Clinical Imaging at 7T with a 16 Channel Whole Body Coil and 32 Receive Channels

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Objective: To investigate the feasibility of full "clinical" whole body imaging with a multi-channel body coil and multi-channel receiver arrays at 7T.

Introduction: In current clinical practice, whole body imaging most typically employs a whole body coil built into the bore of the magnet, and local receiver coils applied to a patient region of interest. The body coil is used to transmit a uniform RF field to excite a homogeneous NMR signal response which is in turn received with high sensitivity from a locally applied array. While promising 7T images have been acquired using local transmit and receive arrays (1,2), and whole body transmit and receive coils (3, 4), "clinical" imaging using a whole body transmit coil together with local receive coils has not been successfully demonstrated. Our aim is therefore to demonstrate the feasibility of whole body clinical imaging with a body coil and local receivers at 7T. Our approach will use new methods of multi-channel coil design, B_1 shimming, active coil decoupling during transmit, and combined signal reception from transmit and receive coils to achieve this aim.

Methods: The methods consisted of hardware development, modeling, and new data acquisition methods.
Hardware Development: 7T equipment specific to human body imaging is not commercially available. Therefore, an actively detuned, 16-channel body coil (Fig1,2) together with the 16 channel RF transmitter (1 kW/channel), 16-channel power monitoring system, 16 channel receive array, and 32 channel receiver were designed in-house.(5) The power amps and phase/gain controller were manufactured by CPC, Hauppauge, NY. The MRI system used for the study included a Magnex 7T, 90 cm bore magnet interfaced to a Siemens console, whole body gradients and shims. The TEM body coil designed to fit between a Siemens bore tube and their Sonata gradients, measured an overall 66.0 cm od x 60.4 cm id x 125.5 cm long.(Fig. 2) The 16 TEM elements measured 25.7 cm, were placed 39.1 cm from the patient entry end. A new, inherently more field efficient and uniform method of decoupling these elements uses shield capacitance C to cancel mutual inductance M. (Fig.1) The TEM elements were independently tuned, matched, and driven in transmit and receive mode for this investigation. Independent preamps, power amps, TR switches, console driven phase and gain control, and tune and match circuits were dedicated to each of the body coil's 16 channels. Low impedance preamps were also interfaced to the 16 loop (8 anterior, 8 posterior) receive array used. The receive array was actively detuned from the body coil during transmit. The body coil was actively detuneable as well; each element being detuned by an independently controlled series PIN diode. In total, 16 transmit channels and 32 receive channels were employed.
Modeling: Initial predictions of B_1 field contours and SAR for 300 MHz body imaging were numerically calculated using the Remcom XFDT package, College Station, PA. Figure 3 shows B1+ contours expected for a "conventional" homogeneous, circularly polarized (CP), TEM body coil at 7T. Note the -40dBm blue regions of severe destructive interference, spatially coincident with the heart.
Measurement: The acquisition parameters for the gradient echo images of Figures 4,5 were: TR/TE=39.5/2.3ms, thk=6 mm, res=2.2x2.2mm, tip=56, scan time = 17 seconds (gated). SAR was monitored per channel, and totaled 1.13 W/kg for the 25 kg FOV. To mitigate the RF artifacts predicted in Fig 3(left), B1+ shimming was performed by first measuring phase maps and then calculating and setting compensatory B_1 for the target ROI.(6) No intensity correction was applied, as is usually done for clinical images acquired with receive arrays.

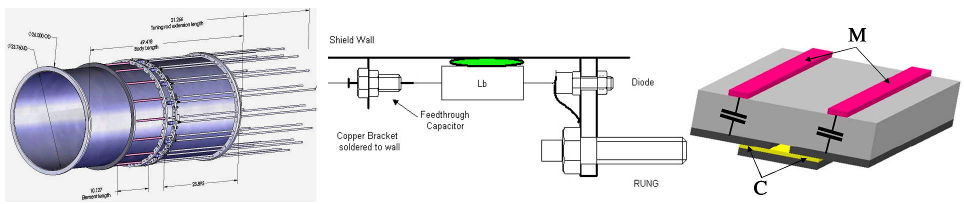

Fig 1. Design: Sixteen channel, TEM body coil (left), series PIN active detuning circuit (center) for each TEM element, and shield plate capacitance decoupling (right) between two TEM elements in body coil.

