Comparison of T1rho imaging between spoiled gradient echo (SPGR) and balanced steady state free precession (b-FFE) sequence of knee cartilage at 3 tesla

Poster No.: C-0291
Congress: ECR 2015
Type: Scientific Exhibit
Authors: T. Nozaki, Y. Kaneko, H. Yu, K. Kaneshiro, R. Schwarzkopf, H. Yoshioka; Orange, CA/US
Keywords: Musculoskeletal joint, MR-Functional imaging, Imaging sequences, Arthritis
DOI: 10.1594/ecr2015/C-0291

Any information contained in this pdf file is automatically generated from digital material submitted to EPOS by third parties in the form of scientific presentations. References to any names, marks, products, or services of third parties or hypertext links to third-party sites or information are provided solely as a convenience to you and do not in any way constitute or imply ECR's endorsement, sponsorship or recommendation of the third party, information, product or service. ECR is not responsible for the content of these pages and does not make any representations regarding the content or accuracy of material in this file.

As per copyright regulations, any unauthorised use of the material or parts thereof as well as commercial reproduction or multiple distribution by any traditional or electronically based reproduction/publication method is strictly prohibited.

You agree to defend, indemnify, and hold ECR harmless from and against any and all claims, damages, costs, and expenses, including attorneys' fees, arising from or related to your use of these pages.

Please note: Links to movies, ppt slideshows and any other multimedia files are not available in the pdf version of presentations.

www.myESR.org
Aims and objectives

Osteoarthritis (OA) is one of the most prevalent disorders in today’s society, resulting in significant socio-economic costs and morbidity (1). A host of new and exciting therapeutic modalities are being developed for the treatment of OA, which include new chondroprotective and chondroregenerative drugs, osteochondral autografting, and autologous chondrocyte implantation. Therefore it is important to detect early cartilage degeneration and understand its natural progression for treatment of OA.

Novel MRI pulse sequences for cartilage assessment have recently received increased attention due to newly developed protocols for physiologic MRI, which include T2 mapping and T1rho mapping (2,3). By providing the information of interactions between motion-restricted water molecules and their local macromolecular environment within cartilage with these techniques, we are able to know the degree of degeneration in cartilage. Increases in T2 relaxation time of cartilage have been associated with matrix damage, particularly with loss of collagen integrity. In contrast, the T1rho relaxation rate in cartilage decreased linearly with the percentage of proteoglycan loss (4,5). T1rho mapping has been shown to be more sensitive to biochemical change in cartilage than T2 mapping, and has enabled early detection of cartilage degeneration in early OA patients before gross morphological change (6,7).

However, it is not well understood what can be considered as a normal range of T1rho values, and factors affecting T1rho mapping such as MR imaging protocols and post-imaging processing like the methodology of operator-dependent manual cartilage segmentation. Many reports have been recently published regarding the T1rho values of healthy and damaged knee cartilage. Their MRI protocols and methodology of segmentation vary among these reports. Regarding MRI sequences, there are two basic types of fast gradient echo (GRE) sequences used in T1 rho mapping. One is a spoiled GRE sequence; residual transverse magnetization is spoiled. The other is a steady-state GRE sequence; transverse magnetization is not spoiled but is refocused to contribute to steady-state formation (8). There is no previous report that compares these two sequences. For clinical use and comparison of the results in previous reports, it is important to know the characteristics and differences of two sequences.

Therefore, the purpose of this study was to investigate reproducibility of cartilage segmentation and the difference of T1rho profiles between spoiled gradient echo (SPGR) and balanced steady state free precession (b-FFE) sequences.

Methods and materials
20 healthy volunteers (mean: 28.9 y.o., range: 19-38) were recruited in this study. Inclusion criteria for all subjects were at least 18 years of age and younger than 40 years of age with no symptoms and no history of knee surgery. The study was approved by institutional review board. Written informed consent was obtained from each person.

