# The relationship between cartilage strain during downhill running and cartilage degeneration after anterior cruciate ligament reconstruction

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**INTRODUCTION**: Cartilage degeneration has been observed within 1 year after anterior cruciate ligament reconstruction (ACLR) using T2 magnetic resonance imaging (MRI) [1]. T2 relaxation time is believed to be a biomarker for cartilage degeneration because it reflects the loss of proteoglycan and collagen [3]. One of the risk factors for cartilage degeneration after ACLR is abnormal kinematics [4], which leads to abnormal stresses on articular cartilage [5]. Cartilage strain is said to reflect cartilage contact stress [6], however, there are no reports of an association between cartilage strain during high demand activity and cartilage degeneration after ACLR. Therefore, the purpose of this study was to evaluate the relationship between cartilage strain during downhill running and cartilage degeneration after ACLR. We hypothesized that cartilage strain during running and cartilage degeneration would increase with time after ACLR and that localized increases in cartilage strain during running would be associated with localized increases in cartilage degeneration after ACLR.

**METHODS**: Patients who underwent anatomic ACLR within 1 year of injury were enrolled following institutional review board approval and informed consent. ACL reconstructed knees were imaged within a biplane radiography imaging system (150 images/sec, 90kV, 160mA, 1ms exposure) for three trials during downhill running (10° slope) at 3 m/s on an instrumented treadmill. Tibiofemoral motion was tracked using a validated volumetric model-based tracking process that matched digitally reconstructed radiographs, obtained from CT, to the synchronized biplane radiographs [7]. Knee kinematics during the first 10% of the gate cycle were calculated following standard conventions [8]. Patient-specific cartilage models, derived from 3D-DESS MRI, were registered to CT-based bone models and cartilage contact strain was calculated from the tibiofemoral cartilage thickness and overlap distance [9]. Averaged data over the three trials each test session were included in the analysis. T2 relaxation time was calculated from a seven-echo sagittal T2-weighted MRI (Siemens Magnetom Trio 3T) using a pixelwise nonlinear least squares fit [10]. Both biplane radiography and MRI data were collected at 6 and 24 months after ACLR. The tibial plateau was divided into 9 sub-regions and the femoral condyle was divided into 18 sub-regions (Figure 1), and the average cartilage contact strain and the average T2 relaxation time were calculated within each region, per compartment. Wilcoxon signed rank test was used to test for differences in cartilage strain and T2 relaxation time between 6 to 24 months after ACLR. The correlation between changes in cartilage T2 relaxation time and cartilage strain between 6 to 24 months after ACLR was evaluated using Spearman's rho, with significance set at $p < 0.05$.

**RESULTS**: 36 patients (12 females; age 21.3±7.1 years, BMI 25.4±3.4 kg/m$^2$) with complete datasets were included in this study. On the femoral side, cartilage contact was seen only in zones 2-4, so only these regions were evaluated. Cartilage strain decreased from 6 to 24 months in eight regions of the medial compartment and four regions of the lateral compartment (Figure 2A). T2 relaxation time increased in one region of the femur and in two regions on the tibia, and relaxation time decreased in four regions on the tibia. A positive correlation between the change in cartilage T2 relaxation time and the change in cartilage contact strain from 6 to 24 months was found in the cental region of Zone 2 in the lateral tibia, while a negative correlation between cartilage strain and T2 relaxation time was observed in the cental region of Zone 2 in the medial tibia and in the central region of Zone 3 in the lateral tibia (Figure 2B).

**DISCUSSION**: Contrary to our hypotheses, we did not find consistent increases in cartilage strain or cartilage degeneration from 6 to 24 months after ACLR. Similarly, a positive correlation between change in cartilage strain and change in T2 values was observed for only one cartilage region. These results may be related to the fact that all surgeries were anatomic ACLR, which have a lower risk of developing post-traumatic osteoarthritis compared to non-anatomic ACLR [11]. Study limitations, including measuring cartilage strain for only a portion of the gait cycle, the relatively short time between observations (18 months), and the relatively small sample size may have influenced these results. Although previous studies suggest that ACLR may change cartilage contact location [12] and T2 relaxation time after ACLR [1], the association between those changes may be too small to detect given the sample size. These inconsistent findings do not support the theory that abnormal loading after ACLR is associated with changes in cartilage health. Other factors, such as cartilage damage at the time of injury, may also need to be considered when investigating the etiology of osteoarthritis after ACLR.

**SIGNIFICANCE**: Although changes in cartilage health and changes in cartilage contact after ACLR have been previously reported, the association between cartilage contact and cartilage health remains unclear.

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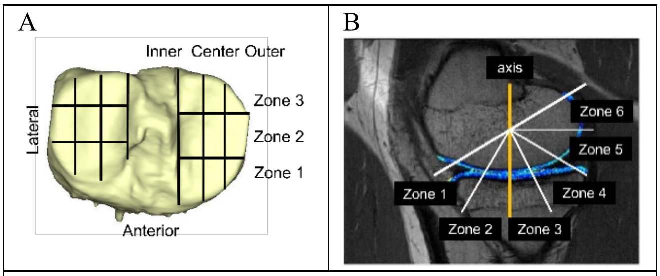


*Figure 1. Division of cartilage zones A) Each tibial plateau was divided into nine sub-regions. B) The femoral condyle was divided into 18 sub-regions. The zones were divided by 30 degrees based on the long axis. Each was divided into outer, center, and inner sections.*

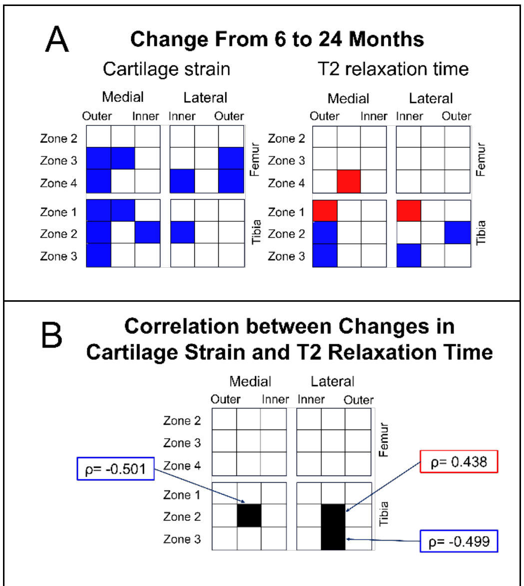


*Figure 2. (A) Changes from 6 to 24 months in cartilage strain and T2 relaxation time (B) Correlation between changes in cartilage strain and T2 relaxation time. Red: Significant increase, Blue: Significant decrease*