9.4T Human Imaging: Preliminary Results

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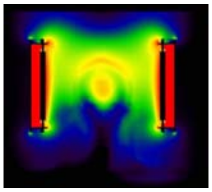
Objective: To investigate the feasibility of human head imaging at 9.4T.

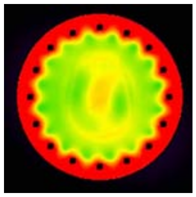
Introduction: Brain imaging has been increasingly used in research applications at 7T and 8T since 1999.[1,2] Can the human brain be imaged safely and successfully at still higher field strengths?[3] The aim of this study is to find out.

Methods: The methods consisted of modeling, hardware development and data acquisition.

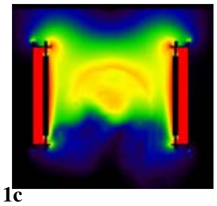
Modeling: Initial modeling used the Remcom Finite Difference Time Domain method to numerically predict RF (B_1) field magnitude and loss contours in the Visual Human digital atlas of the adult male head. Figure 1 shows a scale model of a head within a homogeneous, circularly polarized TEM head coil. The dimesions of the coil are: i.d. = 28cm, o.d. = 34cm, length = 20cm. These models of conventional coils and applications indicate the need for new methods and technologies for 9.4T.



1a

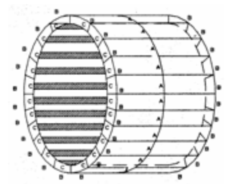


1b

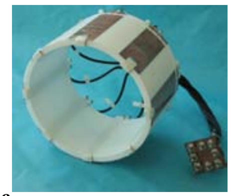


1c

2a



2b



2c

Figure 1. 9.4T predictions of nonuniformities in a head with a homogeneous CP coil. Each color represents a 5dB field contour. The patent drawing and 8-channel implementation of the multi-channel TEM coil used are shown in Figs 2b and 2c respectively. Independent T/R line terminals and control points are lettered in 2b. [4,5]

Hardware Development: A 9.4T, 65cm bore Magnex superconducting magnet (Fig 2a) with a 40cm i.d., assymetric gradient head coil and shim set was used for this study. This hardare was interfaced to a Varian Inova console, and to a custom RF front end including a parallel transceiver with multi-channel TEM coil pictured in Figures 2b, 2c. The transceiver was composed of a multichannel receiver built in-house, and a multichannel transmitter including programmable attenuators, phase shifters, power amplifiers and T/R switches were designed in-house and manufactured by Communications Power Corporation (CPC). The parallel transceiver gave independent phase angle and magnitude control to each independent element of the coils as drawn in 2b, and used for this study in 2c.[6]

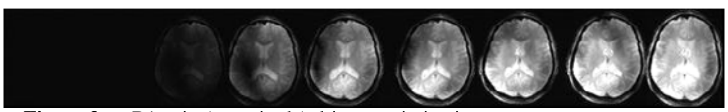


Figure 3a. B1 gain (magnitude) driven optimization.

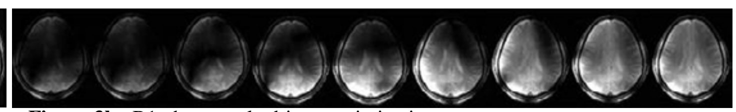
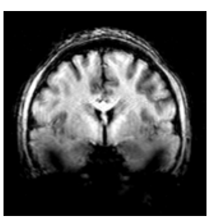
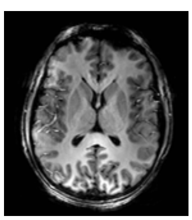


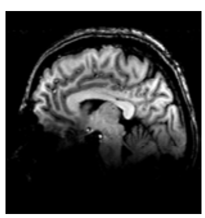
Figure 3b. B1 phase angle driven optimization.

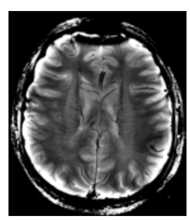
Measurement: For initial results, an eight element coil was used (Fig 2c.). RF magnitude (Fig 3a) and RF phase (Fig 3b) were intereactively controlled from the console to optimize the homogeneity across the head. Initial head images were then acquired. Figure 4 is a gradient echo image set acquired by the parameters: TR/TE = 40/5ms, TI = 1.55 sec, Thk = 3mm, matrix = 256 x 128, SAR = 0.4W/kg. Figure 5 shows a FLASH image, TR/TE = 50/9ms, Thk = 6mm, matrix=512x512, flip ~7°.

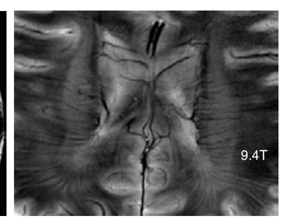
Results: With IDE and IRB approval, and in compliance with FDA guidelines, NMR data and interviews were obtained from an initial 10 healthy normal volunteers; 14 males, and 4 females. Of the 9.4T imaging experience, 10 subjects reported "sleepiness", 8 reported "light headedness or dizziness", 4 reported metallic taste, two got cold, one got warm, and one reported "body numbness". There were no requests to conclude studies early with some lasting two hours, and no other remarkable incidents or long-term effects reported. Figures 4 and 5 were acquired by the new 9.4T technology and methods above and are representative of the images acquired to date. Figure 4 shows three dimensions of the brain with fair uniformity and good T1 contrast. Figure 4a shows eddy current artifacts not resolved at abstract time. Figure 4 images are 8-channel magnitude composites only, without intensity correction or other post-processing. The FLASH image of Figure 5 shows apparent T2* contrasting of the medulary veins together with other features not generally observed at lower fields. Fig 5a shows a superior B0 artifact and a bright peripheral intensity correction artifact.











Figures: **4a** 9.4T coronal GE **4b** 9.4T transverse GE **4c** 9.4T sagittal GE **5a** 9.4T FLASH **5b** Zoomed 5a

Discussion and Conclusions: While we are still fine tuning some technical wrinkles, human MR imaging to field strengths of 9.4T appears to be possible according to these preliminary results. The Larmor wavelength in the human tissue dielectric at 400 MHz is approximately 9cm. By conventional methods and thinking, this wavelength would preclude any possibility of achieving safe and successful human scale imaging. RF interference patterns from a conventional, uniform field volume coil would create severe inhomogeneities in the anatomy, as shown in Figure 1. RF losses to the tissue conductor and the tissue dielectric at 400 MHz would result in severe heating for conventional pulse protocols. However, new methods and technology being developed may not only solve some of these problems, but actually use the short wavelength to great advantage. By controlling the currents in individual RF coil elements, in phase, gain, frequency, and time, the RF field can be manipulated to optimize signal from a targeted region of interest for SNR, SAR, CNR, homogeneity, or other criteria. Such "RF shimming" will be automated much like B0 magnetic field shimming is today. Transmit SENSE will be similarly facilitated. First examples of these new methods, technologies, and results are reported.

Reference: **1.** NMR Biomed11:263-265 (1998) **2.**MRM 46:24-30(2001) **3**. Proc. ISMRM 13 p.953 (2005) **4.** US Pat. 6,633,161 (2003) **5.** MRM 53:434-445 (2005) **6**. US Pat. 60/508, 662 (2005), **Acknowledgements:** NIH-S10 RR139850, NIH- R01 EB000895-04, NIH-P41 RR08079, Keck Foundation