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Altered regional loading patterns on articular cartilage following meniscectomy are not fully restored by autograft meniscal transplantation

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Objective: To quantify the changes in regional dynamic loading patterns on tibial articular cartilage during simulated walking following medial meniscectomy and meniscal transplantation.
Methods: Seven fresh frozen human cadaveric knees were tested under multidirectional loads mimicking the activity of walking, while the contact stresses on the tibial plateau were synchronously recorded using an electronic sensor. Each knee was tested for three conditions: intact meniscus, medial meniscectomy, and meniscal transplantation. The loading profiles at different locations were assessed and common loading patterns were identified at different sites of the tibial plateau using an established numerical algorithm.
Results: Three regional patterns were found on the tibial plateau of intact knees. Following medial meniscectomy, the area of the first pattern which was located at the posterior aspect of the medial plateau was significantly reduced, while the magnitude of peak load was significantly increased by 120%. The second pattern which was located at the central-posterior aspects of the lateral plateau shifted anteriorly and laterally without changing its magnitude. The third pattern in the cartilage-to-cartilage contact region of the medial plateau was absent following meniscectomy. Meniscal transplantation largely restored the first pattern, but it did not restore the other two patterns.
Conclusion: There are site-dependent changes in regional loading patterns on both the medial and lateral tibial plateau following medial meniscectomy. Even when a meniscal autograft is used where the geometry and material properties are kept constant, the only region in which the loading pattern is restored is at posterior aspect of the medial plateau.

Introduction

Over one million meniscal surgeries are performed annually in the United States[1], making it one of the most commonly performed orthopaedic procedures. For severe tears or degenerated menisci, total meniscectomy was historically performed[2], following which progressive cartilage loss and eventual joint degeneration was seen[3–5]. It has been postulated that cartilage damage after total meniscectomy was caused in part by alterations in joint mechanics, specifically increased contact stresses, decreased contact area, and decreased joint stability[6–9]. The early onset of degenerative changes in the ipsilateral knee compartment following meniscectomy is also felt to be due to alterations in contact location, resulting in cartilage regions being subjected to loads that they are not accustomed to[10]. Meniscal allograft transplantation (MAT) is intended to restore 'normal' pre-injury mechanics to knees with deficient menisci[2] – i.e., to distribute loads across articular cartilage and restore joint stability. While it has been shown in previous

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cadaveric studies that MAT does not completely restore contact mechanics to that of the intact knee[11–13], exactly how the subtle change in joint mechanics affects the long-term health of articular cartilage remains unknown.

We have previously developed a dynamic knee simulator which can apply synchronous multidirectional joint forces to mimic the activity of walking on human knees[14]. In tests conducted on a series of 12 human cadaveric knees, we identified commonly occurring dynamic loading patterns on specific regions of tibial articular cartilage, regardless of knee-to-knee variability[15]. If we could characterize how these loading patterns change in meniscectomized knee and then in the meniscal transplanted knee, the quantitative loading patterns could be used as inputs to bioreactors, so that the response of articular cartilage to such physiological loading patterns, and changes in those patterns, can be better understood.

The objective of this study was to quantify the regional dynamic loading patterns on tibial articular cartilage in the medial meniscectomized and meniscal transplanted knees. It was hypothesized that: (1) after medial meniscectomy, there will be a pronounced change in the commonly occurring knee-independent but regionally dependent loading patterns, and (2) meniscal transplantation will fully restore the commonly occurring loading patterns to that of the intact joint.

Material and methods

For this study, we retrospectively analyzed contact mechanics data that were generated from seven fresh frozen human cadaveric knees, subjected to loads that mimic the activity of walking; the knees were tested in the intact, medial meniscectomized and medial meniscal transplanted conditions[13]. For the total meniscal transplantation condition, we selected bone plug suture fixation since it has been previously shown that it restores joint contact mechanics closest to that of the intact knee vs the suture-only fixation condition. Briefly, the specimens were mounted to a modified load-controlled Stanmore Knee Simulator (University College London, Middlesex, UK) after stripping the surrounding soft tissue (fat, musculature) [Fig. 1(A)]. Each knee was subjected to a prescribed, simultaneously controlled cyclic femoral flexion/extension angle and axial force, anterior–posterior force and internal/external torque applied to the tibia to mimic the activity of walking [Fig. 1(B)][15–17]. Contact stresses normal to the tibial plateau surface were recorded in real-time (100 Hz) using a thin electronic sensor (model: 4010N, Tekscan Inc., MA), Fig. 1(C), which was inserted under both menisci of the medial and lateral plateau. Plastic tabs were place along the edges of the Tekscan sensors to allow for suture fixation. Tegaderm™ (3M, St. Paul, MN) adhesive film was then placed on the top and bottom surface of each Tekscan sensor. Approximately 1 cm incisions were made in the menisco-tibial ligaments and joint capsule anteriorly and posteriorly of both menisci. The sensor was curled at its edges and passed underneath the menisci from anterior to posterior by pulling the posterior tab via a posterior incision with minimal disruption of the menisco-capsular attachments. After adjusting its position, the tabs were sutured in place using 3-0 Ethibond sutures which attached to the tibial insertion of the anterior cruciate ligament (ACL) and the posteroinferior capsule.[13,18]

