Assessment of human tibial cartilage-bone interface in osteoarthritis using SWIFT

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TARGET AUDIENCE

Osteoarthritis researchers focusing on cartilage and subchondral bone.

PURPOSE

The zone of calcified cartilage is a mineralized layer that separates the articular cartilage from the subchondral bone. The assessment of calcified cartilage and cartilage-bone interface, which have very short T_2 relaxation times, has been difficult with conventional magnetic resonance imaging (MRI) techniques with echo times (TE) in the millisecond range, resulting in a loss of signal. SWeep Imaging with Fourier Transform (SWIFT) is an MRI technique that uses interleaved RF excitation and signal acquisition allowing imaging of the shortest T_2 species[1]. The calcified cartilage may have a major role in the pathogenesis of osteoarthritis[2] warranting its investigation at different stages of disease. The purpose of this study was to evaluate cartilage-bone interface in human tibial osteochondral samples with varying degrees of degeneration using SWIFT. For reference, micro-computed tomography (micro-CT) imaging and histological methods were used.

METHODS

Osteochondral samples (n = 13) of 6 mm in diameter from human tibial plateau were obtained from patients having total knee arthroplasty. The experiments were approved by the local ethics committee.

MRI was performed at 9.4 T (Oxford instruments Plc, Witney, UK) with a 19 mm quadrature RF volume transceiver (RAPID Biomedical GmbH, Rimpar, Germany) and Varian DirectDrive console (Varian Inc. Palo Alto, CA, USA). Prior to imaging, the specimens were thawed, placed inside a Teflon test tube and immersed in perfluoropolyether (Fomblin® LC08, Solvay Solexis, Milan, Italy). SWIFT imaging was performed with 96000 views, FOV 40^3 mm^3, BW = 62.5 kHz, 384 complex points, 104 µm isotropic resolution and a nominal flip angle of approximately 5-7°, separately optimized for each sample. Water saturated SWIFT images were obtained by applying a hyperbolic secant (HS4) inversion pulse of 1 kHz bandwidth centered at water frequency every 16 views. SWIFT images without saturation pulses were acquired using identical sequence timing. The scan time was approximately 30 minutes per one SWIFT dataset. The SWIFT images were reconstructed using a custom made LabVIEW software. For reference, micro-CT imaging (SkyScan 1172, Kontich, Belgium) of the samples was performed with 28 µm isotropic resolution and 0.5 mm aluminum filter. Micro-CT images were reconstructed using software provided by manufacturer. Finally, the samples were investigated using histological techniques. The histological sections were stained with Masson's trichrome (collagen) and Safranin-O (proteoglycans) stains. Safranin-O stained sections were histologically graded by three observers according to the Osteoarthritis Research Society International (OARSI) grading system (scale 0-6, zero indicating normal healthy cartilage).

For evaluation purposes, 1-mm thick average slices were calculated from SWIFT datasets. Water saturated SWIFT images containing only signal from the long T_2 spins of the medullar fat were subtracted from non-saturated images. The resulting subtraction images represent "fat-saturated" images containing only water signal from both long T_2 and short T_2 spins.

The thickness of the subchondral bone plate was measured from SWIFT and micro-CT images as an average value from 2 mm wide ROI in the middle of the sample. In SWIFT images it was assumed that the subchondral bone plate corresponds to the low-intensity region below the cartilage. Thicknesses were finally compared with Pearson's correlation analysis.

RESULTS

The OARSI grades of the samples varied from 1.4 to 4.1 (average values). For healthy or mildly degenerated samples SWIFT consistently produced a high-intensity signal band at the cartilage-bone interface (Figs. 1A&B, white arrows). Masson's trichrome staining revealed the zone of calcified cartilage for healthy/early degenerated samples. For samples with low OARSI score, the subchondral bone appeared normal in the micro-CT images (Figs. 1A&B). The samples with advanced degeneration lacked the high-intensity signal band in SWIFT images at the osteochondral junction (Fig. 1 C&D, black arrows). In Fig. 1C, histological section reveals very thin zone of the calcified cartilage as well as sclerosis of subchondral bone, also well represented in micro-CT image. In Fig. 1D, subchondral bone appears sclerotic and multiple tidemark-like structures could be seen. Furthermore, fibrillation of the articular surface was detected with SWIFT. However, the signal inside cartilage showed only relatively small alterations with cartilage degeneration. The correlation of subchondral bone plate thickness between SWIFT and micro-CT derived values was high (r = 0.989, p < 0.001).

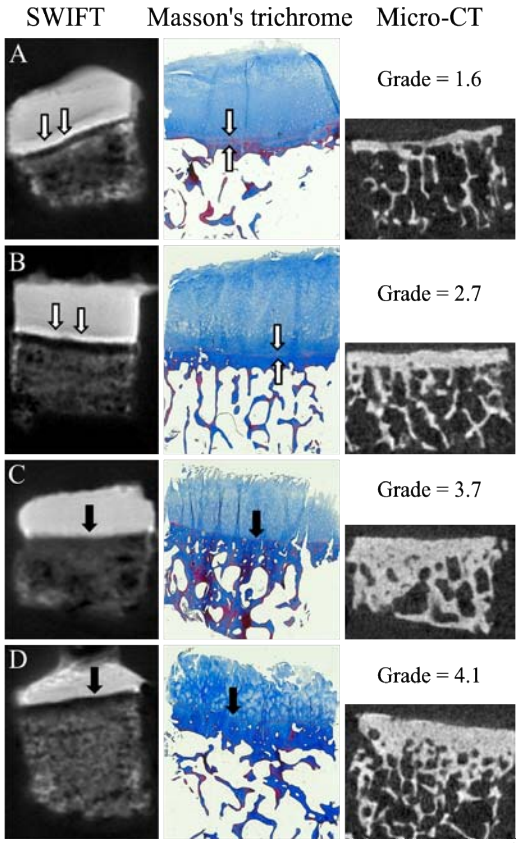

Figure 1. SWIFT subtraction images (water images of long and short T2 spins), histological sections with Masson's trichrome stain and micro-CT slices of the osteochondral samples from human tibial plateau. The white arrows point to normal interface whereas the black arrows point to degenerated cartilage-bone interface.

DISCUSSION

According to the present results SWIFT produces a high-intensity signal at cartilage-bone interface similar as demonstrated in ultrashort echo time (UTE) studies[3]. UTE studies have also shown that the bright line is associated to the calcified layer and deep region of cartilage[3]. The present study supports these observations. The loss of high-intensity signal with advanced degeneration at the osteochondral junction may be due to increased mineralization of the tissues with development of osteoarthritis[2]. The subchondal low-signal intensity region corresponds to subchondral bone and alterations in SWIFT signal intensity are in agreement with micro-CT and histology.

CONCLUSION

SWIFT can elucidate tissue changes in the zone of calcified cartilage and subchondral bone, which are associated to the degree of OA.

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