Real Time fat suppressed MRI of the knee joint during flexion/extension allows the study of PCL motion

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Introduction: The added value of dynamic MRI over conventional static imaging has already been demonstrated in several studies in which bone kinematics could be evaluated during both active and passive motion [1]. However dynamic imaging of soft tissues in the knee such as ligaments and tendons has been investigated less extensively, mostly due to the technical and practical challenge of dynamic fat suppressed imaging during movement of the knee joint. Fat-suppression techniques to be used in real time imaging of joints in fact should not significantly lengthen the acquisition time for a single frame and should also be relatively insensitive to B_0 homogeneity, since significant field distortions are expected as the leg is moved through the scanner bore. The **aim** of this study is to optimize and compare two different chemical shift-based methods for water-fat separation in real time at 3T, namely PS-bSSFP (Phase Sensitive balanced SSFP) and FLASH Dixon and to explore their possible application in the evaluation of posterior cruciate ligament (PCL) during active motion.

Methods: 5 healthy volunteers were scanned with a 3T scanner (Philips Ingenia, Best, The Netherlands). Subjects were placed in the lateral position to allow the maximum range of motion inside the 70 cm diameter scanner bore and asked to periodically flex and extend their knee. A single slice was planned with the knee placed in approximately 15 degrees flexion in such a way to visualize both tibial and femoral attachment point of the PCL. A foam cushion was placed underneath the subject's lateral epicondyle to provide a pivot point in order to maintain the motion of the PCL in the sagittal plane. The maximum achievable knee flexion angle was dependent on the size of the subject and ranged from 45 to 80 degrees. Data was acquired using a 16 channels Torso coil placed on top of the leg of interest, in combination with the posterior coil embedded into the scanner table. In order to minimize banding artifacts in bSSFP sequences in the patella area during motion a pillow filled with pineapple juice was placed on the anterior side of the lower leg.

Acquisition parameters common to the Dixon and bSSFP acquisition were: 2D single slice acquisition, FOV=400x400 mm^2, slice thickness=5 mm, pixel size 1x1 mm^2 and 200 ms temporal resolution. *bSSFP:* flip angle=35°, TR=2.4 ms, TE=1.2 ms. *2 points Dixon:* FLASH sequence with flip angle=8°, TR=4 ms, TE_1=1 ms, TE_2=1.8 ms. For each technique several dynamic datasets were acquired, and series were selected based on highest overall image quality, least imaging artifacts, and largest range of motion. In these series the length of the ligament was measured by manual segmentation of its posterior and anterior surface. The same acquisition parameters used for dynamic imaging were also used for acquisition of two images of the knee in a single flexion position, which were used for SNR calculation.

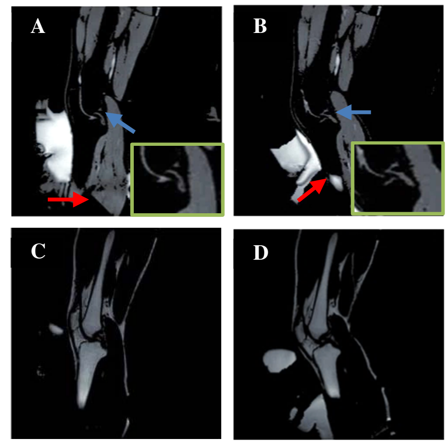

Fig 1: Selected frames with separation of water (A,B) and fat (C,D) components based on PS-bSSFP. The PCL is indicated by the blue arrow. Note the false water/fat separation indicated by the red arrow, which corresponds to banding artifacts in the original image.

Water and fat images based on Dixon were reconstructed on-line by the scanner software. For the images based on PS-bSSFP, both magnitude and phase images were exported and reconstruction was performed offline. Phase images were unwrapped and corrected using a phase errors removal algorithm, as proposed in [2]. With the selected repetition time and center frequency, the water and lipid signal show180º phase difference, and this can be exploited to separate the pixels into water and fat images.

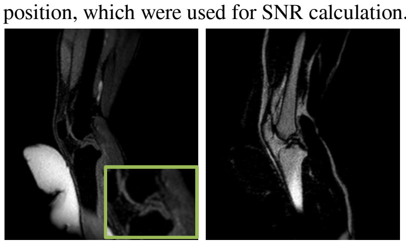

Fig 2: Selected frames with separation of water (A) and fat (B) components based on 2 points DIXON.

Results: Water images obtained from PS-bSSFP (fig. 1) showed an improved SNR (SNR_{PCL}=42.0±10.0) when compared to water images reconstructed from Dixon FLASH (SNR_{PCL}=12.5±2.6) (fig. 2). The higher contrast between PCL and bone and PCL and fat in bSSFP sequences allowed for good visualization and segmentation of the structure, which was not possible in the Dixon-based water images. The PCL appeared curved at relaxed extension, and the curvature decreased for increasing flexion angle, in agreement with the hypothesis that the PCL is slack at full flexion and is increasingly loaded for increasing flexion angles of the knee. The length of the ligament was observed to increase for increasing flexion angle. Results of manual segmentation of the anterior and posterior surface of the posterior cruciate ligament in a dataset with flexion angle ranging from 0° to 80° are shown in figure 3. A gradual decrease in ligament length is observed as the knee moves from maximum flexion to full extension and a similar rate of increase in length can be seen as the knee returns to the flexed position.

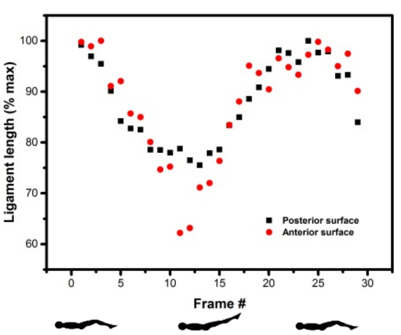

Fig 3: PCL elongation during flexion. Results are indicated as percentage of the maximum observed ligament length, which was measured when the knee was at the maximum achievable knee flexion angle.

Discussion and Conclusion: bSSFP in combination with Phase Sensitive reconstruction allows for robust water and fat separation in dynamic MRI imaging of the knee and for segmentation of the posterior cruciate ligament during motion. The trend of increase in length as a function of the flexion angle is in agreement with previously reported cadaveric experiments [3]. The proposed bSSFP-based imaging technique provides increased CNR of the ligaments compared to Dixon FLASH for equal temporal and spatial resolution. One of the well- known limitations of bSSFP approaches is the high sensitivity to B_0 homogeneity, which can be especially dramatic when large tissue motion occurs through the scanner bore. Since the proposed approach for water-fat separation is based on a standard bSSFP acquisition, it doesn't involve any lengthening of the repetition time and consequently doesn't result in increased sensitivity to off-resonance effects, making it suitable for the study of soft tissue structure in the knee during motion. The ability of visualizing and tracking soft tissue structures in the knee during motion, as preliminarily shown in this work, could greatly enhance biomechanical knowledge of the lower extremities and could add clinically relevant information to the conventional static images.

References: [1] d'Entremont et al, Magnetic Resonance in Medicine 69:1634–1644 (2013). [2] Hargreaves et al. Magnetic Resonance in Medicine 50:210-213 (2003). [3] Belvedere et al, Journal of Biomechanics 45:1886-1892 (2012).