Optimization and Reproducibility Evaluation of Volumetric Cartilage Measurements of the Knee at 1.5T and 3T

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Introduction

Osteoarthritis is a slowly progressive disease characterized morphologically by destruction of cartilage and changes of the adjacent bone such as sclerosis, edema and osteophytes. Cartilage loss is one of the earliest symptoms and can be non-invasively monitored by volumetric measurements obtained from analysis of high resolution MR-images (1). Different studies showed the feasibility of this method, but as high resolution and signal-to-noise ratio (SNR) are needed, imaging time was a major drawback in these studies. However, recent developments in MR-imaging with new pulse sequences, coils and higher field strength can improve these imaging variables. The purpose of this study was twofold: to optimize different pulse sequences at 1.5T and 3T in terms of SNR and contrast-to-noise ratio (CNR), limiting the scan time below six minutes and to compare the different optimized sequences concerning precision and accuracy in quantifying cartilage volume.

Material and Methods

MR images of fresh porcine knees were obtained at 1.5 Tesla and 3 Tesla (Signa, General Electric, Milwaukee, WI) using a quadrature knee coil. Between the measurements, the porcine knees were stored at -80°C. For imaging, the knees were thawed to room temperature in a water quench. At 1.5T we optimized imaging parameters for a fat-saturated spoiled gradient echo sequence (fs-SPGR) varying bandwidth (BW), flip angle (α) and echo time (TE). The repetition time (TR) was chosen as short as possible. Other parameters were kept constant. At 3T the analogous optimization was performed for an fs-SPGR sequence, a water excitation spoiled gradient echo sequence (WE), and a fast imaging employing steady-state acquisition (FIESTA) sequence. Performance of the optimized sequences was compared in terms of SNR and CNR efficiencies. SNR Efficiency (S_E) was defined as the signal intensity (SI) of cartilage divided by the standard deviation (SD) of the background intensity and the square root of the scan time in seconds. CNR efficiency (C_E) was defined as SI of the cartilage minus SI of the menisci and adjacent ligaments divided by the SD of the background and the square root of the scan time. For each imaging sequence a protocol with optimal S_E and C_E at a scan time less than six minutes was chosen to image 20 knees with fivefold repetition of four knees for precision measurements (see Tab. 1). The coefficient of variation (CV% = SD / mean volume) was taken as reproducibility error of each specimen. The precision of the method was calculated as the root-mean-square of the four measured individual reproducibility errors. After the imaging, the cartilage was scraped off and the volume was directly measured using a saline displacement method. The accuracy of the method was calculated as the relative difference and the correlation between the MR-based and the saline displacement volume measurement. For the volumetric measurements only preliminary data from the patella are available at this point.

Results

SNR and CNR efficiencies achieved with the different imaging sequences are shown in Fig.1. All values were plotted relative to the S_E and C_E of the SPGR sequence at 3T, which were 6.2 $s^{-½}$ and 2.6 $s^{-½}$ respectively. The difference between the 3T and 1.5T images is evident: the S_E for the SPGR sequence is 2.3-fold higher at 3T and the C_E is even 4.3-fold higher. Among the sequences used at 3T, the FIESTA sequence performed worst. It had the lowest S_E and C_E as well as significantly more artifacts (see upper part of the patella in Fig. 2). The WE sequence had the highest S_E and C_E, though, the differentiation between cartilage of patella and femur was worse than for the SPGR sequence (see Fig.2).

First results for the volumetric measurements at the patella revealed a precision error of 4 % using the WE-images at 3T. The relative difference of direct and MR-based volume calculation was 5%, 8% and 11% for the WE sequence at 3T, SPGR at 3T and SPGR at 1.5T, respectively. The correlation between direct and MR-based measurements was r = 0.95, r = 0.91 and r = 0.88 for the WE sequence at 3T, SPGR at 3T and SPGR at 1.5T, respectively (n = 18, $p < 0.01$).

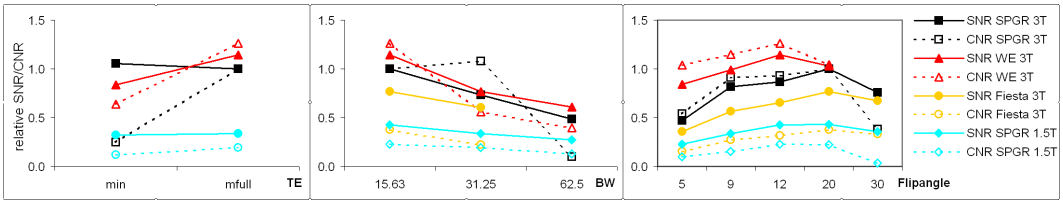

Fig. 1: Optimization of different sequences at 1.5T and 3T.

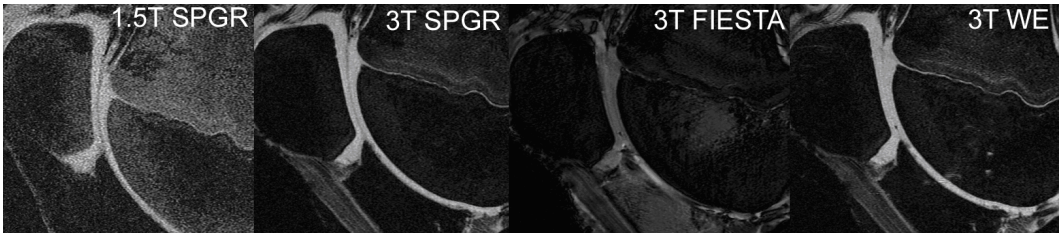

Fig. 2: Representative images of the optimized sequences.

	1.5T SPGR	3T SPGR	3T FIESTA	3T WE
TR (ms)	27.5	27.4	23.1	27.5
TE (ms)	7.5	10.62	11.4	13.12
Flip Angle	20	20	20	12
BW (kHz)	31.25	15.63	14.71	15.63
Time (min)	5:38	5:38	5:20	5:38

Tab.1: Different scan parameters for the used sequences. Common parameters:
Resolution: 0.19 x 0.39 x 1.50 mm/Voxel
Number of slices: 48
Number of Excitations: 1

Discussion

MR imaging of articular cartilage for volumetric measurements involves many technical challenges (2). High resolution, good contrast and SNR have to be achieved within a reasonable scan time. The potential of 3T imaging could be impressively demonstrated in this study. S_E and C_E were improved more than twofold; on the other hand imaging time could be substantially cut down, still resulting higher SNR than at 1.5T. Though advantages in SNR have been reported for the FIESTA sequence, it performed worse than the SPGR sequence in our study (3). Especially due to more artifacts, it is not suitable for volumetric cartilage measurements. With the 3T-WE sequence the cartilage volume could be determined with good precision and accuracy. Compared to earlier studies using 1.5T (accuracy 5.9% - 8.2%) our results were comparable for the SPGR sequence, and slightly better for the WE sequence, with using only about half of the scan time (1).

References

(1) Peterfy CG et al. Radiology 1994; 192(2):485-491.
(2) Eckstein F. Methods Mol Med 2004; 101:191-218.
(3) Hargreaves BA, et al. Magn Reson Med 2003; 49(4):700-709.

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