Susceptibility weighted imaging of cartilage canals of the distal femur *ex vivo* and *in vivo*

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Introduction

Susceptibility-weighted imaging (SWI) is a fairly recent neuroimaging technique that utilizes subtle differences in the magnetic susceptibilities of different tissues to generate contrast (1). Phase data contain information of the local susceptibility differences as well as of the (low frequency) static inhomogeneous background fields (1,2). Unwrapping the phase allows the unwanted low frequency component to be filtered out (2).

Vasculature of epiphyseal growth cartilage is confined within channels known as cartilage canals. In animal models it has been shown that disruption of the blood supply to the growth cartilage may lead to later osteochondral defects (3). Visualization of these canals has been demonstrated with T2-weighted high-resolution MR imaging (4) and Gadolinium-enhanced imaging (5,6). The purpose of this study was to investigate the feasibility of susceptibility weighted imaging for visualizing cartilage canals in a porcine model, *ex vivo* at 9.4T, 7T and 3T and *in vivo* at 7T.

Methods

Specimens of the distal femur from piglets of 1 to 6 weeks of age were obtained for the *ex vivo* study; the right limbs were harvested for MRI and the left limbs perfused with barium sulfate for µCT scanning. For *in vivo* scanning, a 3-week-old piglet was acquired. To assess potential differences in SWI contrast *ex vivo* vs. *in vivo*, a carcass of a 2-week-old piglet was acquired. All animal procedures were approved by the local institutional animal care and use committee.

Ex vivo susceptibility weighted imaging was done using 9.4 T Agilent scanner with VnmrJ3.1. The specimens were immersed in perfluoropolyether and imaged with quadrature volume tranceiver coil (Millipede, Varian NMR Systems, Palo Alto, CA, USA). 3D GRE sequence with TR/TE = 40/14 ms, flip angle = 15°, receiver bandwidth = 16 kHz was used; FOV and matrix size set up to achieve approximately 100 µm isotropic resolution. SWI post processing was done according to Haacke et al (2) using MATLAB. *In vivo* knee/stifle scanning was done under general anesthesia at 7T (Siemens, Erlangen, Germany), utilizing B1+ phase shimming (7) and manufacturer provided SWI protocol with TR/TE = 27/15 ms, flip angle = 15°, receiver bandwidth = 90 Hz/pixel and 3 averages, FOV set to minimum possible with isotropic resolution of 0.25 mm. An 8-channel transceiver knee coil (Virtumed, Minneapolis, MN, USA) with parallel acquisition was used. An e*x vivo* knee scan was done at 7T using a nearly identical set up, and then repeated at 3T (Siemens, Erlangen, Germany) using a similar protocol with TR/TE = 45/28 ms, flip angle = 15° and receiver bandwidth = 40 Hz/pixel, FOV set to the minimum possible with isotropic resolution of 0.375 mm. A single channel knee coil was used at 3T. Manufacturer-provided SWI post processing was used on the 3T and 7T clinical scanners.

Results

Clear visualization of the cartilage canals of the distal femur was obtained at 9.4T in each specimen. The µCT scans of the contralateral limb demonstrated the barium-filled canals. Striking visual similarity in 3D reconstructions of the vessel structures was noted between µCT and SWI (Figure 1). The 7T *in vivo* scan of the 3-week-old piglet demonstrated the feasibility of imaging of the canals with SWI *in vivo* at ultra-high field (Figure 2a). The *ex vivo* scan of a 2-week-old piglet at 7T showed indistinguishable differences in cartilage canal visualization compared to 7T *in vivo*. Further *ex vivo* scan of the same piglet at 3T demonstrated the feasibility at lower field strength, although with some loss of fidelity (Figure 2b).

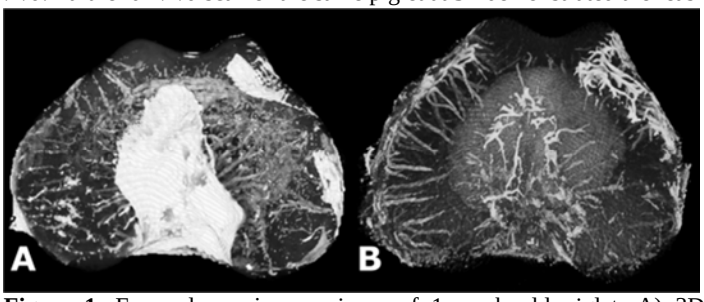

Figure 1. Femoral *ex vivo* specimen of 1 week old piglet. A) 3D visualization of the vessel structure using SWI at 9.4T and B) 3D visualization of the contralateral limb using µCT.

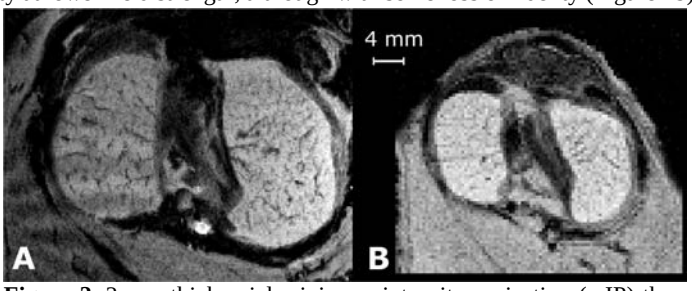

Figure 2. 2 mm thick axial minimum intensity projection (mIP) through femoral condyles of A) a 3-week-old piglet, *in vivo* at 7T and B) a 2-week-old *ex vivo* piglet at 3T.

Discussion and conclusions

In the present study, a new application for SWI was demonstrated for visualization of cartilage canals. High resolution SWI imaging of *in vitro* specimens at 9.4 T demonstrated that the vascular structures are visualized at fairly short echo times (~10 ms) without post processing. Contrast was improved by increasing the echo time to 14-15 ms and was further increased with the SWI post processing (2). The µCT scans confirmed the similarity of the vascular structures to the SWI findings, and these were further confirmed with histological examination of the same specimens (data not shown). *In vivo* imaging at 7T was feasible, with clear depiction of the vascular structures in mIPs. The *ex vivo* scans at 3T and 7T suggested that the method also is feasible at a clinically relevant field strength of 3T. Previous visualization of cartilage canals has been done using Gadolinium-enhanced imaging (6,8). The present method, SWI, provided higher contrast between the vessels and surrounding matrix, without the need of external contrast agents. Although clinical demonstration in human is yet to be shown, the results are very promising and warrant further research efforts utilizing SWI for imaging of cartilage canals. This noninvasive method may prove helpful in understanding the evolution of osteochondral lesions in the developing human skeleton.

References

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Acknowledgments

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