Contact forces applied to each individual sensel across the tibial plateau throughout simulated gait were recorded for three conditions (Fig. 2): (1) intact, (2) meniscectomy, where the medial meniscus was resected with bone plugs en-bloc, and (3) meniscal transplantation, where the bone plugs of the medial meniscus were reduced back to their respective insertions. In order to minimize the factor of graft size, geometry and material properties, a 'remove-replace' method was performed where the native medial meniscus was excised out of the knee in its entirety, and then fixed

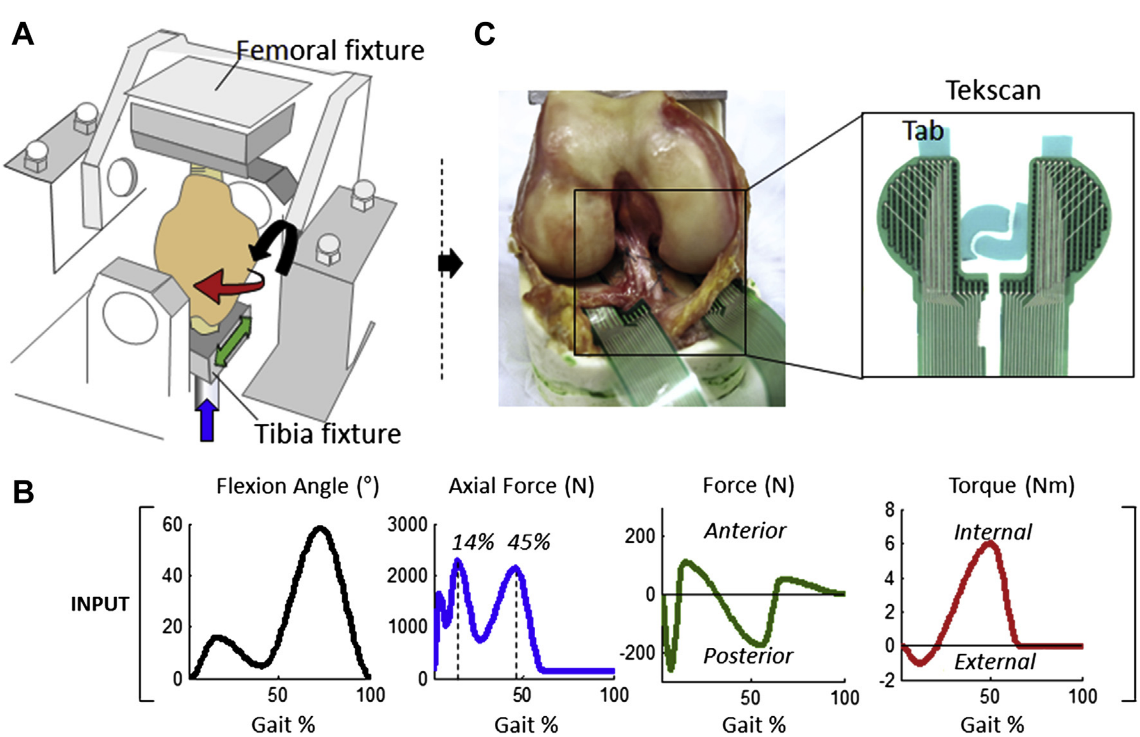

Fig. 1. *Experiment setup.* (A) The femur and tibia were potted into fixtures with PMMA bone cement. The forces and torque were applied on the tibia, and the flexion and extension was applied on the femur, while the varus/valgus rotation and superior/inferior translation were not controlled. (B) The knee simulator applies flexion/extension rotation, anterior/posterior force, axial force and internal/external torque to mimic the dynamic multidirectional loads during gait. (C) The contact stresses on the tibial plateaus were collected in real-time using a Tekscan sensor.