A 7T Coil System for Imaging Humans in the Sphinx Position to Evaluate the Effect of Head Orientation Relative to B0 for MR Imaging

B. Zhang[1], R. Brown[1], C. Wiggins[2], D. K. Sodickson[1], B. Stoeckel[3], and G. Wiggins[1]
[1]Center for Biomedical Imaging, Department of Radiology, New York University School of Medicine, New York, NY10016, United States, [2]CEA/NeuroSpin, Saclay, France, [3]Siemens Medical Solutions USA Inc, New York, NY, United States

Introduction: At 7T the B_0 field has a strong effect on MR imaging. T2* weighted gradient echo scans have revealed surprising variation in image intensity in white matter [1]. Various mechanisms have been proposed, including differences in iron concentration or myelin density in various white matter fiber bundles or variation in density and orientation of venous micro-vascular elements [1]. Tissue orientation relative to the main magnetic field has been demonstrated to be a major component of the white matter contrast variation in high field animal brain T_2^* imaging [2]. Although the effect is smaller at lower field, it has been evaluated in 3T human brain imaging, where it is suggested that T2* varies according to $sin^2(\theta_z)$ in fiber bundles [3]. In addition, strong B_0 gradients at air-tissue interfaces such as under the frontal lobe make it difficult to image some regions.

We have constructed a coil system at 7T which allows the head to be rotated by greater than 90 degrees to further investigate this phenomenon. In order to make full use of the limited space available in the standard 60cm diameter bore 7T scanner (Siemens Healthcare, Erlangen Germany) we have chosen to use traveling waves excited by a patch antenna as our RF excitation [4], effectively using the traveling wave as a body coil, allowing greater flexibility in the design of receive-only arrays. Although traveling wave excitation is difficult to control, it can provide as good or better B1+ uniformity in the head compared with a standard volume coil excitation [5]. To obtain images with the brain in substantially different orientation relative to the B_0 field than in usual experiments, we place the subject in the "sphinx" position with face towards the patch antenna. Since the receive sensitivity of traveling waves is very low compared to local receive coils [6], a six-element U-shaped receive coil was built to wrap over the crown of the head providing sufficient SNR for high resolution T_2^* imaging. We explore the orientation dependence of T_2^* contrast in white matter by comparing data obtained in the sphinx position or in regular head-first prone position. We also explore the different B_0 distributions in the brain in these patient positions.

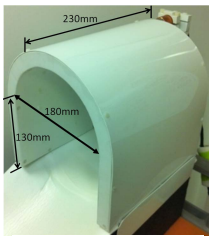

Fig. 1: U-shaped receive head coil

Methods: A patch antenna with quadrature input ports was built based on FDTD simulation [7]. The patch antenna was placed just inside the service end of the bore, with the feed points in the upper half of the disc. A U-shaped head coil 180mm wide and 220mm tall was built for signal reception (Figure 1). 6 coil elements of 140mm ×100mm are mounted on the curved former. A preamp interface board (Siemens Healthcare, Erlangen, Germany) with an active detuning circuit and fuse were mounted directly at the terminals of each coil element. Additional detuning was provided by a passive detuning circuit located opposite from the active detuning circuit. Adjacent elements were overlapped to minimize the coupling. To reduce interaction between the traveling wave excitation and receive cable, receive signals were carried through the bore to the system receivers using a cable bundle with cable traps every 150 mm. Since the traveling wave excitation consists of a TE11 mode, whose E-field is entirely transverse, the receive cable was routed along the bore's main axis, and transverse routing was avoided.

The patient table was retracted from the bore to accommodate the sphinx subject position where the subject lies prone and tilts the head upward such that the face looks along the magnet's main axis (Figure 2). The ratio of maximum local SAR to absorbed RF power obtained in FDTD simulation was used to adjust the SAR limits for in vivo scanning. Power deposition was measured using a 120 mm diameter cylindrical gel phantom (conductivity=0.6 S/m, relative permittivity=52) with four fluoroptic probes (Luxtron, Santa Clara CA). The transmit excitation was calibrated with a long RF pulse 2D GRE sequence at a number of RF pulse amplitudes (TR/TE=1000.00ms/8.1ms, Slice=5mm, BW=200.0, 64×64 matrix, FOV=221×221, RF amplitudes from 50 to 350v and RF pulse length = 4mS). T_2^* brain images were then acquired with a 2D GRE sequence with the same RF pulse length (TR/TE=700.0ms/30.6ms, nominal flip angle = 45°, Slice=1.5 mm, BW=30.0Hz/pixel, 640×640 matrix, FOV=200 mm × 200 mm). A set of 15 images were acquired in coronal slices (with reference to the magnet coordinate system). After shimming, B_0 was mapped in the sagittal and transverse planes via 2D GRE images at TE = 4.08ms and 5.10ms (TR =209ms, Slice=5 mm, 128×128 matrix, FOV=220mm × 220mm, BW=230). The subject was then situated in the traditional supine position. T2* and B_0 mapping images were acquired in approximately matching locations using a 24-channel receive array with volume coil transmit (Nova Medical, Wilmington MA).

