SLIPS - A Novel Method for Rapid Three-Dimensional Spin-Locked Imaging

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Objective

To develop a novel 3D $T_{1\rho}$ MRI pulse sequence based on the balanced steady-state free precession method for time-efficient *in vivo* $T_{1\rho}$ mapping.

Background

A variety of tissue pathologies have been studied *in vivo* by employing $T_{1\rho}$, the spin-lattice relaxation time in the rotating frame. In particular, it has been shown that $T_{1\rho}$ may serve as a surrogate indicator of early degeneration of cartilage (1, 2). However, time requirements for relaxation mapping and RF specific absorption rate (SAR) issues make the current pulse sequence highly time inefficient for certain clinical applications. In the present work, Spin-Locked Imaging with Precession in the Steady State (SLIPS), a novel pulse sequence that allows rapid 3-dimensional $T_{1\rho}$-weighted MRI and overcomes the above-mentioned issues, is described. Performance of the sequence was demonstrated on the human knee, *in vivo*.

Materials and Methods

The Institutional Review Board of our institute approved all experiments. $T_{1\rho}$ mapping was performed on a 1.5T Siemens Sonata clinical MRI scanner using an 8-channel knee coil. For this work, we imaged agarose phantoms and healthy volunteers. For phantom and human scanning, $T_{1\rho}$-weighted image volumes were acquired at 5 to 7 spin-locking times (TSL) ranging from 1 to 40 ms. Figure 1 shows the sequence used. Linear regression was used to fit these volume datasets on a voxel-by-voxel basis to the following equation $S(TSL)=S_0e^{-TSL/T1\rho}$, where $S(TSL)$ is the image intensity for a given voxel. The values calculated were then compiled to generate 3-dimensional $T_{1\rho}$ maps.

Results and Discussion

Phantom data results were used to choose an appropriate value for Delay Time that provides the greatest reduction in imaging time while maintaining sufficient $T_{1\rho}$-weighting and satisfying SAR restrictions. Region of Interest (ROI) analysis of the human cartilage $T_{1\rho}$ maps shows an excellent correlation between SLIPS-acquired values and those calculated from a current "gold standard" turbo spin-echo based $T_{1\rho}$ MRI sequence. As such, we have demonstrated that the SLIPS-sequence enabled us to perform an exam on a human volunteer in less than thirty minutes, including a collection of $T_{1\rho}$ maps in two views (sagittal and axial).

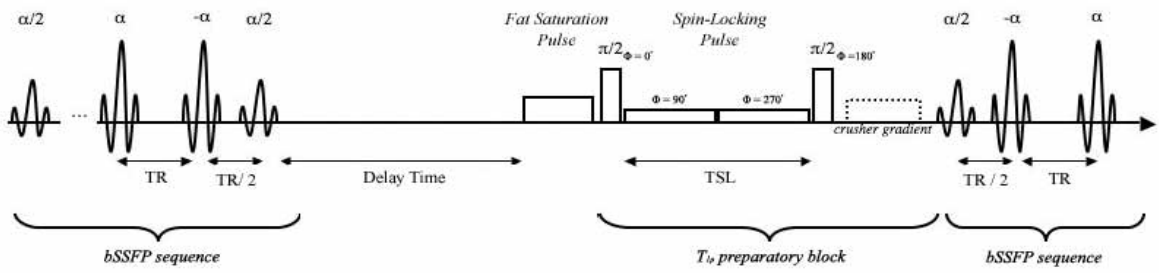
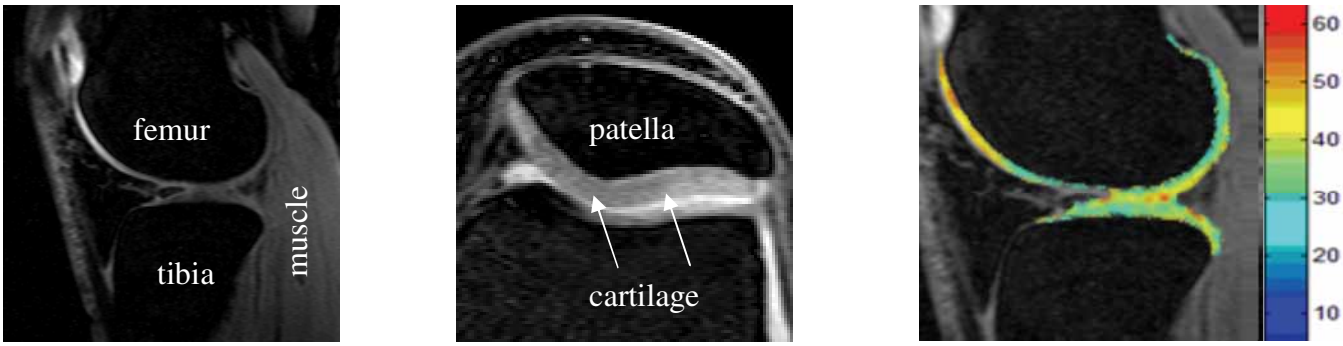


Figure 1: The SLIPS sequence is a variation of a 3-dimensional balanced Steady-State Free Precession (b-SSFP) sequence (3, 4). The k-space of the imaging region is segmented into slices. In each segment, a fat saturation pulse is applied, followed by a spin-locking pulse cluster. There is then a b-SSFP acquisition scheme followed by a variable Delay Time, after which this cycle is repeated with the next segment.



A **B** **C**

Figure 2: Representative SLIPS images of the knee joint of a healthy volunteer in the sagittal (A) and axial (B) views. The anatomy of the knee joint (bright signal from cartilage and synovial fluid, dark signal from bones such as the femur, tibia and patella) is clearly visible in images. A SLIPS-acquired color map (C) of the articular cartilage of the femoral-tibial joint of a volunteer overlaid on a sagittal SLIPS-acquired $T_{1\rho}$–weighted image (in grayscale) of the volunteer's knee joint. The color bar scale indicates $T_{1\rho}$ values in milliseconds.

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