The Effects of Gait on In Vivo Tibiofemoral Cartilage Strains

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Disclosures:

Introduction: During gait, the knee joint experiences cyclic loads several times greater than body weight [1]. In response to compressive loading, articular cartilage behaves like a biphasic viscoelastic material, with deformation causing an outflow of interstitial fluid. The subsequent reabsorption of fluid back into the cartilage is time dependent and may take times on the order of hours to fully recover due to the low permeability of cartilage [2]. Thus, previous studies have utilized magnetic resonance (MR) imaging methods to measure volumetric changes in cartilage by imaging joints immediately following activities such as running, hopping, bending, and static postures [3-4]. However, there is limited data characterizing the compressive strains experienced by tibiofemoral cartilage during gait [5], an essential activity of daily living. This data is important for understanding the biomechanics of normal joint function. Furthermore, these data could provide insight into the mechanisms by which altered cartilage loading can predispose the joint to the development of osteoarthritis [6]. Thus, the purpose of this study was to directly measure compressive strain in response to gait on tibiofemoral cartilage in normal, healthy knees.

Methods: Six healthy adult subjects (4 male and 2 female; 22-30 years of age, average BMI of 22.2) participated in this study. Subjects had no history of injury or surgery to either knee. The study was conducted in the morning, and subjects were instructed to minimize load bearing activity the day prior to testing. Subjects first lay supine for 45 minutes to allow for cartilage equilibration. Subjects had their selected knee (4 right knees, 2 left knees) imaged using a 3T scanner (Trio Tim, Siemens) while lying in a supine position and with their knee relaxed. Sagittal plane images (field of view: 16 cm×16 cm, resolution: 512×512 pixels, thickness: 1 mm) were generated using a double-echo steady state sequence (DESS, flip angle: 25°, TR: 17 ms, TE: 6 ms) [7-8].

After initial MR imaging, subjects walked on a treadmill (F80, Sole Fitness) in a room adjacent to the MR scanner for 20 minutes at a speed of 2.5 mph. After completion of the walking activity, subjects immediately underwent a post-activity MR scan of the same knee. Each MR scan took approximately 10 minutes to complete. The outer margins of bone and cartilage surfaces were manually segmented and converted to 3D surface mesh models [8]. This method accurately measures tibiofemoral cartilage thickness to within 1% [8].

Pre- and post-activity bony models were registered using an iterative closest point technique (Geomagic Studio, Geomagic Inc.). Next, a uniform grid system was created to span the femoral condyles (36 points) and tibial plateaus (18 points) (Figure 1A) [8]. Cartilage thickness was calculated at each individual mesh node (Figure 1B, 1C). Strain was defined as the normalized change in thickness before and after activity and was calculated at each grid point by averaging all nodes within a 2.5 mm radius of the grid point. A two-way ANOVA was used to determine whether location and activity had statistically significant effects on cartilage thickness. Differences were considered statistically significant where p < 0.05.

Results: Cartilage on the lateral tibial plateau was significantly thicker on average than cartilage on the medial tibial plateau (p < 0.001). Walking resulted in a statistically significant decrease in tibial cartilage thickness (p<0.001), corresponding to a compressive strain of 4%. No statistically significant interactions were observed between activity and location (p = 0.30). Medial and lateral femoral cartilage thicknesses were similar (p =0.96). Walking resulted in a statistically significant decrease in femoral cartilage thickness (p<0.001), corresponding to a relatively small compressive strain of 1% (p < 0.001). No statistically significant interactions were observed between activity and location (p = 0.40).

Discussion: Walking is an important activity of daily living. However, there is limited in vivo data characterizing the effects of gait on cartilage loading [5]. The current study used a new methodology to measure in vivo tibiofemoral cartilage strain in normal, healthy knees in response to walking on a treadmill for 20 minutes. The results show that walking causes significant compressive strain in the tibiofemoral cartilage. This decrease in cartilage thickness after dynamic activity is likely due to exudation of water from the cartilage matrix during loading.

In this study, the tibial cartilage experienced larger compressive strains (4%) compared to femoral cartilage (1%). This is potentially due to the larger areas of contact that femoral cartilage experiences during dynamic flexion-extension movements. In contrast, smaller areas of tibal cartilage may be more consistently loaded throughout knee motion. Establishing baseline strain data for normal knee function is essential to understanding mechanisms of the pathogenesis of knee conditions [8]. Therefore, characterizing the effects of gait on cartilage compression will provide important information regarding the mechanisms by which alterations in normal joint motion contribute to the development of osteoarthritis.

Significance: This study measured in vivo tibiofemoral cartilage strains in response to walking. This data provides important...
information regarding cartilage function during an essential activity of daily living. Characterizing normal cartilage function is essential to understanding how altered joint loading can predispose the knee to the development of osteoarthritis.

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Figure 1: A) 18 point tibial grid used for computing cartilage strain. 9 points were included for each compartment on the tibial plateau. B) Representative Pre-Activity cartilage thickness map. C) Representative Post-Activity cartilage thickness map.