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PHOTOACOUSTIC IMAGING OF CARTILAGE-BONE COMPLEX

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Purpose: Ultrasonography (US) is quick, inexpensive and gives the highest resolution imaging for evaluating the articular cartilage. However, it is not sufficient to diagnose the subchondral and cancellous bones. Photoacoustics (PA) is the conversion of nano-second pulse lasers to ultrasound (US) by thermal expansion of the material. The PA method enables high resolution and deep penetration imaging of the biological tissue. The purpose of this study is to compare images of the articular cartilage and cancellous bone by US and PA.

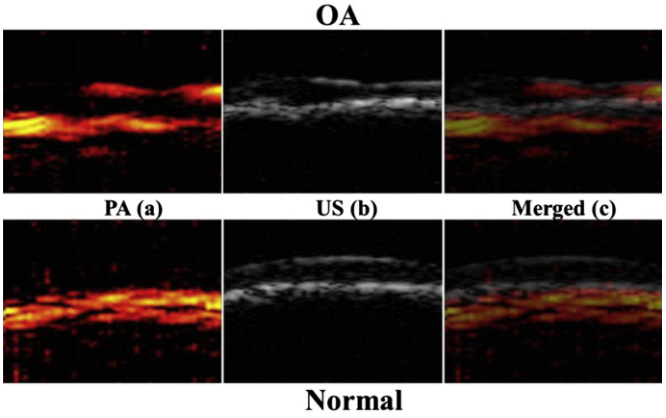
Methods: Photoacoustic imaging (PA): PA imaging is a hybrid imaging modality based on optical and ultrasound imaging. An ultra-short pulsed laser is illuminated on the biological tissue. When light energy is absorbed, a local temperature rise leads to thermal-elastic expansion and the generation of a pressure wave (called a PA signal). The signal is then detected to produce an image of the internal optical absorption distribution.

Experimental Setup: Laser pulses were generated by a semiconductor diode laser with a wavelength of 532 nm, a pulse width of 3.4ns, an output power of 430 μJ and a repetition rate of 100 Hz. The PA signal was received by a 50 MHz focused ultrasound transducer.

Specimen: The protocol for the experiments was approved by the Animal Research Committee of the Tohoku University School of Medicine. Adult male Sprague-Dawley rats (body weight 380-400 g) were used in this study. The unilateral knee joints were immobilized at 150 degrees of flexion with an internal but extra-articular fixator for 4 weeks to make osteoarthritis (OA). The knee capsule was cut with a surgical knife and the joint opened after administration of an overdose of sodium pentobarbital. After resection of ligaments and meniscus, the tibia was cut and a cartilage-bone complex was obtained. Contra-lateral sides of the immobilized knees are used as a control.

Results: Fig. 1 shows (a) PA tomography of a normal knee cartilage immersed in saline. In addition (b) ultrasound tomography, Fig. 1 (c) shows a merged image of (a) and (b). A plane of 2×1.5 mm was imaged at a scanning step of 20 μm. PA signals were averaged at 50 times to reduce noise. The acquisition time of one image was 2 sec which was approximately five times as fast as our previous PA imaging system using a YAG-laser. In the normal cartilage, the signals from the cartilage surface and subchondral bone were strong in US imaging. However, low signal intensity was observed in the articular cartilage but high signal intensity in the cancellous bones in PA imaging. In the OA cartilage, the signal from the cartilage surface was irregular and weak but strong in the subchondral bone in US imaging. However, higher signal intensity was observed in the articular cartilage and subchondral bone in PA imaging.

Conclusions: In the OA cartilage, the PA signal from the subchondral bone was stronger than that from the subchondral bone of the normal cartilage. The results suggest the possibility of increased blood flow together with inflammation. The combination of US and PA imaging is more sensitive than US alone for the evaluation of the OA cartilage.