All MR studies were performed on a 3.0-T unit (Achieva, Philips Healthcare, Netherland) utilizing an 8-channel knee receive-only RF-coil. Two sagittal T1rho-weighted images of each subject were acquired on the pulse sequence of b-FFE and SPGR. All sagittal images were obtained without oblique angulation, parallel to the magnetic static field (B0). The acquisition parameters were as follows. SPGR: mode = 3D, fat-saturation method = PROSET, TR/TE = 6.4/3.4msec, Band width = 475Hz, ETL = 64, NEX = 1, FOV = 140*140mm, Slice thickness/gap = 3/0mm, Flip angle = 10 degree, Image-matrix = 512*512mm, number of slices = 31, spin-lock frequency = 575 Hz, Time of spin-lock (TSL) = 20/40/60/80msec, acquisition time = 4min09sec *4, and b-FFE: mode = 3D, fat-saturation method = SPIR, TR/TE = 4.8/2.4msec, Band width = 606 Hz, ETL = 154, NEX = 1, FOV = 140*140mm, Slice thickness/gap = 3/0mm, Flip angle = 25 degree, Image-matrix = 512*512mm, number of slices = 31, spin-lock frequency = 575Hz, Time of spin-lock (TSL) = 20/40/60/80msec, acquisition time = 3min57sec *4. Parallel imaging was used on all imaging sequences utilizing Sensitivity Encoding (SENSE) with an acceleration factor of 2.

Images were transferred in DICOM (Digital Imaging and Communications in Medicine) format to a personal computer (PC; Windows 7), which was used to perform all post-processing and analyses. For possible motion between the scans T1rho series were first realigned with respect to the first TSL images using rigid-body transformation before being fitted to mono-exponential function on a pixel-by-pixel basis for generation of T1rho maps: \( S(TSL) = S_0 \times \exp(-TSL/T1rho) \), where \( S_0 \) is the signal intensity when TSL=0. Cartilage was extracted from the first TSL images on a slice-by-slice basis. T1rho angle-dependent profile was investigated by angular segmentations in step of 4-degree over the length of segmented cartilage (the angle 0 defined along B0) (Fig.1). All of image processing described above was performed using an in-house developed and implemented software in Matlab (Mathworks, Natick, MA, USA).

Manual cartilage segmentation of the entire knee was performed in each T1rho image by a board-certified orthopaedic surgeon and a board-certified radiologist sub-specialized in musculoskeletal radiology independently. Images of TSL=20msec were used for cartilage segmentation because the signal to noise ratio (SNR) was the highest. The inter- and intra-observer reproducibilities of cartilage segmentation on two T1rho images were measured.

We calculated the average T1rho values of entire femoral cartilage with 4-degree stepwise analysis on both T1rho sequences, and compared the difference of T1rho values between two sequences.
A board-certified radiologist measured the mean and standard deviation (SD) of signal intensity (SI) of the cartilage, joint fluid and subchondral bone of the knee, placing regions of interest (ROI) into each of the 20 knee by the same method which was previously reported (9). The ROIs were identical in size and placed in identical positions on matching sections. We used relative SI and relative contrast for direct comparison of image quality between the SPGR and b-FFE images, because all sequences in our study were obtained with a parallel imaging technique. Relative SI of each structure was calculated SI/SD. Relative contrast of "structure A" to "structure B" was defined as \((\text{SI}_A - \text{SI}_B)/\sqrt{(\text{SD}_A^2 + \text{SD}_B^2)}\).

The difference of T1rho values between SPGR and b-FFE sequences was statistically analyzed using the Wilcoxon signed-rank test. Comparison of relative SI and relative contrast between two T1rho sequences were also analyzed using Mann-Whitney test.

Inter-observer reliability and the variability of T1rho values between two imaging protocols were calculated as inter- and intra-class correlation coefficient. In the evaluation of the reproducibility of segmented area between two operators and intra-operators, we performed Bland-Altman plots analysis.

Statistical analyses were performed with use of R version 3.0.2 for Windows software (R Development Core Team, Vienna, Austria).