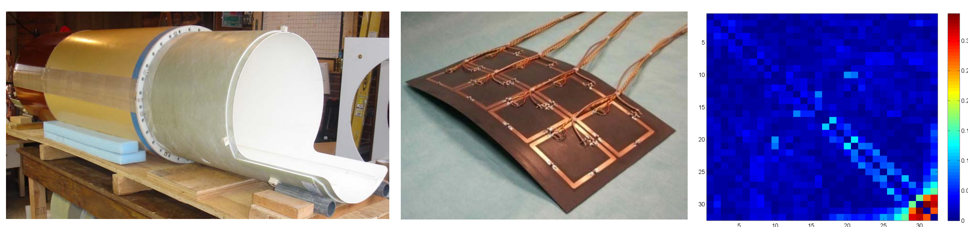

Fig 2. Implementation: TEM Body coil on Siemens bore tube (left), One of a pair of eight channel receiver arrays (center), and the decoupling matrix for the body coil + receive array. Low % coupling is noted between all TEM elements in body coil, and between body coil and receiver coil. The bottom, right corner shows high coupling between receiver loops surrounding a loop with a faulty diode.

Results and Discussion: Models predict severe (>40 dB) RF contour gradients for CP body coils loaded with human bodies at 300 MHz. Observed in both models (Fig 3) and images (4) are sharp lines running longitudinally through the body, primarily due to destructive interference of the short (12 cm) wavelengths in the tissue dielectrics at 300 MHz. B_1 shimming facilitated by the 16 channel body coil was used to compensate these artifacts in ROIs. Coil efficiency likely suffered (Qu/Ql < 3), from too little space for efficient TEM conductor pairs, due to limited coil space between the bore tube and gradients. Even so, SAR was successfully monitored and maintained well within the FDA guidelines. The observed artifacts and RF power requirements do not appear to preclude the possibility of useful whole body imaging at 7T.

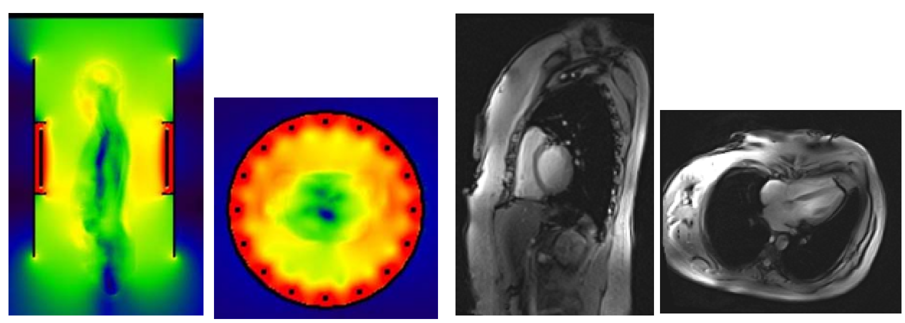

Fig. 3 Predictions and Results: Predictions (left) showing 40dB field contours in B1+ field with conventional CP coil at 7T. Note also the high B1+ in the head, well outside of the active elements of the body coil. Image data was acquired using 16 transmit channels of the body coil, the combined 32 receive channels from the body and receiver arrays, and B1+ shimming.

Conclusions: Clinical mode, whole body imaging with a whole body coil and local receive arrays is now demonstrated. To make this possible, an actively detuneable 16 channel body coil, B_1 shimming, and an actively decoupled 16 channel receiver coil were used. The cine' segment images (Fig 3.) were acquired while receiving from 16 body coil channels and 16 receive array channels simultaneously. By these new technologies and methods, clinical whole body imaging at 7T appears feasible.

References: 1.) MRM2008; 59:396-409; 2.) CJ Snyder et.al. "Initial Results of Cardiac Imaging at 7T" MRM2008(in press); 3.) MRM 2004;52:851-9; 4.) JT Vaughan et.al. "7T Whole Body Imaging; Preliminary Results" MRM2008(in press) 5.) MRM2006;56:1274-1282 6.) MRM2005; 54:1503-1518.
Acknowledgments: NIH- R01 EB000895-04, EB006835, NIH-P41 RR08079