Development of a Shield-Room Free Compact MRI System with a Highly Homogeneous RF Coil for Bone Density Measurements at the Calcaneus

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Introduction

An important application of compact MRI is the measurement of trabecular bone volume fraction (TBVF) in peripheral bones for diagnosis of osteoporosis [1,2]. We reported a compact MRI system for TBVF measurement of the calcaneus and demonstrated its usefulness by discovering the age dependence of the relaxation times of the bone marrow protons [3]. However, there are still several disadvantages to this system. In this study, we developed a local RF shield to reduce the installation space, and an RF coil to produce a highly homogeneous RF magnetic field to reduce the measurement time by using a multiple spin echo (SE) sequence.

Shield-Room Free Compact MRI System and Highly Homogeneous RF Coil

The compact MRI system consists of a 0.2 T permanent magnet (160 mm vertical gap, 35 ppm homogeneity in 20 cm × 20 cm × 12 cm DEV), a gradient coil set, an RF probe, a local RF shield, and a compact MRI console. The local RF shield consists of an RF shield box, a flexible RF shield plane, and an LC balun circuit (Fig.1). The RF shield plane consists of a 0.1 mm thick copper sheet with thin plastic sheets attached to both sides.

The RF coil is an oval solenoid (aperture: 175 mm × 85 mm, length: 120 mm) whose aperture is optimized for the calcaneus. As multiple SE sequences require a homogeneous RF magnetic field, the coil wire distribution of the oval solenoid was optimized using a genetic algorithm. Figures 2 and 3 show the RF coil and RF field distribution in the central plane measured using an oil phantom.

Experiments

To demonstrate the advantage of the homogeneous RF magnetic field, the right calcanei of 73 female subjects and six male subjects were measured using the following two protocols: two single SE sequences with different echo times (TE = 16, 96 ms) and a multiple SE (TE = 16, 32, 48, 64, 80, 96 ms) sequence. As the first protocol requires two separate scans, the measurement time of the first one (179.2 s) was twice that of the second (89.6 s). The calcanei of the six male subjects were measured 10 times repeatedly without repositioning to evaluate the reproducibility of the TBVF measurements.

Results and Discussion

Figure 4 shows the correlation between the TBVF measured for the 73 female subjects using the two protocols. The high correlation coefficient ($R = 0.964$, $p < 0.0001$) clearly shows equivalence of the two protocols.

The percentage CV (coefficient of variance (standard deviation divided by the mean) expressed as a percentage) calculated for the repeated measurements averaged over the six male subjects was 2.2% and 2.9% for the multiple SE sequence and single SE sequences. This result clearly demonstrates the advantage of the multiple SE sequence over the single SE sequences in reproducibility.

Although the application of single SE sequences to TBVF measurements has an advantage that the measured value is insensitive to the inhomogeneity of the RF magnetic field, the highly homogeneous RF field developed here reduced the measurement time by 50%, with a 30% CV reduction. To conclude, we achieved a reduction in installation space and measurement time in the compact MRI system for TBVF measurements of the calcaneus.

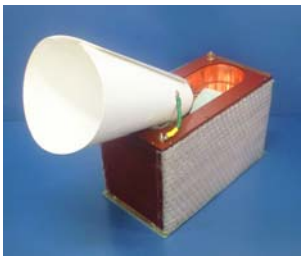

Fig.1 RF probe with local shield

Fig.2 RF coil

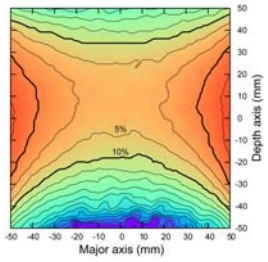

Fig.3 10% homogeneous area

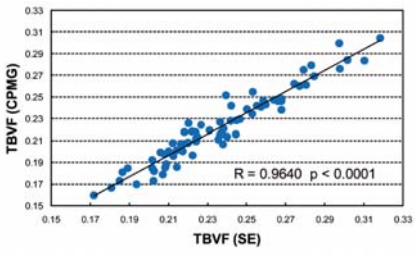

Fig.4

References

[1] K. Kose et al. Magn Reson Med 52, 440-444 (2004). [2] S. Tamoiha et al. Magn Reson Imaging 23, 333-335 (2005). [3] S. Tomiha et al. Magn Reson Med 60, 485-488 (2008).