Quantitative assessment of bone marrow edema and the overlying cartilage in OA and ACL injuries using MR imaging and spectroscopic imaging at 3T

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INTRODUCTION

Bone marrow edema (BME), defined as areas with high signal intensities in T2-weighted, fat-saturated magnetic resonance (MR) images, are present in knee osteoarthritis (OA) (1) and acute knee injuries, such as anterior cruciate ligament (ACL) tear (2). This increase in signal has been attributed to a number of factors, including abnormal trabeculae, bone marrow necrosis, swelling of fat cells, marrow bleeding and marrow edema (3). While these MR findings are common, little is known about the natural history and significance of these lesions, or about their relationship with local and global cartilage degeneration. A number of studies have proposed that the overlying cartilage may have sustained irreversible injury during impact of acute injuries (4). Previously we have developed a $T_1$ mapping technique to assess cartilage degeneration in OA (5,6). The aim of this study was to study BME using MR imaging and spectroscopic imaging and to evaluate the BME-overlying cartilage using $T_1$ quantification in patients with OA and ACL tears.

MATERIALS AND METHODS

Ten patients, 4 with OA and 6 with ACL tears who showed BME, were studied using a 3T GE MR scanner and a quadrature knee coil. All the ACL tear patients were imaged prior to surgery. Sagittal $T_1$-weighted images were acquired using the previously developed sequence based on a 3D-SPGR sequence (6) (FOV=12cm, slice thickness = 3 mm, TR/TE = 10/5.8 ms, TSL = 0/10/40/80 ms, spin lock frequency = 500 Hz, total acquisition time approximately 13 mins). The protocol also included sagittal 3D water excitation high-resolution spoiled gradient-echo (SPGR) imaging, and fat-saturated $T_2$-weighted fast spin-echo (FSE) images. Point RESolved Spectroscopy (PRESS) voxel selection was used to acquire 3D-MRSI data (TR/TE=2000/38, phase encoding step=8*8*8, nominal voxel size = 5*5*5 mm$^3$) in the edema.

BME was semi-automatically segmented using a threshold method based on T2-weighted images and volume of BME was calculated. From 3D spectral data, water at 4.7 ppm, unsaturated lipids (UnsatLip) at 5.4 ppm and saturated lipids (SatLip) at 0.9-1.3 ppm were estimated for each voxel. Volumes of significantly elevated water and unsaturated lipids were calculated for each patient (7). $T_1$ maps were reconstructed by fitting the $T_1$ weighted images pixel-by-pixel. $T_1$ maps and T2-weighted images were aligned to SPGR images. Cartilage was segmented semi-automatically in SPGR images. From this, 3D contours for BME imaging and surrounding cartilage were defined manually using the aligned T2-weighted images. These contours were overlaid to $T_1$ maps and the mean, standard deviation of $T_1$ values were calculated. The increase percentage was defined as ($T_1$ overlying – $T_1$ surrounding)/ $T_1$ surrounding. A non-parametric rank test was used to compare average $T_1$ between BME-overlying cartilage and surrounding cartilage. A Spearman rank correlation was performed to study the relationship between spectral data and BME volume, and between $T_1$ changes and BME parameters.

RESULTS

The average $T_1$ values in BME-overlying cartilage were significantly higher than that in surrounding cartilage (51.8 ± 10.8 ms vs. 43.0 ± 8.3 ms, P=0.032) in the ten patients, as one example shown in Fig. 1(a). Patients with ACL tears tended to have a higher increase percentage than patients with OA, but with this small pilot sample size, it was not significant (29.15% ± 20.75% vs. 6.31% ± 11.40%, P=0.06). Volume of BME correlated significantly with volume of elevated water based on 3D-MRSI (R=84.4%, P=0.004) but not with volume of elevated unsaturated lipids. Spatially elevated water correlated with BME-overlying cartilage and surrounding cartilage. A Spearman rank correlation was performed to study the relationship between spectral data and BME volume, and between $T_1$ changes and BME parameters.

DISCUSSION

$T_1$ quantification in cartilage and 3D MRSI in bone marrow provide quantitative assessment of cartilage and bone lesions in knee injuries. Significantly elevated $T_1$ values in BME-overlying cartilage were observed. The results suggested that there may be degeneration (or more severe degeneration) in these regions. Two patients have been confirmed to have cartilage damage using arthroscopic images (one is shown in Fig. 1(b)). Three patients (two OA and one ACL tear) showed no significant $T_1$ elevation in BME-overlying cartilage. We are currently following these patients longitudinally to determine if there is any difference in cartilage degeneration in these patients compared with others. Although the BME volume and MRSI parameters are not associated with the increase of $T_1$ in this cohort of patients, the resolution of BME and the progression of cartilage degeneration can be followed quantitatively using the developed technology. This technology will allow us to critically evaluate medical and surgical treatments for ligament and degenerative conditions of the knee.

REFERENCES


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