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ACCESSIBILITY TO COMBINED ASSESSMENT OF MORPHOLOGY AND PHYSIOLOGY IN ARTICULAR CARTILAGE USING 23NA/1H COIL AT 1.5 TESLA MRI

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Purpose: Osteoarthritis (OA) can be characterised by the gradual loss of articular cartilage (AC). At the early stages of OA, physiological (loss of proteoglycan associated with loss of sodium) and morphological (thickness, surface curvature, volume) changes in AC have been measured. Magnetic Resonance Imaging (MRI) at >3Tesla provides an excellent anatomy (morphology) and quantification of various compositions (physiology) of. This work aims to investigate the possibilities of combined assessment of AC morphology and physiology using 23Na/1H coil at 1.5Tesla MRI.

Methods: Four human knee scans were performed at 1.5T clinical MR system using a dual tuned knee coil (23Na/1H). RF field inhomogeneity of coil is corrected using the fiduciary markers and then, performance of the coil was evaluated by measuring a signal-to-noise ratio (SNR) as shown in Figure 1(a). For the sodium imaging, a 3D Gradient Echo sequence (TR=11.4ms, TE = 4.0 ms, flip angle = 62°, image resolution = 2.81x2.81x 8mm3, and scan time ~30 min) was used. A calibration marker (300mmol/L sodium concentration) was placed next to the human knee as sodium reference. Proton imaging was performed using 3D MEDIC sequence (TR=37ms, TE=20 ms, flip angle=8°, image resolution = 0.47x0.51x1.5mm3, and scan time ~5 min). Physiology of AC is assessed by measuring sodium concentration from sodium knee MR images using the Equation 1.

$$[Na]AC = (SNa/S(Naref))*[Na]ref \quad (1)$$

where, [Na]AC - Sodium concentration in AC, SNa and SNaref - mean signal intensities in cartilage and sodium reference, respectively and [Na]ref - 300mmol/L sodium concentration. For the morphology, cartilage region in proton images were enhanced by fusing sodium information extracted from sodium images with proton images and an automated extraction of cartilage boundary is performed. >

Results: Dual tuned ("23Na/1H") knee coil allows acquisition of sodium images with significant SNR values in standard phantom (~5.93) cartilage region (~8.3) and sodium marker region (~12.5) that shows an adequacy of physiological imaging. However, a RF field inhomogeneity was observed during the experiment which was corrected in sodium images using the fiduciary markers as shown in Figure 1(b) and 1(c). Sodium concentration in AC was measured from the sodium images that were acquired after the correction of RF field inhomogeneity. The results as shown in Figure 2 (first row) demonstrate that the sodium concentration measured in AC from 4 data sets (estimated sodium concentration ~225 ± 19 mmol/l, coefficient of variation- 8.4%) matches to the values reported earlier. Furthermore, extracted sodium region in all slices were re-sampled using cubic spline interpolation followed by the normalization of slices which were then merged with

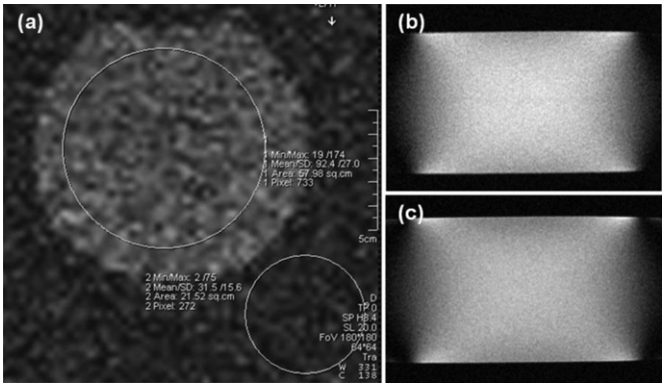

Figure 1. Dual tuned knee coil performance measurement: (a) Signal-to-noise ratio (SNR) measurement in phantom image as the ratio of mean signal intensities in region of interest to standard deviation of signal-free area from MR images and (b) Sodium image of phantom before correction of RF homogeneity and (c) after correction of RF homogeneity.

proton slice sequence as shown in Figure 2 (second row). Here, cartilage boundaries are extracted automatically using the enhanced information in cartilage.

