# Estimation of Patellar Tendon Strain In Vivo During Static and Dynamic Loaded Knee Flexion

C. Draper[1], T. Besier[1], J. Santos[2], S. Blemker[3], J. Pauly[2], G. Beaupre[4], S. Delp[3], G. Gold[5]

[1]Dept. of Mechanical Engineering, Stanford University, Stanford, CA, United States, [2]Dept. of Electrical Engineering, Stanford University, Stanford, CA, United States, [3]Dept. of Bioengineering, Stanford University, Stanford, CA, United States, [4]Bone and Joint Center, Palo Alto VA Healthcare System, Palo Alto, CA, United States, [5]Dept. of Radiology, Stanford University, Stanford, CA, United States

**Introduction:** Characterizing the *in vivo* motion of the bones, ligaments, and muscles of the knee is critical to understanding normal and pathological knee mechanics. For example, the extensibility of the patellar tendon affects the motion of the patella, the mechanical advantage of the quadriceps, the joint reaction forces, and may be related to clinical disorders such as patellar tendonitis. Patellar tendon strains have been measured previously in cadavers [1] and *in vivo* [2] using cine phase contrast MRI under minimal loading conditions. However, it is not clear whether these measurements represent the behavior of the patellar tendon under physiological loading conditions. Using an open MR scanner, we have obtained images during static, weight-bearing knee flexion [3]. Additionally, recent advances in MR technology have enabled real-time image acquisition of joint motion [4]. In the current study, we collected static and real-time MR images in an open scanner and established the feasibility of measuring the patellar tendon strains during static and dynamic weight-bearing knee flexion.

**Methods:** We examined four volunteers with no history of knee injury or surgery. Using a 0.5T Signa SP open MRI scanner, we obtained static images as subjects maintained upright, loaded postures at knee flexion angles of 30° and 60°. Real-time images of loaded, dynamic knee flexion were then acquired from one subject who slowly flexed from full extension to 60°, while maintaining an upright, weight-bearing posture. A custom-built backrest [3] reduced motion artifact during image acquisition. We acquired the static images using a transmit-receive coil, a sagittal spoiled gradient echo sequence, and a 20cm field-of-view. The imaging matrix was 256x160 with a TR/TE of 33/9ms and a 45-degree flip angle. We acquired 32 sections of 2mm thickness in a scan time of 2:13m [3]. An undersampled spiral sequence was used to obtain real-time images using the same coil and field-of-view. Our spiral sequence used 6 interleaves, a 16ms readout trajectory, and had a spatial resolution of 2.6mm. Images were obtained at 5-6 frames per second.

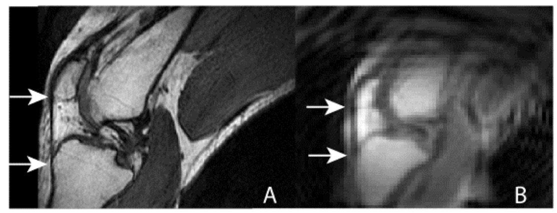


**Figure 1:** MR images indicating the origin and insertion of the patellar tendon. A) Static image of knee at 30° of knee flexion. B) Single frame of real-time movie of dynamic knee flexion showing knee at 30° of knee flexion.

The strain in the patellar tendon ($\varepsilon$) was calculated as the stretch of the tendon ($\Delta l$) divided by the rest length of the tendon ($l_R$). That is, $\varepsilon = \Delta l / l_R$. The stretch was calculated as the difference between the length of the patellar tendon and its rest length. The length of the tendon was measured from the inferior pole of the patella to the insertion on the tibial tuberosity (Figure 1). The resting length of the tendon was defined as the length of the tendon at 30° of knee flexion in a non-weight-bearing condition. This angle was chosen to avoid the effects of tendon crimping at full extension. Values of patellar tendon strain were measured at 30° and 60° during static knee flexion and at 3° increments during dynamic flexion. We determined the knee flexion angle in the dynamic images by visual comparison with the corresponding static images and interpolating between 30° and 60°. Measurements of patellar tendon length in the static images were taken in a plane similar to that seen in the real-time images.

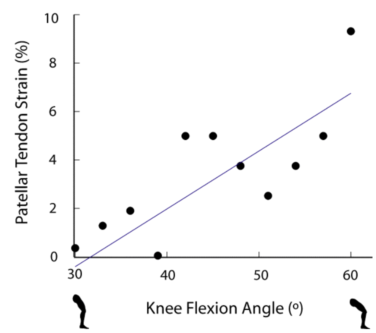


**Figure 2:** Plot of patellar strain measurements (single subject) during dynamic knee flexion. The curve represents a linear fit to the strain data.

**Results:** Figure 1 presents a sample image acquired during static knee flexion and a single frame of the real-time movie of dynamic flexion. Real-time images contained minimal motion artifact in the center of the field-of-view (Figure 1B), enabling us to measure the length of the tendon at numerous knee flexion angles. The average patellar tendon strains of our four subjects in the static condition were 3 ± 2% and 5 ± 3% at 30° and 60° respectively. Figure 2 presents the patellar tendon strains in one subject during dynamic knee flexion from 30° to 60°. To avoid errors due to tendon crimping at low flexion angles, we limited strain calculations to those occurring during this range of motion.

**Discussion:** These results demonstrate that patellar tendon strains can be measured under upright, weight-bearing load from both static and real-time MRI. The advantage to using real-time image acquisition is that we can obtain continuous measurements of tendon length under dynamic conditions. However, several limitations should be addressed. Patellar tendon strain measurements are influenced by the calculation of the resting length of the tendon. Due to crimping in the tendon, this rest length is difficult to determine; therefore, we measured the resting length of the tendon from a non-weight-bearing position of 30° knee flexion. Additionally, measurement errors in tendon length can occur if the patellar tendon moves out of the imaging plane during the dynamic movement. Finally, the spatial resolution of the real-time images in the open scanner is 2.6mm, which may account for strain differences of up to 6%. To reduce these errors and improve the repeatability of patellar tendon strain measurements we will develop a robust method of determining rest length of the tendon and use a rigid-body tracking algorithm to determine the three dimensional kinematics of the patella, femur, and tibia.

**Conclusion:** This study demonstrates the feasibility of extracting measurements from static and real-time MRI of individuals moving under physiologically loaded conditions. These *in vivo* measurements can improve our understanding of the passive structures of the knee and the function of these structures under loaded joint movement.

**References:**

1. Benedict, JV J Biomech 1:53-63 (1966)
2. Sheehan and Drace, Clin Orthop, 370:201-207 (2000)
3. Gold, et al., J Magn Reson Imaging, 20:526-530 (2004)
4. Santos, et al., IEEE EMBS 26th, 1048, 2004