Toward high resolution anatomical imaging of large ex vivo brain samples with specialized 9.4T RF coils

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INTRODUCTION

The investigation of small human tissue samples post mortem in pre-clinical MRI systems (animal scanners or spectroscopy systems) has brought important information on fundamental neuroanatomy at the mesoscale. Recently, this has been extended to diffusion imaging, with applications in both high-detail imaging of white matter tracts and in imaging gray matter circuits and layers. For instance, a high resolution 3D atlas of the human brain stem could be created [1]; cortical layers in primary motor (M1) and primary sensory (S1) cortex could be distinguished and the areal boundary identified [2]; cerebellar cortical layers could likewise be discriminated and the trajectory of most of its mesoscale circuit-fibers could be reconstructed [3]; finally, layer-specific intracortical connectivity in human V1 could be modeled [4]. All these studies were limited to relatively small tissue samples that fit preclinical gradient and RF coils systems. Here, we test extending high resolution post mortem diffusion MRI to larger tissue samples by moving to a large-bore human 9.4T MRI system and using custom-built RF-coils specific to moderate and large sample sizes. As a first proof of principle we designed and built a 9.4T RF-coil for imaging moderately sized specimens that fit a standard 4 cm Petri dish. The target was to achieve white matter and gray matter fiber orientational modeling from diffusion MRI at resolutions better than 300 µm in a cat brain sample which would be difficult to achieve in a larger coil designed for imaging the human brain in vivo.

METHODS AND MATERIALS

The constructed 'Petri dish coil' consists of a single conformal receive coil (Rx) and a separate transmit coil (Tx) in quadrature [**Fig. 1** (**L**)]. This allows us to create uniform B_1^+ and B_1^- fields and high SNR. The sample is placed inside the 4,2cm diameter Rx coil, allowing for a close Rx coil fit. The Tx coil is 8cmx4cm in size and was etched on a standard 1.5mm single-sided printed circuit board. The (orthogonal) quadrature geometry required no further passive detuning on the Rx coil. The sample used for MR imaging was an 8mm thick coronal section of a formalin fixed cat brain embedded in phosphate buffered solution (PBS) and 1% sodium azide. Diffusion MR images were acquired at 250µm isotropic using a 3D pulsed-gradient spin echo (PGSE) sequence (TR/TE = 400ms/48ms, FOV = 40mm, b-value = 2844mm/s^2, 48 directions + 2 b0's) in an investigational 820mm bore human 9.4T magnet equipped with an 80mT/m maximum amplitude gradient set (Siemens MAGNETOM 9.4T with AC84mkII).

RESULTS

Once in the scanner, an excitation voltage of 32V was required to achieve a 90° flip angle in the Region of Interest (ROI), with uniform B1+ field in the full sample, necessary for spin-echo imaging. The high SNR achieved resulted in 250µm diffusion MR images of the whole sample, suitable for orientational modelling with the diffusion tensor model in the full sample **[Fig 1R, 2L]**. Tractography of large white matter tracts such as the corpus callosum could be performed with deterministic tractography **[Fig. 2R]**. The layered structure in the feline cortex is visible in the mean diffusivity maps (MD) with higher MD in more superficial layers [**Fig. 3**] and dominant diffusion orientations showing radial (deep gray matter) and tangential (superficial gray matter, putative layer I) intracortical fiber orientations **[Fig. 3R].**

CONCLUSION AND DISCUSSION

The custom built coil achieves high resolution diffusion MRI of both white and gray matter in a large bore 9.4T MRI system with gradient performance an order of magnitude below that of small bore pre-clinical systems. The 250µm resolution achieved allows delineation of intracortical fiber orientations even in very thin superficial layers. Future analysis work will include more sophisticated data modelling, including multiple fiber orientations per voxel. This project shows the value, for high resolution post mortem diffusion MRI, of building specific coils optimized for a target sample size. Future work will include the realization of phased array RF coils for larger post mortem sample sizes (~8x8x8cm[**Fig.4**]) too large for preclinical systems.

REFERENCES

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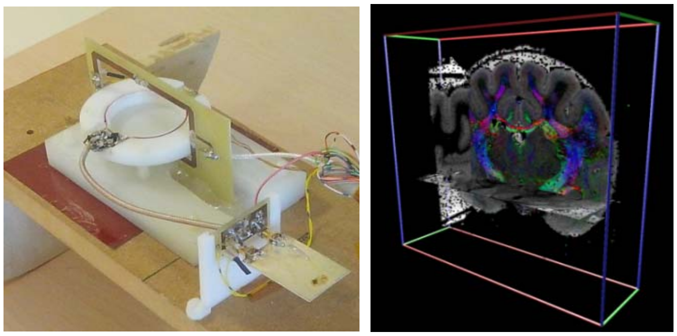

Fig. 1 (**L**): *The assembled coil, with Tx coil oriented perpendicular to the Rx coil* (**R**): *Overview of coronal cat brain tissue slab with 3 orthogonal sections through the DTI MD map and direction colour coding on coronal section*

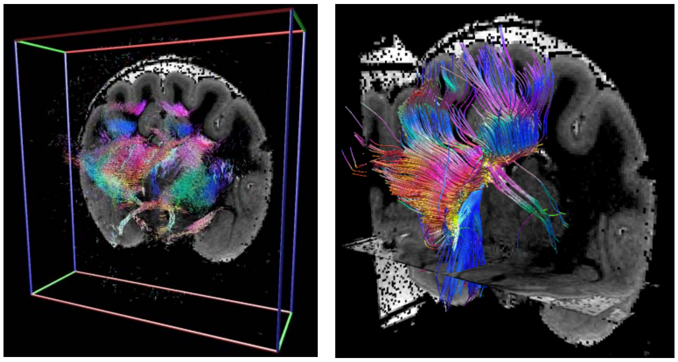

Fig 2 (**L**): *3D rendering of local fiber orientations using DTI superimposed on a coronal MD map* (**R**): *Tractography of the corpus callosum*

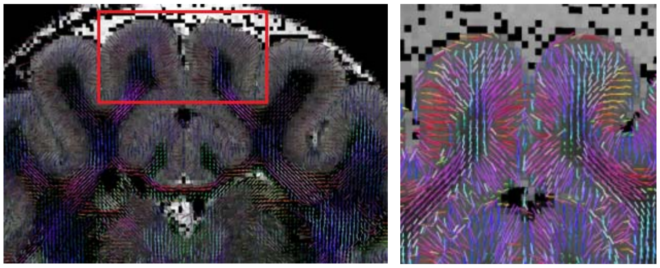

Fig. 3: *Magnified detail of a coronal section of dominant fiber orientations in cortex superimposed on an MD map*

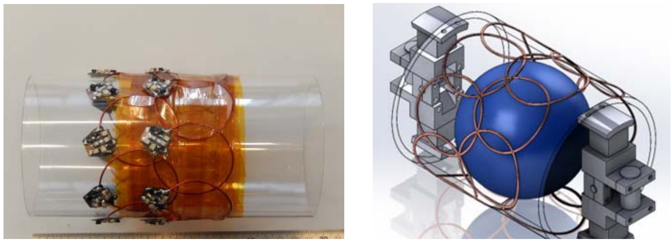

Fig. 4 (**L**): *A 16 ch 9cm diameter phased array receiver layout for larger samples* (**R**): *Rendering of a gimbal device for 2-axis rotation for magnetic susceptibility imaging and diffusion imaging of spherical samples.*