Imaging of the osteochondral interface and deep cartilage using SWIFT

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INTRODUCTION

The involvement of the osteochondral interface in osteoarthritis (OA) is known, but perhaps less investigated than warranted (1). Recent developments in ultrashort/zero-echo time imaging methods have enabled MRI investigation of the calcified layer and subchondral structures (2, 3). A new appreciation of these structures from an MR point of view is beginning to take off. In studies utilizing ultrashort echo times, a bright line in the bone-cartilage interface has often been reported (3, 4). Generally, this feature has been associated with the calcified layer and deepest layers of cartilage (3), but its characterization however, is incomplete at present, especially for SWIFT. In this study, SWIFT imaging was utilized to investigate the bright feature in porcine cartilage-bone tissue. For reference, histological assessment of the interface and associated cartilage was performed.

MATERIALS AND METHODS

A full thickness cartilage-bone sample (approximately 10x10x10 mm) was prepared from the medial femoral condyle of an 18-month-old pig. The sample was first immersed in physiological saline solution and prior to imaging, into Fluorinert to provide a clean signal background. Imaging was conducted at room temperature using a 9.4 T 31 cm bore horizontal magnet and Agilent DirectDrive console (VnmrJ 3.1). The sample was placed in a glass vial and positioned inside a home-built single-loop transmit-receive coil tuned to proton NMR frequency. SWIFT imaging was repeated at three orientations of the sample: normal of the cartilage-bone interface was oriented 1) perpendicular to B_0, 2) along B_0 and 3) at approximately 45 degrees to B_0. For each orientation, images were obtained without saturation (SWIFT) and with different saturation schemes (2, 5): saturation of the short T_2 pool with off-resonance saturation using a 20-ms 180 degree HS2-pulse of 1 kHz bandwidth at +3 kHz or +5 kHz. Saturations were interleaved into the imaging sequence after every 16 spokes, with the same timing in each sequence. For each image, 256 000 spokes were acquired with 192 complex points using an FOV of 25 mm^3. A nominal flip angle of 10 degrees was used for excitation in each case. The images were reconstructed off-line with a combination of Labview & Matlab programs to a matrix of 384^3 (yielding 65 µm nominal resolution). After imaging, the samples were processed for histology and evaluated after staining with Hematoxylin & Eosin.

RESULTS AND DISCUSSION

The appearance of the bright feature in the interface between cartilage and subchondral bone was faintly visible in the SWIFT images (Figure 1A-C). After subtracting short T_2 - saturated images from SWIFT, essentially preserving only the signal from short T_2 fraction, the bright line at the osteochondral interface was further emphasized invariably at all orientations (Figure 1D-F). The observation was similar for subtraction images at +3 kHz saturation offset (data not shown). The SWIFT phase images (Figure 1D-F), however, were found to exhibit orientation dependence at the osteochondral interface; at approximately magic angle, the phase image shows virtually no change at the interface, while the parallel and perpendicular orientations reveal a modulation of the phase across the interface, indicative of a susceptibility difference (6).

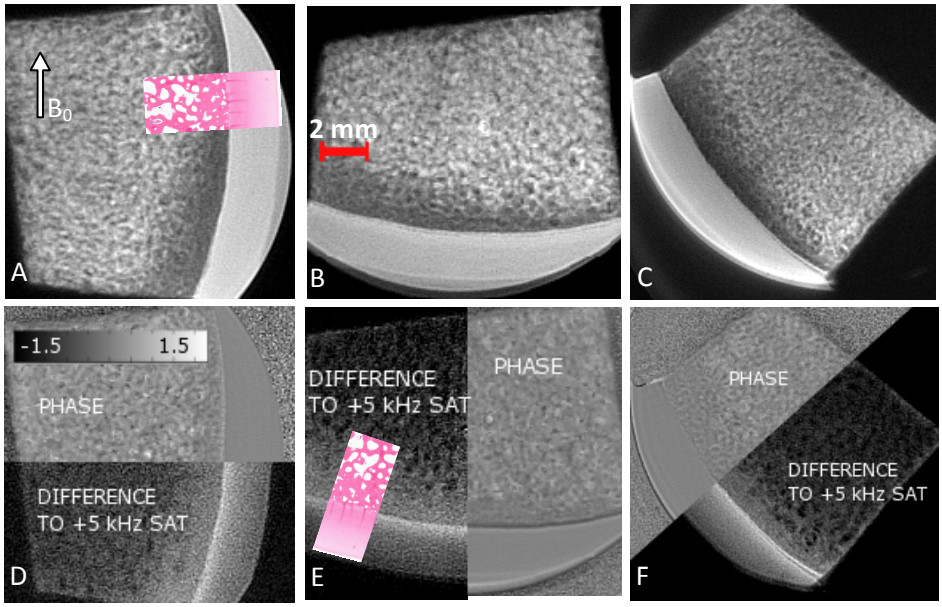

Figure 1. A-C) SWIFT images without saturation at different sample orientations with respect to B_0. D-F) Phase images for SWIFT and result of subtracting the image with short T_2 saturation at +5 kHz off-resonance from the corresponding SWIFT image. While the bright line in the interface is preserved at all orientations, the phase images demonstrate clear orientation dependency at the interface. Images were averaged over 1 mm thickness and the red scale bar indicates 2 mm. The superimposed microscopic image shows the calcified layer at the osteochondral interface.

The histological images confirmed the existence of the layer of calcified cartilage in the sample. The thickness of the calcified layer was measured to be approximately 120 micrometers, corresponding to about two pixels in SWIFT images. However, the thickness of the bright feature in the subtraction SWIFT images exceeds the thickness of the calcified layer. This indicates both the calcified cartilage and deep region of cartilage as the origin of the bright feature in SWIFT. At orientations other than magic angle, however, in addition to the short T_2 fraction (4), the susceptibility difference between the bone and cartilage may also contribute to the observed signal as the signal will be dislocated (6). Future work will include the investigation of the effects of cartilage maturation and osteoarthritis on the SWIFT properties of the deep and calcified cartilage.

REFERENCES

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