***In Vivo* Time-dependent 3D Morphology of Loaded Articular Cartilage of the Tibiofemoral Joint: a Proof-of-concept Study**

PURPOSE – A solid understanding of the biomechanical characteristics of cartilage can provide valuable insights into joint health. In numerous instances, joint disorders have been linked to altered biomechanical characteristics of cartilage.[1, 2] The biomechanical behavior of cartilage can be best described when the cartilage is considered as a multi-phasic medium[3] with time-dependent creep response under a constant load. Given that *in vivo* cartilage deformation on the sub-millimeter scale occurs mostly in the first few minutes after compression,[4, 5] MRI has a limited ability to capture the time-dependent response of cartilage due to its relatively long imaging time and lower spatial resolutions, compared to CT systems. Here, we measured the *in vivo* time-dependent cartilage deformation during constant loading of ¾ body weight using contrast-enhanced C-arm cone-beam CT (CECT).

METHODS – A healthy volunteer was recruited for arthrography of the knee joint under an IRB-approved protocol. A standard non-ionic iodinated contrast agent (Omnipaque 300) of 40ml at 50% dilution was injected into the knee joint. The scanning protocol consisted of a single supine scan (non-weight-bearing, shown in Fig.1[a]), followed by standing scans (weight-bearing, shown in Fig.1[b]) at four early time points (5sec, 15sec, 25sec, and 1min) and two late time points (5min and 15min) after a load of ¾ body weight was applied. A multi-sweep C-arm CT scan protocol was used to obtain the first three standing scans (5sec, 15sec, and 25sec). A force plate with 0.3N resolution was incorporated into the standing platform to help the volunteer maintain the desired constant load throughout the standing scans with visual feedback. The acquired images were reconstructed as a 3D volume with 0.20mm isotropic voxel size using filtered back projection. Bones and cartilage were segmented to create point cloud models. After smoothing the point clouds, they were fit by triangular meshes. Based on the created cartilage surfaces, the voxel-wise compressive strain (% change in thickness) of the tibial cartilage was calculated as shown in Fig. 1(c). The region of interest for the strain analysis was the contact area between the tibial and femoral cartilage surfaces.

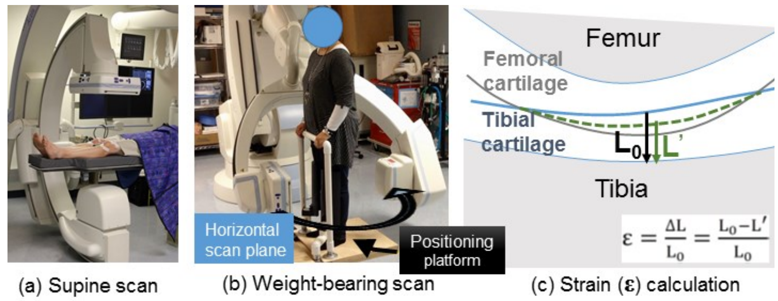

Figure 1. Experimental setups to calculate a subject-specific relative change (i.e., engineering strain) in the tibial cartilage thickness. A healthy volunteer was scanned while (a) on the patient table (b) or standing in a C-arm CT scanner. (c) The voxel-wise strain was calculated as the ratio of cartilage thickness change ($L'-L_0$) to the initial cartilage thickness (L_0), where L' and L_0 were measured from the weight-bearing and non-weight-bearing scans, respectively.

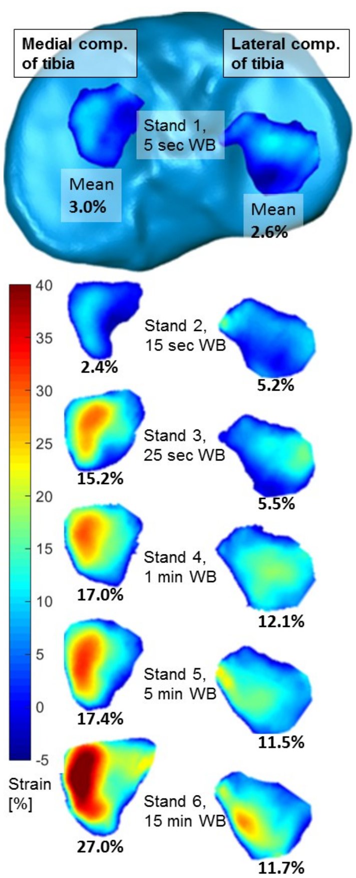

Figure 2. Tibial cartilage strain (%) distribution in the medial and lateral compartments of the tibia at six different weight-bearing (WB) time points (Stands 1-6).

RESULTS – By implementing a multi-sweep protocol, the 3D cartilage deformation at the early time points (5sec, 15sec, 25sec, and 1min) was acquired. The values of the strain ranged from approximately -5 to 40% (Fig. 2). The strain in the medial and lateral compartments generally increased over time. Figure 3 presents the mean strain in the two compartments to visually compare the mean values as a function of time. Given the mean values at the early time points, the mean sharply increased within 1min. As time further elapsed, the mean generally reached a plateau in the lateral compartment as expected, but continued to slowly increase in the medial compartment. The behavior of the last data point in the medial compartment needs to be confirmed with additional data.

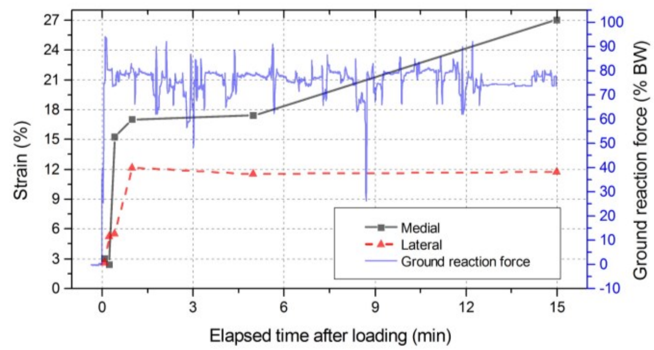

Figure 3. The mean of the strain in the medial and lateral compartments as a function of time; ground reaction force corresponding to the elapsed time after weight-bearing.

DISCUSSION – The preliminary results showed time-dependent creep deformation behavior in the tibial cartilage under compressive static loading. The creep response of osteoarthritic (OA) cartilage is expected to differ from that of normal cartilage, since damage to articular cartilage is one of the features of OA[6]. We expect that both the initial (first minute) and secondary rate and magnitude of the deformation response curve will vary with degenerative state, and these metrics may be valuable as indicators of OA severity and progression. Diffusion of the contrast agent in articular cartilage is a potential confounding factor, and we are working on decoupling the diffusion effects from tissue deformation.

CONCLUSION – Tibial cartilage showed a time-dependent creep deformation behavior during compressive static loading. Future work to determine whether differences exist in the creep response of cartilage between OA and normal cartilage makes CECT as a possible indicator of progression of OA.

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REFERENCES – [1] Swann et al, Br J Rheumatol (1993) [2] Eckstein et al, Surg Radiol Anat (1993) [3] Morton et al, Am J Occup Ther (1990) [4] Halonen et al, J Biomech (2014) [5] Hosseini et al, Osteoarthr Cartilage (2010) [6] Buckwalter et al, Clin Symp (1995)