Conclusions: Direct measurement of sodium concentration in AC enables early OA detection while extracted cartilage boundaries in fused images may enable reconstruction of 3D models of articular cartilage that can be used to measure accurate cartilage thickness on load wearing sites as well as in different zones. This study confirms that use of dual tuned knee coil will enable the combined assessment of cartilage physiology and morphology for early detection of OA.

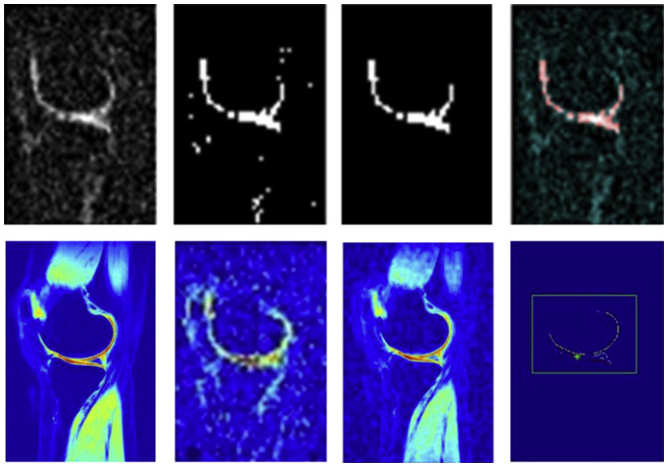

Figure 2. Physiological and morphological measurements: First row-sodium signal intensity extraction in cartilage, Second row-fusion of sodium image with proton and cartilage boundary extraction.

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7 TESLA SODIUM (23NA) IMAGING FOR THE ASSESSMENT OF PATELLAR CARTILAGE DAMAGE AFTER PATELLA-DISLOCATION: PRELIMINARY RESULTS

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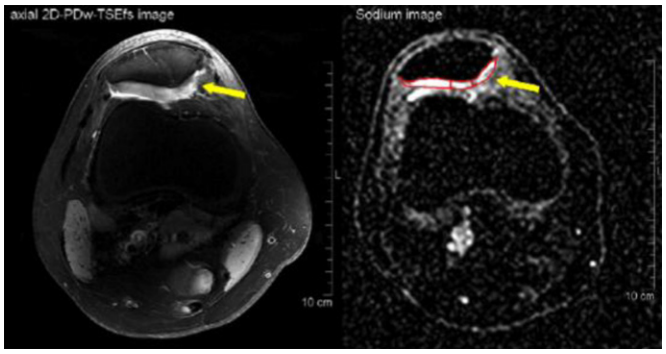
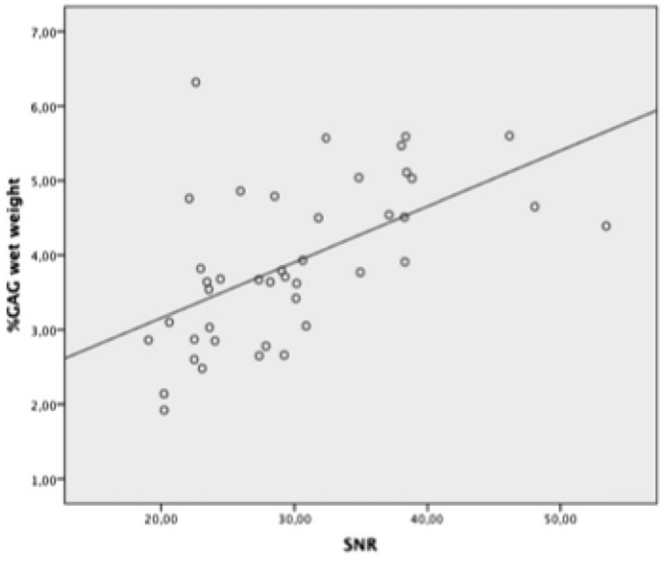
Purpose: As OA is resulting in total joint replacement, it is of high interest to detect early changes of the articular cartilage. In the last decade, great afford has been made to develop biochemical MRI techniques, in order to determine the composition of articular cartilage. One of these techniques is Sodium imaging which directly correlates with the quantitative occurrence of glycosaminoglycans (GAG). Loss of GAG is known as the earliest change of cartilage degeneration before other changes occur. The purpose of this study was to evaluate the feasibility of 23Na (sodium) MR imaging, for the detection of OA at the patella cartilage in patients after patella-dislocation and to compare the results to healthy volunteers and cadaver samples.