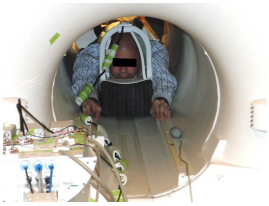
Fig. 2: Subject in the sphinx position, with the patch antenna removed

Results: Figure 3 demonstrates that the extra space afforded by removing the patient table allowed the subject to assume the sphinx position in which the head was rotated nearly 90° relative to the traditional position.. T2* -weighted images (Figure 4) show substantial reversal of contrast in many regions of white matter. B_0 maps of show a significant reduction of B_0 gradient over the nasal sinuses when the subject is in the sphinx position (Figure 5).

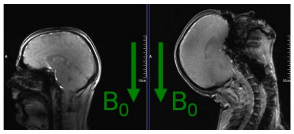

Fig. 3 Sagittal images (in scanner coordinates) with subject supine (left) or in sphinx position (right)

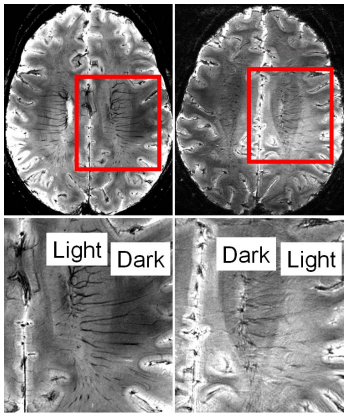

Fig. 5 T_2^* weighted GRE in supine position (left) and sphinx position (right). White matter contrast is reversed in the centrum semiovale when the B_0 orientation is changed.

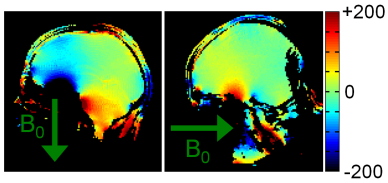

Fig.4 Sagittal B_0 maps (in patient coordinates) for supine (left) and sphinx position (right)

Conclusions: Using the full diameter of the bore allows for more flexible subject positioning which was exploited to explore the orientation dependence of T_2^* contrast in white matter. We also observe B_0 distribution dependence on brain orientation and show that the sphinx position offers significant reduction of B_0 gradient over the nasal sinuses. This should allow improved imaging of the frontal lobes and potentially imaging of the olfactory bulbs. Other potential applications include imaging the knee joint in a wide range of angular extensions and general use of the receive array for extremity and shoulder imaging in conjunction with traveling wave excitation. The reversal of contrast in various white matter locations suggests that tissue orientation relative to the static B_0 field is definitely a significant contribution to T_2^* contrast in white matter. Due to the inefficient nature of traveling wave excitation is has been necessary to use a very long RF pulse, limiting the nature of the sequences which can be run. While it would be possible to dispense with the traveling wave excitation and use the 6 channel array in a Tx/Rx mode, there are some drawbacks to this approach. When using a local coil for both transmit and receive, the simultaneous drop-off in transmit field and receive sensitivity outside of the coil creates fast signal drop off and limits the useful field of view. In addition, creating a reasonably uniform excitation with a U-shaped local transmit array would likely require B1 mapping and RF shimming, considerably complicating the experiment.

[1] Duyn et al. PNAS 104(26):11796-1180,2007 [2] Wiggins CJ, et al, ProcISMRM 2008 p237 [3] Bender B, et al, NMR Biomed, p1071-11076, 2010 [4] D.O. Brunner et al. Proc. ISMRM 2008 [5] Wiggins G, et al, ProcISMRM 2008 p434 [6] Andreychenko A, et al, ProISMRM 2010, p430 [7] Zhang B, et al, ProcISMRM 2008 p4746