Full-Flexion Patellofemoral Joint Kinematics with Real-Time MRI at 0.5T

J. M. Santos[1], G. E. Gold[2], T. F. Besier[3], B. A. Hargreaves[1], C. E. Draper[3], G. S. Beaupre[4], S. L. Delp[5], J. M. Pauly[1]

[1]Electrical Engineering, Stanford University, Stanford, California, United States, [2]Radiology, Stanford University, Stanford, California, United States, [3]Mechanical Engineering, Stanford University, Stanford, California, United States, [4]Palo Alto VA Medical Center, Palo Alto, California, United States, [5]Bioengineering, Stanford University, Stanford, California, United States

Introduction: Patellofemoral (PF) joint maltracking and other kinematic alterations may increase the stress on the knee cartilage and produce pain. However, clinical studies have not been able to clearly demonstrate alignment differences between patients with PF pain and healthy individuals. We have developed a real-time imaging method that will allow us to study the PF joint kinematics and relate them to clinical PF pain.

Methods: To study the PF joint kinematics under physiologic loading conditions, we designed a custom-built backrest to be placed inside an open GE Signa SP magnet. This setup allows the subject to be in an upright, weight-bearing position and perform squats from full extension to 80 degrees of free flexion (see figure 1). We use the RTHawk real-time system [1] for imaging. This system provides great flexibility for the pulse sequence design as well as the necessary infrastructure for real-time acquisition, control and reconstruction. As we are interested in dynamically imaging the bony structures, the acquisition method was designed to enhance bone marrow contrast, while at the same time providing good temporal and spatial resolution.

Excitation: The frequency separation between fat (bone marrow) and water at 0.5T is only 73Hz. Chemically-selective imaging then becomes time consuming, limiting the temporal resolution of the acquisitions. Alternatively, fat-water contrast can be increased by selecting an appropriate flip angle given the relative T1 of bones/fat and muscle. In particular, for a 30 ms TR we selected an angle of 30 degrees. This is a good compromise between the Ernst angle for the bone marrow and minimizing signal from the muscles.

Figure 1: Backrest placed inside the SP magnet.

Readout: We used a spiral acquisition to efficiently traverse k-space. Long readouts are typically chosen to increase the temporal resolution by reducing the number of acquisitions required. Unfortunately this also makes the acquisition more sensitive to phase errors due to off-resonance. A 6 interleave 16 ms readout trajectory was designed to obtain 5.5 full frames per second (fps) with 2.6 mm spatial resolution over a 20 cm FOV. To minimize image blurring, the RF excitation was tuned to the fat (bone marrow) center frequency instead of water, since this is the brightest component.

Given the hardware constraints, for a particular FOV and resolution, temporal resolution can be further increased by undersampling certain spatial frequencies. By allowing the high spatial frequency components to alias, variable density spirals allow increased temporal resolution without introducing significant artifacts [2]. With respect to uniform density spirals, if the spatial resolution is fixed, the number of acquisitions or the readout length can be reduced. We have also designed a variable density spiral (VDS) trajectory for the same resolution and FOV with 4 interleaves of 16 ms duration. Sampling frequency was linearly reduced from 20 cm FOV for low spatial frequencies to 6.8 cm FOV for high spatial frequencies. The reduction in number of acquisitions increases the temporal resolution to 8.2 full fps, allowing us to study fast joint motion closer to physiological loading conditions.

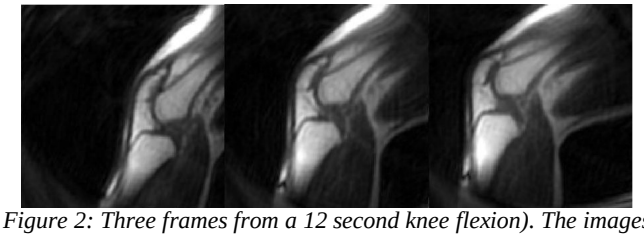

Figure 2: Three frames from a 12 second knee flexion). The images were acquired with uniform density spirals at 5.5 FPS.

Figure 3: VDS acquisition at twice the flexion rate (6 seconds) acquired at 8.2 FPS. Note that the increased aliasing artifacts don't obscure the area of interest.

Results and Discussion: Six healthy volunteers were studied. To increase SNR and for mechanical flexibility purposes, a transmit/receive crown coil was placed around the knee. A 5.8 mm excitation pulse was used in all the experiments. Figure 2 shows several frames of a continuous acquisition using the uniform density spiral acquisition. Figure 3 shows frames of an acquisition using the VDS trajectory, where the patient was asked to do squats at twice the rate of the first experiment (12 seconds for full flexion and back to extension). The VDS acquisition shows an increased level of artifacts that are outside the area of interest, but has the advantage that resolves the faster motion adequately.

Conclusions: We have developed a real-time system for joint-motion studies in an open 0.5T scanner. Our technique allows for 8.2 fps, 20 cm FOV, 2.6 mm resolution and adequate SNR for imaging bone in motion.

References: [1] Santos J, Wright G, Pauly J, IEEE EMBS 26th, 1048, 2004. [2] Tsai, C, Nishimura D, Mag Res Med. 43:452 (2000).