TIBIA-FEMUR JOINT SPACE IN UNINJURED AND ACL-RECONSTRUCTED KNEES WHILE RUNNING

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Introduction
Radiographic measurement of joint space narrowing is the current gold standard in clinical measurement of articular cartilage loss\(^2\). This technique estimated joint space narrowing at a rate of 0.20 mm/yr in osteoarthritic knees over 16-month and 30-month periods\(^3\). Unfortunately, this technique provides an estimate of joint space for only one orientation of the joint under a static load, and standardized positioning exists only for the knee joint.

The purpose of the present study was to compare the joint space in uninjured and ACL-reconstructed knees while the joint was dynamically loaded. An additional goal was to determine if joint space changed over time. We hypothesized that joint space in uninjured knees would not change over time and that joint space would decrease over time in the ACL-reconstructed knees.

The present study used roentgen stereophotogrammetry to accurately track bone motion in vivo. Precise in vivo bone kinematics were combined with subject-specific bone data from computed tomography (CT). In this way, joint space was measured while the joint moved through a range of motion and was dynamically loaded.

Methods
Sixteen patients (9 male, 7 female; age 36.1 ± 0.7 yrs) who had ACL-reconstructive surgery served as subjects. Informed consent was obtained and our institutional review board approved all procedures. Three 1.6 mm diameter tantalum beads were implanted into both the femur and the tibia of each leg during surgery. Testing sessions were 5 and 12 months after surgery. Subjects were tested running downhill (10 % slope) on a treadmill set at 2.5 m/s. Data included from foot touchdown to 100 ms after touchdown (early to mid stance). A high-speed kilovoltage x-ray system tracked the implanted beads at 250 frames per second. Standard DLT techniques were used to calculate the 3D location of the implanted beads with an accuracy of ±0.10 mm\(^4\). Three trials were collected per leg per test session.

The distal end of the femur and proximal end of the tibia were CT scanned after tantalum beads were implanted. CT slice spacing was 1.25 mm, with in-plane resolution between 0.55 and 0.59 mm depending on subject size. CT scans were reconstructed into 3D surface models\(^4\). The locations of the implanted beads within the CT scan were combined with the tracked bead locations from the x-ray images to precisely position the bone surface reconstructions in 3D space.

An index was created to quantify joint space during running. This index, called the functional joint space (FJS) score, was determined by finding the closest 400 mm\(^2\) region between the articulating surfaces during the entire motion. The FJS score was calculated for the medial and lateral compartments of each knee. Color maps indicating the minimum distance between articulating surfaces and the associated FJS score were created (Figure 1). The effect of time (5-month, 12-months), leg (uninjured, reconstructed) and compartment (medial, lateral) on joint space score was tested with a 3-way repeated measures ANOVA, with significance set at p<0.05.

Results
Joint space scores for the femur and tibia were highly correlated for both the uninjured and ACL-reconstructed knees (R\(^2\) > 0.99). Thus, only results from the femur were included in the statistical analysis.

Mean joint space scores for the medial and lateral compartments of the uninjured and ACL-reconstructed knees are in Table 1. The mean medial compartment joint space score was significantly less than the mean lateral joint space score for both knees on both test dates. The joint space score increased significantly (0.30 mm) between the 5-month and 12-month tests in the medial compartment of the ACL-reconstructed knee (Fig. 2).

Discussion
The results presented here are unique, in that joint space was measured in vivo during a dynamic loading condition. As expected, the medial compartment joint space was significantly less than the lateral compartment for both uninjured and ACL-reconstructed knees during the impact phase of downhill running. Interestingly, the joint space score increased 0.30 mm in the medial compartment of the ACL-reconstructed knee between the 5-month and 12-month tests. It would be expected that joint space scores would decrease as cartilage thinned over time. We are continuing to test these subjects to determine when and at what rate dynamic joint space differences present themselves after ACL-reconstruction surgery.

References

<table>
<thead>
<tr>
<th>Test Date</th>
<th>Uninjured Median</th>
<th>Uninjured Lateral</th>
<th>ACL-Reconstructed Median</th>
<th>ACL-Reconstructed Lateral</th>
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<tbody>
<tr>
<td>5 months</td>
<td>3.12±1.09</td>
<td>4.12±1.25</td>
<td>2.86±1.08</td>
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<tr>
<td>12 months</td>
<td>3.32±0.94</td>
<td>4.22±0.98</td>
<td>3.16±0.02</td>
<td>4.64±0.59</td>
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*Table 1: Mean ± SD joint space scores in millimeters*