In Vivo Micro-MRA of the Cat Intracortical Vasculature at 9.4T

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Introduction

The study of cerebral vasculature is important for many clinical and research applications. The large surface vessels, typically > 100 µm, are commonly imaged with magnetic resonance angiography (MRA) techniques, using either exogenous contrast agents or flow-sensitive methods such as phase-contrast or time-of-flight (ToF) angiography. The intracortical vessels are generally too small to be directly visualized. While principal intracortical veins, which have diameters of 80-125 µm in humans (*1*) and penetrate perpendicular to the cortical surface, can be seen using T_2^*-weighted venograms (*2*), intracortical arteries have not been detectable in previously published reports of whole-head micro-MRA (*3,4*). In this work we describe a novel MR methodology that combines time-of-flight (inflow) angiography with exogenous contrast-enhanced susceptibility imaging to produce very high resolution angiograms in which penetrating arteries and veins are distinctly identifiable.

Methods

All experiments were performed on a 9.4T/31cm horizontal magnet (Oxford, UK) interfaced with a Unity Inova spectrometer (Varian, CA). A 1.4 cm diameter surface coil was used for RF transmission and reception. Cats (n=2, 1.4 Kg) were kept under isoflurane anesthesia (1% in a N_2O:O_2 mixture of 70:30) throughout the experiment, while blood pressure, end-tidal CO_2, and body temperature were maintained at normal conditions. T_1-weighted 3D FLASH imaging was performed in the axial orientation with FOV 20 x 20 x 5 mm, matrix 256 x 256 x 24, TR/TE = 32/5.5 ms, nominal flip = 60 degrees, and NEX = 4. This sequence provides strong T_1-weighting for inflowing spins and sufficient T_2^* weighting to enable differentiation of arteries and veins based on oxygenation levels, and produces a image with resolution of 78 x 78 x 208 µm in 13.25 minutes. The slab position was adjusted to maximize inflow effects in the small arteries perpendicular to the axial slab. Imaging was repeated following a bolus injection of MION (10mg Fe/kg). Image reconstruction and volume rendering was performed using Matlab (Natick, MA) and Amira (TGS, CA).

Results

Figure 1 shows axial and coronal views from pre-MION and post-MION images of the marginal gyrus. Numerous vessels are visible in the post-MION images (b, e). Based on the signal intensity in the pre-MION images (a, d), vessels were identified as arteries and veins and illustrated in Fig. 1c and f. A volume reconstruction from the same data set (Fig. 2) shows the efficacy of MION-subtraction MRA for visualization of the full cerebral vascular system.

Discussion

The careful combination of both T_1- and T_2^*- weighting in the pre-MION image provides sufficient contrast with the cortical tissue to identify and distinguish both arteries and veins. Arteries are bright due to fast flow perpendicular to the slice orientation; veins are dark due to slower flow (thus a reduced inflow effect) and lower oxygenation. In the post-MION image, both arteries and veins appear dark because the strong magnetic susceptibility artifact becomes dominant, making variations in flow rates and oxygenation negligible. While most vessels were detectable in the pre-MION image, the MION greatly increases their visibility by producing and/or expanding the void artifact that extends into the surrounding cortical tissue. Although the T_2^* effect varies with the angle of the vessel relative to B_0, in this orientation the penetrating vessels are nearly perpendicular with the B_0 field, which maximizes the susceptibility contrast. This technique of combining the inflow effect with T_2^*-weighting provides a fast, highly sensitive method of performing micro-MRA, with the additional specificity of being able to distinguish arteries from veins. This can complement existing MR methods in many applications involving cerebral microvasculature, including fMRI, stroke, and angiogenesis.

References

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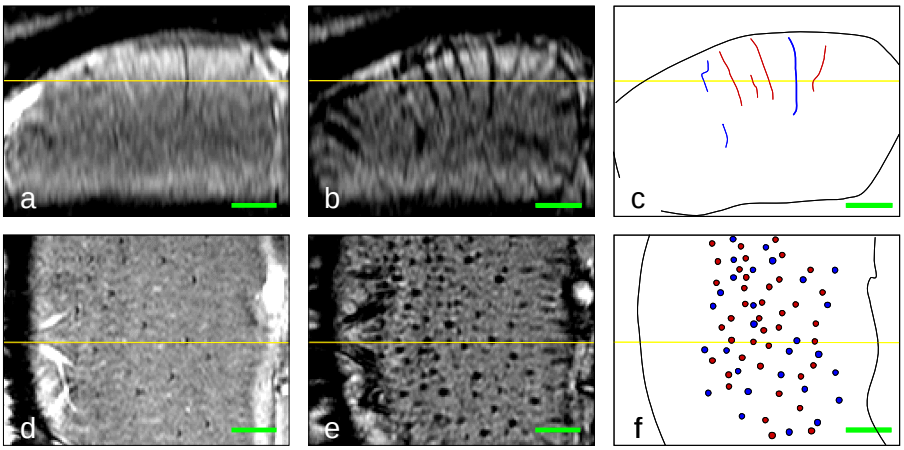

Figure 1. Coronal (a, b) and axial (d, e) slices from 3D images, zerofilled to 39µm isotropic resolution, acquired pre-MION (a, d) and post-MION (b, e). The green bar indicates 1 mm. The yellow line in the upper row indicates the position of the axial slice in the lower row, and vice versa. Drawings (c) and (f) indicate penetrating vessels that can be identified as arteries (red) and veins (blue).

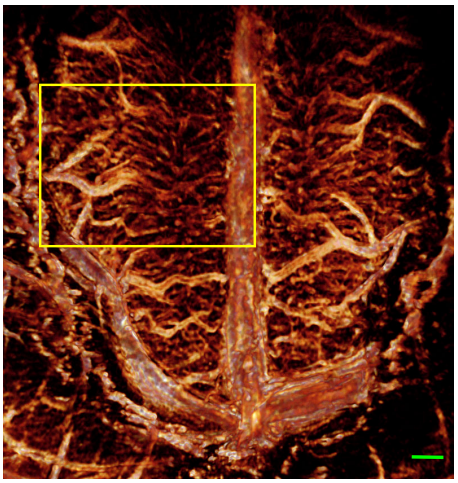

Figure 2. Dorsal volume reconstruction of the MION-subtraction angiogram. The green bar indicates 1mm. The yellow box delineates the region shown in Figure 1.