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A study of the relationship between meniscal injury and bone microarchitecture in ACL reconstructed knees

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ABSTRACT

Background: Anterior cruciate ligament (ACL) tears increase the risk of developing knee osteoarthritis. This risk increases further with concurrent meniscus injury. The role of bone changes during knee osteoarthritis development are not well-understood, but may be important to its etiology.
Purpose: To explore the effects of ACL tears on bone mineral density (BMD) and bone microarchitecture at five years post-op and their relationship to meniscal pathology, using high-resolution peripheral quantitative computed tomography (HR-pQCT).
Methods: Twenty-eight participants with unilateral ACL reconstructions five years prior and no evidence of clinical or radiographic osteoarthritis were recruited. All participants represented one of three meniscus statuses: meniscus intact, meniscus repair, or meniscectomy. BMD and bone microarchitecture of the subchondral bone plate and adjacent trabecular bone were assessed using HR-pQCT, and percent-differences between the injured and contralateral knee were determined.
Results: Subchondral bone plate thickness in the lateral femoral condyle was higher in the reconstructed knee (9.0%, $p = 0.002$), driven by the meniscus repair and meniscectomy groups (15.2% to 15.4%, $p < 0.05$).
Trabecular BMD was lower in the reconstructed knee in the medial femoral condyle (-4.8% to -7.6%, $p < 0.05$), driven by all meniscus statuses. In the lateral compartments, few differences in trabecular bone were found. However, accounting for meniscus status, the meniscus intact group had lower trabecular BMD throughout both femur and tibia.
Conclusions: Five years post-op, reconstructed knees demonstrated detectable differences in BMD and bone microarchitecture, despite having normal radiographs. Meniscus damage affected primarily the lateral compartment, warranting further investigation to determine if these changes relate to osteoarthritis development.

1. Introduction

Anterior cruciate ligament (ACL) tears are associated with an increased risk of developing post-traumatic osteoarthritis (OA) [1, 2]. However, isolated ACL tears only account for 10% of these injuries and are often accompanied by additional soft tissues injuries, such as meniscus tears, that can either be repaired or resected [3–7]. It has been shown that meniscectomies in the absence of ACL tears increase OA risk [8, 9], and in the presence of ACL tears the risk of OA development is further elevated [1, 10–15]. Consequently, it has been suggested that meniscal repair should be performed over meniscectomy whenever possible [10–16].

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Furthermore, joint instability and activity-induced joint pain related to meniscus injury have been reported to increase in individuals with partial or complete meniscectomies [10, 13, 14, 16]. Based on these observations, the status of the menisci has been reported as an important indicator for future OA risk [8, 15, 16].

It is not currently known what factors lead to the increase in OA risk following meniscus treatment, especially meniscectomy. Changes in joint biomechanics have been suggested, with biomechanical studies having demonstrated an increase in peak shear stress over a smaller area on the cartilage and bone of the weight-bearing surfaces as compared to healthy knees [17–21]. In addition to effects on cartilage, changes in joint mechanics may affect the underlying bone's density and microarchitecture due to modified loading. In studies of bone changes in acutely injured knees using animal models, trabecular bone is initially lost as reflected by a decrease in bone mineral density, bone volume fraction, trabecular thickness, and increased trabecular separation, but these changes may be transient and may partially recover at later points in time, and even increase in bone volume fraction beyond control knees [22–24]. In addition to trabecular changes, the subchondral bone plate increases in thickness [25–27]. It appears that bone changes are important to the etiology of OA, yet there is a need to better understand bone mineral density and bone microarchitecture changes induced by meniscal damage and surgical intervention, particularly in human knees.

The aim of this cross-sectional study is to evaluate bone mineral density and bone microarchitecture in the subchondral bone plate and trabecular bone of the weight-bearing regions in ACL-reconstructed and contralateral knees. Bone was assessed using newly established high-resolution peripheral quantitative computed tomography (HR-pQCT). In addition, we assessed the relationship between bone differences and meniscus status at the time of ACL reconstruction. Participants had no signs of clinical or radiographic OA and represent three meniscus statuses at the time of ACL reconstructive surgery five years post-op: meniscus intact, meniscus repair, and partial meniscectomy.

2. Material and methods

2.1. Participants

Participants were recruited from an ongoing clinical trial that is assessing clinical outcomes of three different types of ACL reconstructions performed by the same surgeon: patellar tendon, quadruple stranded hamstring tendon, and double bundle techniques [28]. From this cohort, 28 participants (men: $n = 15$; women: $n = 13$) with unilateral ACL reconstructions 5.2 median years prior to imaging (inter quartile range: 4.99–5.40 years) were randomly recruited as a convenience sample. They were grouped based on meniscus status at the time of surgery: meniscus intact ($n = 5$), meniscus repair ($n = 11$), and partial meniscectomy ($n = 12$). Only participants with no evidence of clinical or radiographic OA five years post-op were selected. Radiographic OA was determined using the International Knee Documentation Committee (IKDC) grading score based on standing posterior–anterior view radiographs with 30° knee flexion. All patients were classified as Grade A indicating normal knee radiographs. Additionally, none of the contralateral knees had a previous history of severe knee injury or surgery. All procedures were approved by the University of Calgary Conjoint Health Research Ethics Board and all participants gave informed consent prior to entering this study.

2.2. Clinical assessment and questionnaires

Weight and height was measured, and body mass index (BMI) was computed. Basic injury information including time since injury, time since reconstruction, and surgical meniscus intervention were collected. Knee circumference was measured to ensure participants would fit into the HR-pQCT scanner (circumference ≤ 42 cm). Each measurement, taken by one of two trained technicians, was performed twice to ensure that there was no deviation of more than three millimeters, and the average value was recorded.

2.3. HR-pQCT knee imaging

Both of the participants' knees, including the ACL reconstructed (ACLR) and contralateral knee, were imaged with HR-pQCT (XtremeCT II, Scanco Medical, Switzerland) to assess bone mineral density and bone microarchitecture in the subchondral bone plate and trabecular bone of the weight-bearing regions using a newly established protocol developed in our laboratory [29]. Images were acquired covering 61.2 mm of the knee including the distal femur and proximal tibia. Image resolution was 61μm isotropic voxel size with an acquisition time of 18 min for 1008 axial slices per knee (68 kVp, 1470 μA, 100-ms integration time) [29].

2.4. Image processing and bone microarchitecture analysis

HR-pQCT image data were processed and analyzed [29] to quantify bone mineral density and bone microarchitecture features in the subchondral bone plate and trabecular bone for the weight-bearing regions of both the distal femur and proximal tibia. Articular and endosteal bone surfaces were segmented using a semi-automated analysis tool. For both the medial and lateral compartments of the femur and tibia a region of interest (ROI) covering the weight-bearing articulated surface was defined by manually selecting points and fitting a polynomial curve to them (Figure 1).

The subchondral bone plate was identified as the compact bone between the articular and endosteal bone surfaces below each ROI. For the subchondral bone plate the following bone parameters were assessed: subchondral bone plate bone mineral density

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