Methods: Nine patients after patella-dislocation, mean age 26.4 years (± 5.6), nine healthy volunteers, with a mean age of 26.1 years (±5.0) and 5 cadaveric samples (mean age 75.8 ± 7.4 years), were enrolled in this study. All measurements were performed on a 7T MR whole body system (Magnetom, Siemens Healthcare, Erlangen, Germany) using a twenty-eight-channel transmit/receive knee array coil (Quality Electrodynamics LLC, Cleveland, OH, US) and a 15-channel 23Na-only transmit/receive knee coil (Quality Electrodynamics LLC, Cleveland, OH, US). For morphological imaging a 2D-PDw-TSEfs-sequence (TR/TE = 4390/26 ms; FOV = 159*130 mm2, 20 slices; matrix size = 448*366; resolution = 0.36*0.36*3.0 mm3; flip angle = 130; bandwidth = 245 Hz/pixel) and a T1w-3D-GRE sequence (TR/TE = 8.3/3.57 ms; FOV = 185*156 mm2, 224 slices; matrix size = 384*324; resolution = 0.48*0.48*0.48 mm3; flip angle = 8; bandwidth = 450 Hz/pixel) were performed. Axial sodium images were derived from an optimized 3D GRE-sequence (TR/TE = 17.0/8.34 ms; FOV = 190*190 mm2, 32 slices; matrix size = 64*128; resolution = 1.48*1.48*3.0 mm3; bandwidth of 80 Hz/pix; 13 averages; 50 degree flip angle). Morphological cartilage grading was performed and sodium SNR values were calculated. Mean global sodium-values and SNR were compared between patients and volunteers and cartilage defect grades using an analysis of variance. In cadaver samples, the patella was divided into medial and lateral and from each side, 5 contiguous cartilage samples were analyzed with a GAG assay (Blyscan B3000 GAG Assay) for GAG content quantification. These values were compared with SNR values.

Results: The mean SNR in sodium images for cartilage was 13.5±2.5 in patients and 14.8 ±3.7 in volunteers (p= 0.014). ANOVA-analysis yielded a marked decrease of the sodium-SNR with increasing grade of cartilage lesions (0.002). SNR values according to the number of patella dislocations also showed significantly different values (P= 0.010). The mean SNR in sodium images for cadaver samples was 27.4 ± 8.4 on the medial side of the patella and 30.6 ± 8.2. on the lateral side. The mean GAG values were 3.9 ± 1.1 %GAG wet weight on the medial side and 3.9 ± 11 %GAG wet weight on the lateral side. The results between sodium SNR and the biochemical assay demonstrated a statistical significant correlation (r=0.563; p<0.001).

Discussion: The results demonstrate the feasibility of 23Na (sodium) MR imaging for the detection of defects of the patella cartilage in patients after patella dislocation. The data depict a lower GAG content in patients after patella dislocation. These results are in good agreement with findings by Sillanpää et al. Furthermore sodium imaging in patella cadaver samples has shown a high correlation with histochemical evaluation of GAG content. In conclusion, 23Na MR imaging helps to differentiate between native and degenerated patella cartilage in patients after patella luxation and has the potential to detect early stages of OA.





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MULTIPLE SUBCHONDRAL CYST FORMATION HAS STRONG CORRELATION WITH BONE SCLEROSIS: EX VIVO HR-PQCT STUDY

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