Images for this section:

Fig. 1: Sagittal images from T1rho sequence of knee MRI after manual segmentation with post-processing. (A) Spoiled gradient echo (SPGR) image. (B) balanced steady state free precession (b-FFE) image. Two observers segmented the entire femoral cartilage of the both images slice by slice independently. After manual segmentation, angular analysis in step of 4-degree was performed automatically.
Results

Intra- and inter-observer reproducibility of manual segmentation between SPGR and b-FFE sequences

Figure 2 summarizes the inter- and intra-observer reproducibility regarding the T1rho values and segmented area in the each layer. For measurements of average T1rho values of entire femoral cartilage, the interclass correlation coefficient was higher on SPGR (0.846) than on b-FFE (0.824). Intraclass correlation coefficient in the whole layer was also higher on SPGR (0.878) than on b-FFE (0.836).

The correlation coefficient of the segmented area between two operators is 0.641 on SPGR and 0.588 on b-FFE, and the correlation coefficient between intra-operators is 0.858 on SPGR and 0.796 on b-FFE. The intra- and interobserver reproducibility of segmented area was higher on SPGR than on b-FFE.

Quantitative analysis with relative signal intensity and relative contrast

Figure 3 and 4 showed mean values of relative SI and relative contrast on each sequence. Relative SI of cartilage was 11.86±4.17 (mean±SD) on SPGR and 13.03±6.81 on b-FFE, respectively, without significant difference. The relative SI of joint fluid was higher on SPGR than b-FFE with significant difference (p<0.001), while that of subchondral bone was higher on b-FFE than SPGR with significant difference (p<0.001). Relative contrast of fluid-cartilage was a positive value with 4.53±1.62 on SPGR and a negative value with -3.50±3.31 on b-FFE. Relative contrast of fluid-subchondral bone on SPGR was higher than that of b-FFE. Likewise, that of cartilage-subchondral bone on SPGR was higher than b-FFE. There were significant differences in fluid-cartilage, fluid-subchondral bone, and cartilage-subchondral bone relative contrast (all p<0.001) between two sequences.

Analysis of T1 rho profiles

Figure 5 showed T1rho profiles on both sequences. T1rho values tend to be greater on b-FFE sequence than on SPGR sequence in all layers. There was angular variation of T1rho profiles on both sequences. Average T1rho value of the femoral cartilage was 56.97±2.82 on SPGR and 59.54±2.82 on b-FFE with significant difference (p<0.05).

Images for this section:
**Fig. 2:** ICCs and B-A plots for intraobserver and interobserver reproducibility

<table>
<thead>
<tr>
<th>Analyses</th>
<th>SPGR</th>
<th>b-FFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interobserver reproducibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1rho value</td>
<td>0.866 (0.757, 0.904)</td>
<td>0.824 (0.665, 0.903)</td>
</tr>
<tr>
<td>Segmented area</td>
<td>0.641</td>
<td>0.588</td>
</tr>
<tr>
<td></td>
<td>-0.065</td>
<td>-0.036</td>
</tr>
<tr>
<td>Intraobserver reproducibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1rho value</td>
<td>0.878 (0.806, 0.925)</td>
<td>0.836 (0.741, 0.898)</td>
</tr>
<tr>
<td>Segmented area</td>
<td>0.858</td>
<td>0.796</td>
</tr>
<tr>
<td></td>
<td>0.171</td>
<td>0.16</td>
</tr>
</tbody>
</table>

**Fig. 3:** Comparison of relative signal intensity (SI) of each structure between SPGR and b-FFE. The relative SI of joint fluid was higher on SPGR, while that of subchondral bone was higher on b-FFE with significant difference (p<0.001). There was no significant difference in relative SI of cartilage.
Fig. 4: Comparison of relative contrast between SPGR and b-FFE. There were significant differences in relative fluid-cartilage, fluid-subchondral bone, and cartilage-subchondral bone contrast (all p<0.001) between two sequences.
Fig. 5: Comparison of T1rho value of entire femoral cartilage between SPGR and b-FFE. T1rho values tend to be greater on b-FFE sequence than on SPGR sequence. There was angular variation of T1rho profiles on both sequences.
Conclusion

Inter- and intra-reader reproducibility of measurement on femoral cartilage T1rho mapping is excellent on both SPGR and b-FFE sequences and higher on SPGR than b-FFE. T1rho value tends to be higher on b-FFE than SPGR. We need to pay attention to factors of different sequences which causes variability of T1rho values in clinical applications.

Personal information

References