7T Transmit Four-Channel Receive Array for High-Resolution MRI of Trabecular Bone in the Distal Tibia

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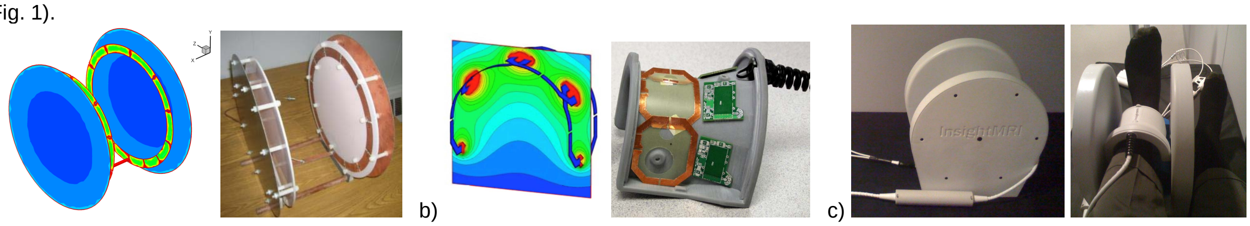
Introduction

Osteoporosis is a disease involving loss of trabecular bone, and it has been shown that the quality of the trabecular network is an important determinant of a bone's strength and resistance to fracture (1). Micro-MRI at intermediate field strengths (1.5 and 3 T) has been used to obtain three-dimensional images of trabeculae in bones of the appendicular skeleton such as in the distal radius and tibia (2). While such image data, combined with specialized algorithms for quantifying the trabecular network topology, have proven to be powerfully predictive of fracture risk and osteoporosis treatment efficacy in humans, the accuracy of these quantitative methods can be greatly benefited by increases in SNR. With the advent of new whole-body 7 T research scanners, we have therefore explored the potential of performing similar methods at 7 T.

Methods

Coil design: The coil was designed to be interfaced with a Siemens 7 T whole-body MRI scanner, operating at 297.2 MHz. Since there is no body-transmit coil, a Helmholtz pair local transmit coil with a decoupled 4-element phased array receive coil was chosen based on success with an identical 3 T version of the 4-element array. Simulations were performed using custom-written software to estimate the B_1 field maps of both transmit and receive coils. The Helmholtz pair was found to require a shield to reduce radiation losses and interactions with the bore of the magnet. The shield was further slotted to reduce possible effects of gradient-induced eddy currents. The final assembly was compact and provided intrinsic immobilization for the foot (Fig. 1).



a) b) c)

Fig. 1 a) Helmholtz transmit coil design steps. b) 4-channel receive array (4 cm loops), with on-board preamps. c) Final transmit/receive coil assembly.

Imaging tests: We tested the operation of the transmit-receive coil on a phantom consisting of a plastic bottle of vegetable oil, using a standard gradient echo sequence. The transmit coil was simultaneously loaded with two leg-sized bottles of saline solution. Uncombined images were saved to examine the degree of cross-talk between receive channels. For in vivo imaging, two volunteers were scanned, one with a larger and one a smaller ankle. We used a 2D single slice turbo spin echo with a long TR to allow full relaxation of the fat signal, which at 7 T has a T_1= 550 ms (3). The following parameters were used: TR/TE = 4450/12 ms, ETL = 7, refocusing flip = 90° or 180°, BW = 355 Hz, FOV = 80 (320x320) mm or 60 (256x256) mm, voxel size = 250x250x800 μm^3 or 234x234x800 μm^3, scan time = 3:30 min or 2:50 min, for the larger and smaller ankles, respectively.

Results

The phantom images of a bottle of oil showed that the four receive elements were functioning and demonstrated good mutual isolation (Fig. 2).

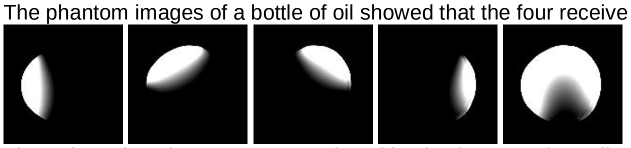
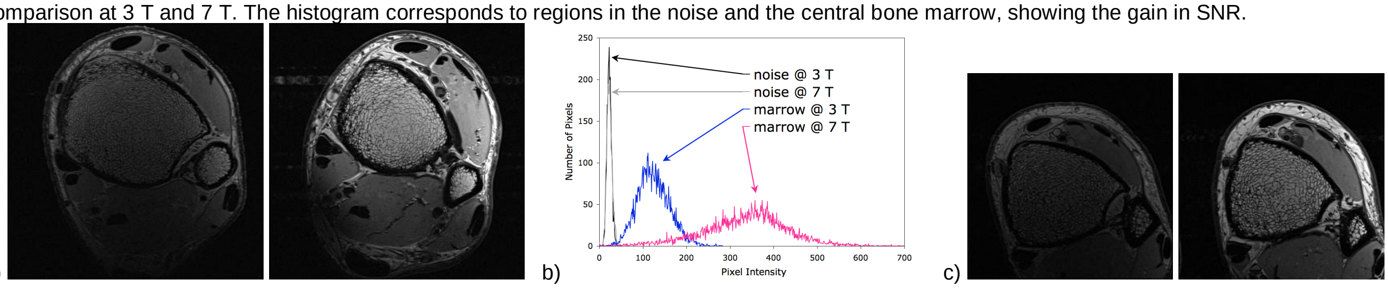


Fig. 2 Gradient echo images of an oil phantom, showing uncombined channels and combined image (on right).

The turbo spin echo sequence produced in vivo images of excellent quality at 7 T, in which fine trabeculae are clearly visible. Mean SNR at 7 T in the fatty bone marrow of the distal tibia for two volunteers having a larger and a smaller ankle was 14.4 and 18.0, respectively. Images acquired on each individual at 3 T and 7 T are shown in Fig. 3 with the same relative size scale. Also, images are displayed using the same window/level settings for each comparison at 3 T and 7 T. The histogram corresponds to regions in the noise and the central bone marrow, showing the gain in SNR.



a) b) c)

Fig. 3 a) Volunteer's ankle imaged in vivo at 3 T (left) and at 7 T using the same pulse sequence and parameters (right). SNR gain = 2.7x. b) Histogram from images in a). c) Another volunteer with a smaller ankle imaged using similar parameters as used in a). SNR gain = 3.1x.

Discussion

The local transmit/4-channel receive array has performed very well in preliminary tests. SNR gain observed here at 7 T is consistent with the relatively small size and non-conductive composition of the distal tibia. A linear increase in SNR (2.4x) would be expected for body-dominated noise, whereas for coil-dominated noise a gain of 4.7x is predicted ($\omega^{7/4}$). It is possible therefore that our 4-channel receive arrays (3 T and 7 T versions) are not operating fully in the body noise-dominated regime and could be optimized still further by reducing the size of elements and/or adding more elements. As the 7 T transmit coil was designed to accommodate larger legs, the voltage required for a 180° flip was found to be sensitive to the load in the coil, being lowest for the larger leg of Fig. 3, which can have implications on SAR limits for non-optimal loads. Furthermore, it is interesting to note the greater visibility of in-flow artifacts at 7 T due to fully relaxed in-flowing blood from outside the local transmit field in contrast to the whole-body transmit field at 3T. While there are many challenges associated with imaging at 7 T, we have found our initial experiences to be promising for the imaging of trabecular bone.

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References: 1. Guo XE, et al., *Bone* **30**:404 (2002). 2. Wehrli FW, et al., *NMR Biomed* **19**:731 (2006). 3. Ren J, et al., *J Lipid Res* **49**:2055 (2008).