Visualization of the anterior cruciate ligament using 3D ultrashort echo-time MR imaging at 3.0T

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Introduction

Anterior cruciate ligament (ACL) injury is one of the most common, and serious, injuries in sports. In Japan more than 20,000 athletes per year suffer an ACL injury. Operative reconstructions with bone-patellar tendon-bone or quadrupled semitendinosus tendon grafts are usually performed. At least six months of athletic rehabilitation are needed after the operation in order to regain lost muscle power and to mature the grafted tendons. MRI plays an important role in supporting the diagnosis of acute and chronic ligament injures; however, currently the only method available to measure the maturation of tendons and ligaments is the ultrashort echo-time (UTE) technique [1, 2]. UTE techniques can visualize short-T2 components in highly ordered tissues such as tendons, ligaments, menisci, or periosteum. Thus, after cruciate ligament repair they may offer direct positive contrast ACL visualization and provide excellent contrast between normal tissue and affected tissue. Furthermore, 3D UTE techniques yield isotropic spatial resolution, allowing for easy data reformatting to visualize the course of the ACL through the knee anatomy. On the other hand, in MR imaging of the knee the magic angle phenomenon can greatly affect the appearance of the ligaments. The aim of this work is to demonstrate the potential of 3D UTE imaging for visualization of the knee ligaments, especially the ACL.

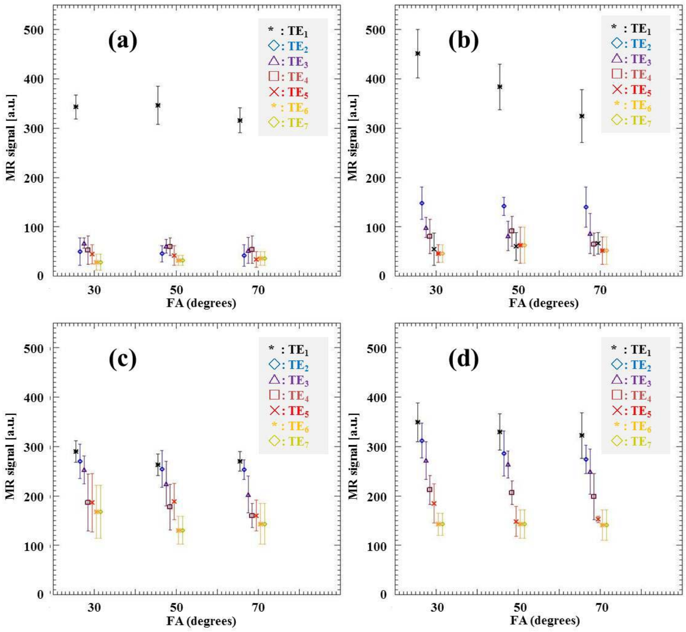

Figure 1. MR signals at several FA. (a) Patellar ligament (PL), (b) Lateral collateral ligament (LCL), (c) Anterior cruciate ligament (ACL), (c) Posterior cruciate ligament (PCL). $TE_1 = 0.07$ ms, $TE_2 = 2.46$ ms, $TE_3 = 4.92$ ms, $TE_4 = 7.38$ ms, $TE_5 = 9.84$ ms, $TE_6 = 12.30$ ms, $TE_7 = 14.76$ ms. The LCL MR signal in TE_1 decreased as the FA increased.

