Improved Assessment of Cartilage Repair Tissue using Fluid-Suppressed 23Na Inversion Recovery MRI at 7 Tesla: Preliminary Results

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Introduction. Over the last two decades, there has been remarkable progress in the field of cartilage restoration procedures. Focal cartilage defects that were once considered permanent are now amenable to treatment with a variety of surgical options including microfracture, osteochondral autografting/allografting, and matrix-assisted autologous chondrocyte implantation (*1*). Magnetic resonance imaging (MRI) plays an important role in assessing the surgical outcome and status of the cartilage repair tissue. Beyond evaluation of repair tissue morphology, biochemical imaging techniques (T2 mapping, dGEMRIC, T1rho, ^{23}Na MRI) permit evaluation of native and repair tissue collagen and proteoglycan content (*2, 3*). One challenge to the performance of sodium MRI of cartilage is that sodium is present both within cartilage (bound sodium, $[Na^+]$=250-300 mM) and synovial fluid (free sodium, $[Na^+]$=140-150 mM). Quantitative assessment of sodium within cartilage tissue alone could therefore be rendered inaccurate secondary to the presence of synovial fluid at the cartilage surface or within cartilage fissures. Recently, it has been reported that a fluid-suppressed, adiabatic inversion recovery (IR) pulse sequence at 7 Tesla can distinguish these two pools of sodium based on differences in their T1 relaxation times (*4*). The goal of this study was to evaluate cartilage repair tissue and native cartilage using a 3D-radial, ultrashort-echo time (UTE) ^{23}Na MR pulse sequence without and with an inversion recovery (IR) preparation pulse for fluid suppression at 7 Tesla.

Methods. This study had institutional review board approval. We recruited eleven consecutive patients (41.5±11.8 years) from an orthopedic surgery practice status post knee cartilage restoration procedure. Subjects were examined postoperatively (median=26 weeks) with 7 Tesla MRI using:1) proton-T2 (TR/TE=3000 ms/60 ms), 2) sodium UTE (TR/TE=100 ms/0.4 ms), 3) fluid-suppressed, sodium UTE adiabatic IR. Cartilage sodium concentrations in repair tissue ($[Na^+]_R$), adjacent native cartilage ($[Na^+]_N$), and native cartilage within the opposite, non-surgical compartment ($[Na^+]_{N2}$) were calculated using external NaCl phantoms. For the non-IR and fluid-suppressed IR images, we used a two-tailed paired t-test to compare calculated mean sodium concentrations between: 1) $[Na^+]_R$ and $[Na^+]_N$ and 2) $[Na^+]_N$ and $[Na^+]_{N2}$.

Results. The cartilage repair procedures included microfracture (n=5), osteochondral allografting (n=1), osteochondral autografting (n=1), synthetic resorbable graft placement (n=1), detached osteochondral fragment re-implantation (n=1), matrix-assisted autologous chondrocyte implantation (n=1), and juvenile cartilage implantation (n=1). Repair tissue had predominantly: partial thickness defect filling (9/11), incomplete border integration (6/11), surface irregularity (7/11), non-homogeneous structure (6/11), and isointense signal (6/11). Figure 1 shows sagittal 7T MR images of the osteochondral allograft patient obtained with proton, conventional sodium, and fluid-suppressed sodium IR techniques. On non-IR images, mean $[Na^+]_R$, $[Na^+]_N$, $[Na^+]_{N2}$ were 177.8±54.1 mM, 170.1±40.7 mM, 172.2±30 mM. Differences in $[Na^+]_R$ versus $[Na^+]_N$ (p=0.59) and $[Na^+]_N$ versus $[Na^+]_{N2}$ (p=0.89) were not significant. On IR images, mean $[Na^+]_R$, $[Na^+]_N$, $[Na^+]_{N2}$ were 108.9±29.8 mM, 204.6±34.7 mM, 249.9±44.6 mM. Decreases in $[Na^+]_R$ versus $[Na^+]_N$ (p=0.0.0000035) and $[Na^+]_N$ versus $[Na^+]_{N2}$ (p=0.015) were significant.

Discussion. We have applied a fluid-suppressed, sodium IR pulse sequence at 7 Tesla to evaluate cartilage repair patients postoperatively. This sequence suppresses the signal from free sodium within synovial fluid in the same manner that fluid-attenuated inversion recovery (FLAIR) is used in brain imaging to suppress signal from mobile free water protons in cerebrospinal fluid. As a result, it is feasible to quantitatively assess the sodium signal from within cartilage tissue alone. In this study of cartilage repair patients, use of this sodium IR sequence allowed statistically significant decreases in sodium concentration to become detectable in: 1) cartilage repair tissue compared to adjacent native cartilage tissue and 2) adjacent native cartilage tissue compared to native cartilage tissue within a different knee compartment not involved in surgery. Without the use of the IR sequence, these differences were not detectable. Fluid-suppressed sodium IR imaging may allow improved assessment of $[Na^+]$ within cartilage repair and native tissue. This technique could also be applied to study osteoarthritis or other disorders of cartilage degeneration.

References.

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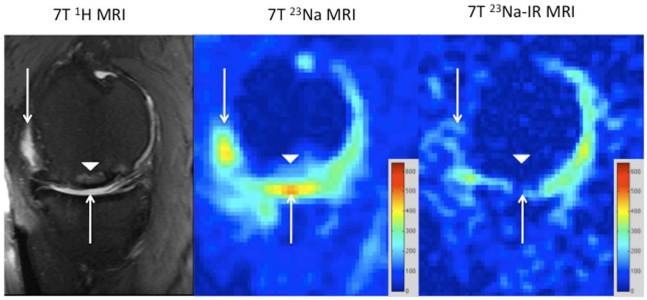

Figure 1. Sagittal 7T MRI of an osteochondral allograft (arrowhead) at the weight-bearing aspect of the medial femoral condyle using a T2 ^{1}H sequence (left panel), a 3D-radial ^{23}Na UTE sequence (middle panel) and a fluid-suppressed, adiabatic IR 3D-radial ^{23}Na UTE sequence (right panel). There is synovial fluid at the articular surface (arrows). On the ^{23}Na-IR image, the signal from free sodium within synovial fluid is suppressed, allowing more accurate quantification of repair tissue sodium content.