High contrast and high resolution in vitro Susceptibility Weighted Imaging (SWI) at 7 Tesla

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Introduction:

Susceptibility Weighted Imaging (SWI) is an imaging technique that combines both magnitude and phase information to enhance contrast of structures that have different magnetic susceptibility compared to the surrounding tissue [1]. Up to now, SWI has mainly been used to visualize venous vessels of the human brain, but recently it was shown in vivo that high resolution SWI at high fields reveals small anatomical structures such as laminae of the cortex [2]. Within this study we tried to exploit the rich anatomical information that is present in the contrast of SWI scans with the main focus on visualization of small anatomical structures and vessels of a formalin-fixed human brain and the comparison to a standard anatomical atlas.

Material and Methods:

MRI: The measurement was performed on a 7 Tesla whole body MR scanner (Siemens, Germany) with a quadrature transmit/receive extremity coil (Invivo Corp., USA). 14 SWI measurements (44:28 min/measurement) were performed using a 3D gradient-echo (SWI) sequence on a formalin-fixed human brain with the following sequence parameters: TE = 15.8 ms, TR = 31 ms; matrix = 448 x 448 pixel; 256 slices; resolution = 0.4 mm isotropic. An isotropic resolution was chosen to improve data reslicing in all views and to provide ideal conditions for automatic processing, e.g. vessel segmentation. SWI image processing was performed by using phase unwrapping and a Gaussian filter kernel (fwhm 6mm in image space) for phase filtering and two phase mask multiplications for contrast enhancement. A MPRAGE sequence with: TR/TI/TE 1500/900/1.9 ms; averages = 20; resolution = 0.4x0.5x0.5mm^3; TA = 4:12 hours was used to acquire T1-weighted images.

Automatic Vein Segmentation: For automatic vein segmentation the technique introduced by Koopmans et al. [2] was applied to the SWI magnitude data. In brief, this involves the combination of a vesselness filter and a vessel enhancing diffusion (VED) filter. VED is an iterative process which improves the vesselness filter output by applying diffusion in the direction of the tubular structures (a detailed description can be found in [2]).

Results:

The performance of SWI venography is demonstrated in Fig. 1 where the sub region (marked with the white rectangle) is displayed in the upper frame (blue) without SWI processing and in the lower frame (red) after SWI processing and Minimum Intensity Projection (MIP) over 2 mm. For anatomical comparison, brain atlas data reprinted from [3] was used on the left side of Fig. 2 and Fig. 3. Fig. 2 shows a slice through the basal ganglia. Note the clear separation of the internal/external parts of the globus pallidus (marked with red arrows), the internal structure of the putamen (yellow arrow) and the caudate nucleus (blue arrows) which is separated from the putamen by the internal capsule (green arrows). A transverse section through the midbrain showing the location of the red nuclei and the substantia nigra is shown in Fig. 3. The result of automatic vessel segmentation is presented in Fig. 4 with vessels overlaid using a 2 mm projection.

Discussion and Conclusion:

The ability to visualize deep brain structures and veins, using SWI, with excellent contrast was demonstrated as well as the possibility of automatic vessel segmentation. In this in vitro experiment, care was taken to minimize artifacts caused by air bubbles and large blood vessels. Contrast of anatomical structures was more pronounced on T2* weighted images compared to T1 weighted images. Phase contrast revealed additional structures in regions of the basal ganglia, the midbrain, and the brainstem. As most of the structures could already be seen on the images of one single measurement (~45 minutes), this holds promise that similar contrast and resolution can be achieved in vivo when using multi-channel coils. More accurate planning for the implantation of stimulation electrodes into the subthalamic nucleus of Parkinson disease patients is one potential application for this high resolution measurement.

References:

1) Haacke EM. et al. Magn Reson Med. 2004 Sep;52(3):612-8.
2) Koopmans PJ. et al. MAGMA. 2008 Mar; 21(1-2):149-58
3) BrainMaps.org

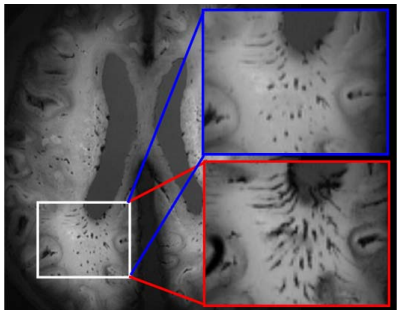

Fig. 1: SWI demonstration: blue frame: no SWI processing; red frame: SWI processing plus MIP over 2mm.

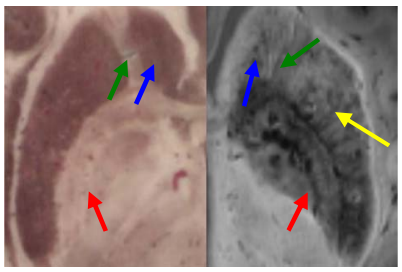

Fig. 2: slice through the basal ganglia: Note the very clear separation of the internal/external parts of the globus pallidus (red arrow) on MRI data.

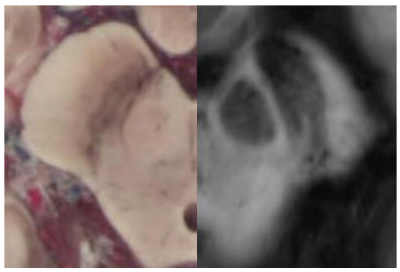

Fig. 3: Visualisation of the red nuclei and the substantia nigra.

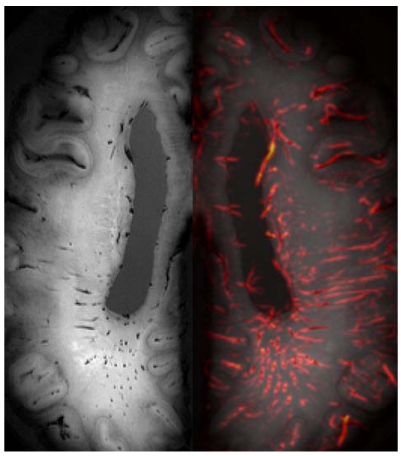

Fig. 4: Example for automatic vessel segmentation: left: SWI magnitude image; right: the same hemisphere overlaid with automatically segmented vessels.