Experimental Evaluation of In Vivo MREIT Conductivity Image of Human Musculoskeletal Tissues

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Target audience

The need for direct information on the electrical tissue properties of human is often and strongly felt among scientists and researchers who are involved in the interactions of electromagnetic (EM) fields and biological systems.

Purpose

The purpose of this study is to show *in vivo* human musculoskeletal tissue conductivity images providing a unique tissue contrast and compared the resulting human results with *ex vivo* biological tissue phantom images.

Methods

Five healthy volunteers (25-35 years old) participated in this study. Four electrodes were attached around the knee or calf region to inject currents (Fig. 1a). Using a current source, the currents I_1 and I_2 were sequentially injected with two different directions through two pairs of opposing electrodes (Fig. 1b and c). The imaging current was determined the amplitude as 95% of the smaller pain threshold. The experimental protocol was approved by IRB. To verify the resulting human images, we prepared a cylinder-shaped acrylic phantom with 13 cm in diameter and 16 cm in height. The phantom was filled with a saline solution having a conductivity of 0.20 S/m. Two different kinds of anomalies were positioned inside the phantom to create a contrast (Fig. 1d). One was an insulating film of cellulose acetate with four equally spaced 3-mm-diameter holes. The other was porcine tissues including two different bones, muscle, and adipose tissue. The imaging current was set to 9 mA for phantom imaging. After the setup, we placed the imaging objects inside the bore of 3T MR scanner. Multi-spin-echo pulse sequence combining with a chemical shift artifact correction method was used to obtain both the MR magnitude and magnetic flux density (B_z) images (Fig. 1c). The imaging parameters were TR/TE = 800/15, 30, 45 ms (3 echoes), FOV = 180×180 mm^2, slice thickness = 3 mm, NEX = 8, matrix size = 128×128, and number of slices = 8. The total imaging time was 40 min. After the imaging, absolute conductivity image was reconstructed from the measured B_z by the projected current density method[1].

Results and Discussion

Figure 2 shows *in vivo* MREIT images of human lower extremity. The cancellous bone are highly vascular and contain red bone marrow, the epiphysis in the knee appeared to be more conductive than the muscle. The diaphysis of the tibia and fibula in the calf is composed of a ring-shaped cortical bone and contains yellow bone marrow. The yellow bone marrow shows lower conductivity than that of the muscle in the calf. The subcutaneous adipose tissues around both the knee and calf show slightly higher conductivity values than the transversal conductivity of the muscle. This stems from body fluids and blood inside the adipose tissues in their *in vivo* wet state. The conductivity of muscle appeared to be least conductive among all tissues of the knee and calf due to the anisotropic characteristic at low frequencies with a much smaller conductivity value in the transversal direction[2]. The enhanced conductivity contrast around the synovial fluid in knee and crural fascia, intermuscular septum in calf represent our MREIT conductivity imaging is sensitive to the conductive fluids which are not clearly observed in the MR magnitude images.

Figure 3 shows *ex vivo* MREIT images of biological tissue phantom. Two different porcine bones of cancellous and cortical bone, adipose and muscle tissues were imaged. In the insulating film with holes, the injected current could partially penetrate the insulating wall through the holes. The conductivity images in Fig. 3b show unique contrasts inside the film depending on the B_z created by current flows and measured its value 0.035 S/m. Comparing two different bones, the cancellous bone shows high conductivity than cortical bone. The measured conductivity was 0.097 and 0.029 S/m, respectively. The adipose tissue and muscle in Fig. 3b show high conductivity comparing to the insulating film with 0.035 S/m. The measured values of adipose and muscle tissue were 0.055 and 0.124 S/m. Unlike human results, the conductivity of adipose tissue was clearly lower than muscle.

Conclusion

Comparing with *in vitro* or *ex vivo* results, *in vivo* human conductivity images showed similar pattern except muscles and adipose tissues due to the anisotropic characteristic of muscle and irrigation of high conductive fluids in the adipose tissue.

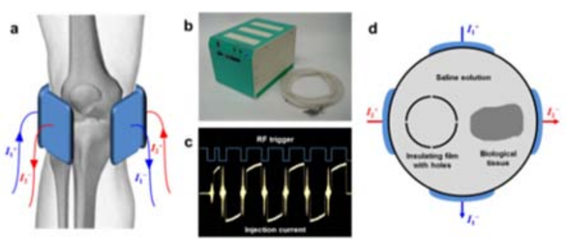

Fig. 1. Experimental setup for *in vivo* human and *ex vivo* biological tissue phantom imaging experiments.

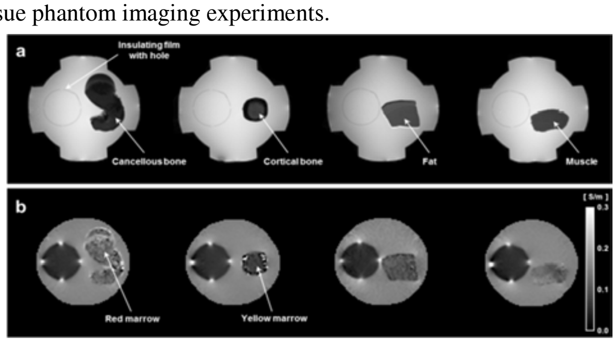

Fig. 3. *Ex vivo* MREIT images of two different porcine bones, adipose tissue, and muscle. (a) MR magnitude and (b) conductivity images.

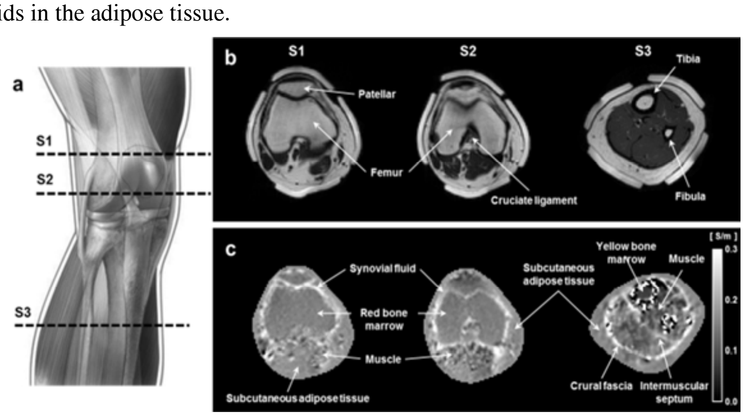

Fig. 2. *In vivo* MREIT images of human lower extremity. (a) Imaging slices were located at two different slices of knee and a calf region. (b) and (c) are MR magnitude and reconstructed conductivity images.

References

1. Sajib SZK, Kim HJ, et al. Regional absolute conductivity reconstruction using projected current density in MREIT. Phys. Med. Biol. 2012;57:5841-5859.
2. Gabriel S, Peyman A, et al. Electrical conductivity of tissue at frequencies below 1 MHz. Phys. Med. Biol. 2009;54:4863-4878.