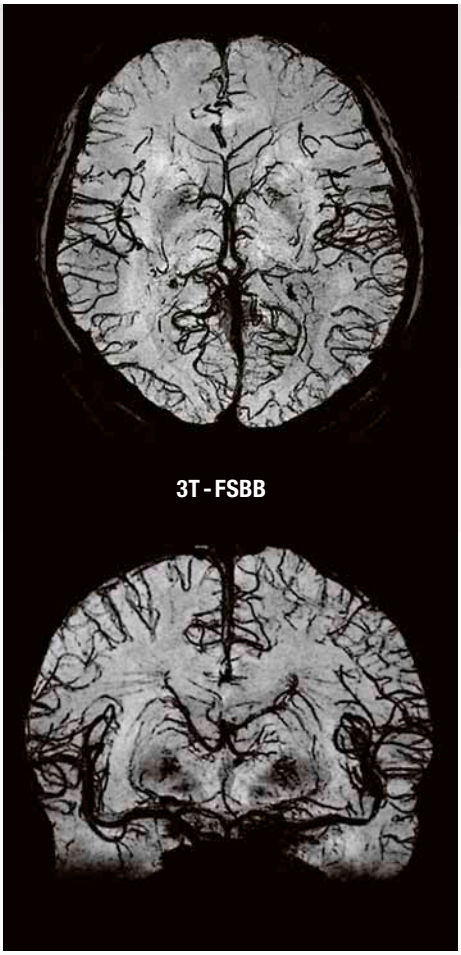

Fig. 5: FSBB images (minIP) acquired on Titan 3T. Note the increased spatial and contrast resolution.

ultra-high field MR scanners are still research systems not cleared yet for clinical routine use. Therefore 7T MR systems are not widely available; making it difficult to run large scale (multi-center) clinical studies at present time.

FSBB is a new MR angiography technique that allows the visualization of the cerebral microvasculature at clinical MR field strength (1,5T and 3T). This technique is made available to the wider research community and can benefit all patients having access to standard clinical MR scanners.

The FSBB technique was successfully used at 1.5T to visualize the microvasculature of AVMs, brain tumors, and even lenticulostriate arteries in healthy volunteers and stroke patients.

It is a promising technique and the increased spatial resolution at 3T, down to 0.3 mm or less (see Fig. 5) opens the way to new clinical applications such as small vessel and/or degenerative diseases (vascular dementia, Alzheimer's diseases, Multiple sclerosis, etc.).

Toshiba has recently proposed a hybrid version[11], called Hybrid Opposite contrast MRA, combining both TOF and FSBB is a dual echo 3D gradient echo technique for a bright blood visualization of the microvasculature. K. Tsuchiya and co-authors from Kyorin University Faculty of Medicine,Tokyo (Japan), showed in their initial experience a great potential of this technique for the visualization of collateral micovasculature in major trunk steno-occlusive diseases[12].

Toshiba is continuously working on further optimization and innovation in cerebrovascular imaging[13]. Exiting clinical studies are taking place at luminary sites and more clinical evaluations of these innovative techniques are to be expected.

References

[1] Cho ZH, Kang CK, Han JY, et al. Observation of the lenticulostriate arteries in the human brain in vivo using 7.0 T MR angiography. Stroke 2008; 39:1604–06

[2] Kang CK, Park CW, Han JY, et al. Imaging and analysis of lenticulostriate arteries using 7.0-Tesla magnetic resonance angiography. Magn Reson Med 2009; 61:136–4

[3] Kang CK, Park CA, Park CW, et al. Lenticulostriate arteries in chronic stroke patients by 7T magnetic resonance angiography. Int J Stroke 2010; 5:374–80

[4] Kimura T, Ikedo M, Furudate N, Takemoto S. Flow-sensitive susceptibility-weighted imaging. In: Proc Joint Annual Meeting, ISMRM-ESMRMB, Berlin; May 19–25, 2007:3015.

[5] Suchiya K, Tateishi H, Yoshida M, et al. Flow-sensitive susceptibility-weighted imaging of the brain: initial experience in ischemic lesions. In: Proc Joint Annual Meeting ISMRM-ESMRMB, Berlin; May 19–25, 2007:3016.

[6] Kodama T, Yano T, Tamura S, et al. Flow-sensitive black blood imaging for evaluating vascular malformations. In: Proceedings of the 17th Annual Meeting of ISMRM, Toronto, Canada, 2008. (abstract 3425).

[7] V. Sawlani, J. Spark, F. Admiraal-Behloul, Flow-Sensitive Black Blood Imaging: Clinical Intracranial Applications, In: Proceedings of the 20th Annual Meeting of ISMRM, Stockholm, Sweden, 2010. (abstract 2263).

[8] Gotoh K, Okada T, Miki Y, et al. Visualization of the lenticulostriate artery with flow-sensitive blackblood imaging in comparison with time-of-flight MR angiography. In: Proceedings of the 17th Annual Meeting of ISMRM, Toronto, Canada, 2008. (abstract 2893).

[9] Gotoh K, Okada T, Miki Y, et al. Visualization of the lenticulostriate artery with flow-sensitive black-blood acquisition in comparison with time-of-flight MR angiography. J Magn Reson Imaging 2009; 29:65–69

[10] Okuchi S, Okada T, Ihara M, et al. Visualization of Lenticulostriate Arteries by Flow-Sensitive Black-Blood MR Angiography on a 1.5T MRI System: A Comparative Study between Subjects with and without Stroke. AJNR Am J Neuroradiol. 2012 Oct 11. [Epub ahead of print]

[11] Kimura T, Ikedo M, Takemoto S. Hybrid of opposite-contrast MR angiography (HOP-MRA) combining time-of-flight and flow-sensitive black-blood contrasts. Magn Reson Med. 2009 Aug; 62(2):450–8.

[12] Tsuchiya K, Kobayashi K, Nitatori T, et al. Hybrid of opposite-contrast MRA of the brain by combining time-of-flight and black-blood sequences: initial experience in major trunk steno-occlusive diseases. J Magn Reson Imaging. 2010 Jan; 31(1):56–60.

[13] Kimura T, Ikedo M, Takemoto S. Phase enhancement for time-of-flight and flow-sensitive black-blood MR angiography. Magn Reson Med. 2011 Aug; 66(2):437–47.

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