Methods

Measurements were performed on a 3.0T clinical whole body MR system (Magnetom Verio; SIEMENS AG, Erlangen, Germany) using an eight-channel knee coil (Invivo, Gainesville, FL). The pulse sequence was a fat suppressed ultrashort TE (FUTE) with repetition time (TR) = 39.00 ms, echo time$_1$ (TE_1) = 0.07 ms, $TE_2 = 2.46$ ms, $TE_3 = 4.92$ ms, $TE_4 = 7.38$ ms, $TE_5 = 9.84$ ms, $TE_6 = 12.30$ ms, $TE_7 = 14.76$ ms, $TE_8 = 17.22$ ms, $TE_9 = 19.68$ ms, $TE_{10} = 22.14$ ms, matrix size 192×192, flip angle (FA) = 30, 50, 70, bandwidth (BW) = 635 Hz/Px, voxel size = 0.937×0.937×0.937 mm, field of view (FOV) = 180mm×180mm, NEX = 1, and an acquisition time of 6 min 30 s (for 1 echo). All TE were in phase, and the signal gain of the MR signals was constant. The FUTE sequence was SIEMENS' work-in-progress (W.I.P.). Knee imaging was performed in healthy male volunteers ranging in age from 21 to 34 years. Regions of interest (ROI) were set at several places in patellar ligament (PL), anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), and lateral collateral ligament (LCL). After scanning, the images were transferred to a computer for image analysis using Image J, a Java-based version of the public domain NIH image software (Research Services Branch, National Institutes of Health). In addition, we used Interactive Data Language (IDL: ITT Visual Information Solutions, Boulder, CO, USA) for analysis. The image analysis data were used to calculate averages and standard deviations. The MR signals for each TE, and the subtracted MR signals (SUB) from the MR signal of the first echo to the MR signal of each subsequent echo (e.g. SUB_{12} = MR signal of TE_1 ($MRTE_1$) -MR signal of TE_2 ($MRTE_2$)), were compared.

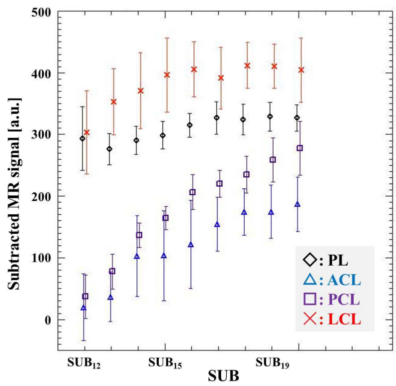

Figure 2.The changes of subtracted MR signals (SUB) in FA = 30. $SUB_{12} = MRTE_1 - MRTE_2$, $SUB_{15} = MRTE_1 - MRTE_5$, $SUB_{19} = MRTE_1 - MRTE_9$. Patellar ligament (PL), anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), and lateral collateral ligament (LCL).

Results and Discussion

Figure 1 shows representative changes in the MR signals at each FA. The MR signals in regions affected by the magic angle phenomenon (PL, ACL, and PCL) did not changed with the FA. However, the LCL MR signal in TE_1 decreased as the FA increased. Because TR, TE and T1 are constant, these results could be influenced by the recovery of longitudinal magnetization at the larger FA. Hence, we suggest that a smaller FA is optimum for UTE imaging. Figure 2 shows representative changes of SUB at FA = 30 degrees. For both the PL and the LCL all SUB values are high, including SUB_{12}, and good subtracted dFUTE images were generated of both ligaments. However, visualization of the ACL and PCL using subtracted FUTE imaging was not possible at SUB values under SUB_{16}. These results are in agreement with previously published signal intensity data [3]. Figure 3 shows representative subtracted d FUTE images of the right knee. If the TE of the subtracted echo is less than 12.30 ms, then the ACL is affected by the magic angle phenomenon and cannot be clearly visualized. Thus, we suggest that the subtracted echo in 3T must be set to a TE of more than 12.30 ms to optimize visualization of the ligaments of the knee.

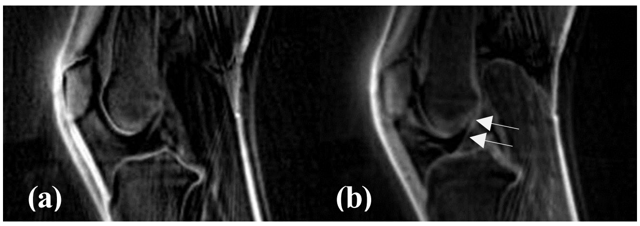

Figure 3: Representative right knee d FUTE images at FA = 20. d = different image produced by subtraction of a subsequent image from the first. (a) d FUTE (TR/TE = 39/0.07 minus 2.46) images, (b) d FUTE (TR/TE = 39/0.07 minus 12.30) images. Arrows denote the ACL.

Conclusion

In this study we demonstrate the potential of UTE techniques for MR imaging of the knee. If we utilize appropriate imaging parameters, UTE imaging can directly visualize short-T2 components in all ligaments of the knee.

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