A dynamic measurement method for knee biomechanics

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INTRODUCTION Osteoarthritis is generally believed to be initiated by, and its progression facilitated by, abnormal joint mechanics such as those caused by obesity and poor joint alignment, which are both risk factors for knee joint cartilage loss[1]. While altered forces (magnitude and position) have long been identified as causes of osteoarthritis, recent work has also implicated kinematics (specifically velocity at the joint surface) in cartilage damage in a canine model[2].

Our overall aim involves relating cartilage health to mechanical factors in the knee, primarily knee kinematics. We are currently able to assess the joint kinematics at static positions over a range of motion (ROM) under loading using a validated magnetic resonance (MR) imaging technique[3]. Limitations of this method include the static nature of the scans and the limited number of flexion positions we can image in a reasonable time. To help address these limitations, we developed a new dynamic imaging method for kinematic measurement in MR. The purpose of this study was to test the viability of this protocol.

METHODS A MR-compatible loading rig was created to allow free leg motion with a force of 15% body weight applied in the ankle-hip direction. A novel stretchable 8-channel knee coil array was used which permits knee flexion while maximizing the SNR independently of the knee size and shape[4]. A fast imaging protocol based on an ultrafast gradient echo sequence with water suppression was developed to image the knee in motion.

One normal female subject (32, right knee) was imaged on a 3T Philips Achieva scanner. One high-resolution scan was taken (multi-slice T1-weighted FSE, 8:52 min), which provided detailed subject-specific bone models. Then three types of low-resolution loaded scans were taken: static standard (16 slices, 2D TSE, 38 seconds), static fast (8 slices, ultrafast gradient echo, 1.5 seconds) and dynamic (30 sets, 8 slices each, ultrafast gradient echo, 45 seconds). The two static scans were performed together at each flexion angle. The dynamic scan was performed following six sets of static scans. Angles for the static scans were chosen to cover the same flexion range as the dynamic scan. The subject was asked to move very slowly during the dynamic scan, but no specific rate of motion was required.

In each image, bones were segmented to create bone models. Anatomical axes were added to the high-resolution models, and these models were then shape-matched to each low-resolution set (static standard, static fast, dynamic). Finally, translations and rotations for the tibia and patella were calculated with respect to the femur. Each kinematic parameter was plotted against tibial flexion. Differences between the static standard and static fast parameter results were calculated for each flexion angle.

RESULTS The average differences between the two types of static scans were 0.93 degrees and 0.69 mm. The ROM of the static scans was 5.5 to 26.1 degrees, while the ROM of the dynamic scans was 4.2 to 24.3 degrees. The subject performed about two knee flexion cycles.

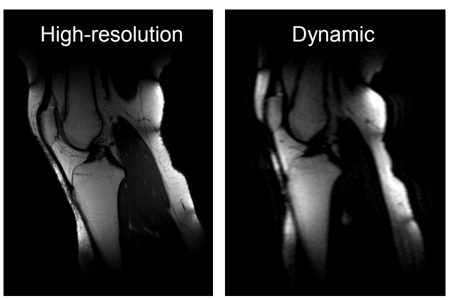
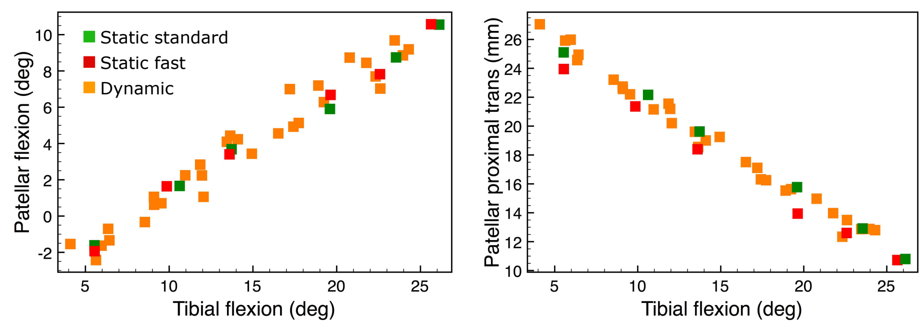


Figure 1: Sample images



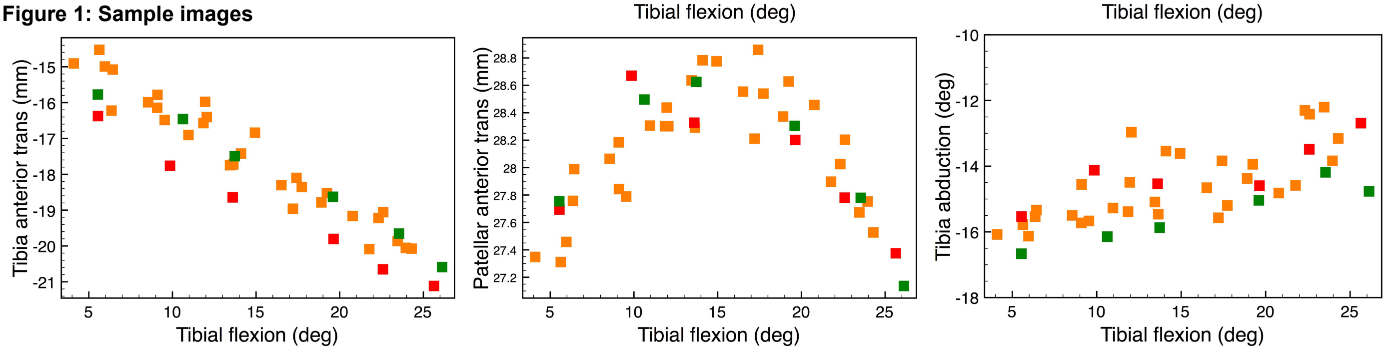


Figure 2: Several representative kinematic parameters (rotations and translations) of tibia and patella.

DISCUSSION The average differences between static scans are less than the method's stated mean errors of 1.75 degrees and 0.88 mm[3]. While we only have one subject, there is no initially observable difference in kinematics between static and dynamic data.

Advantages of the dynamic sequence, beyond the actual moving of the joint, include faster collection of data and more flexion angles, which reduces the burden on the subject and increases the richness of the data. Having more data points allows a better understanding of changes in each parameter with knee flexion. Also, data covering the range of motion can be collected in just one knee flexion cycle. Limitations of this study include the single subject, although scanning of subjects continues. Another limitation is the ROM of the dynamic scans due to the need to keep the knee in the center of the FOV. A prone subject position would permit a larger ROM. Additionally, we are limited to very slow knee motions.

Other applications of dynamic scanning for kinematic measurement include a method using cine phase contrast MR (cine-PC)[5]. While this approach provides rich velocity data and the ability to record faster motion, drawbacks include longer imaging time and the need to synchronize motion with acquisition. These two methods (cine-PC and current) seem to be complementary and each may be appropriate for particular applications.

In conclusion, this is a viable method for measuring the kinematics of the knee which allows much faster scanning of subjects, requires a minimum of knee flexion cycles and permits a mechanical environment closer to that of daily activities than previous static work.

1. Wilson DR, Rheum Dis Clin North Am 2008, 2. Anderst WJ, J Orthop Res 2009, 3. Fellows RA, JMRI 2005, 4. Nordmeyer-Massner JA, ISMRM 2008, 5. Sheehan FT, J Biomech 1998