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Differential knee joint loading patterns during gait for individuals with tibiofemoral and patellofemoral articular cartilage defects in the knee

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SUMMARY

Objective: To determine compartment-specific loading patterns during gait, quantified as joint reaction forces (JRF), of individuals with knee articular cartilage defects (ACD) compared to healthy controls (HC).
Methods: Individuals with ACDs and HC participated. Individuals with ACDs were divided into groups according to ACD location: PF (only a patellofemoral ACD), TF (only a tibiofemoral ACD), and MIX (both PF and TF ACDs). Participants underwent three-dimensional gait analysis at self-selected speed. TF joint reaction force (TF-JRF) was calculated using inverse dynamics. PF joint reaction force (PF-JRF) was derived from estimated quadriceps force (F_{QUAD}) and knee flexion angle. Primary variables of interest were the PF- and TF-JRF peaks (body weight [×BW]). Related secondary variables (gait speed, quadriceps strength, knee function, activity level) were evaluated as covariates.
Results: First peak PF-JRF and TF-JRF were similar in the TF and MIX groups (0.75–1.0 ×BW, $P = 0.6–0.9$). Both peaks were also similar in the PF and HC groups (1.1–1.3 ×BW, $P = 0.7–0.8$), and higher than the TF and MIX groups ($P = 0.004–0.02$). For the second peak PF-JRF, only the HC group was higher than the TF group ($P = 0.02$). The PF group walked at a similar speed as the HC group; both groups walked faster than the TF and MIX groups ($P < 0.001$). With gait speed and quadriceps strength as covariates, no differences were observed in JRF peaks.
Conclusions: The results suggest the presence of a TF ACD (TF and MIX groups), but not a PF ACD (PF group), may affect joint loading patterns during walking. Walking slower may be a protective gait modification to reduce load.

Introduction

Healthy articular cartilage serves to protect the bones from repetitive loads and movement encountered in everyday life[1]. An articular cartilage defect (ACD) in the knee changes the mechanical properties of the remaining cartilage. The presence of the ACD is known to increase the stress in the remaining healthy cartilage[2–5] and reduces the ability of the surrounding tissue to withstand compressive and shear forces, rendering the remaining cartilage vulnerable to degeneration from mechanical loading[3,4,6]. With walking, knees are subjected to millions of loading cycles throughout a lifetime, thus the manner in which people load the knee during gait could either exacerbate or reduce stresses in the remaining cartilage. It is critical to develop an understanding of the baseline gait biomechanics of individuals with ACDs, as these

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loading patterns likely have implications for the development of osteoarthritis in this population.

Symptomatic ACDs are often accompanied by knee pain, joint swelling and muscle weakness[7,8]. These signs and symptoms are common in other populations with knee pathology, and can elicit protective changes in joint loading patterns during gait[9–12]. While ACDs are similarly prevalent in the patellofemoral (PF) and tibiofemoral (TF) compartments of the knee[13–16], it is unknown if individuals with symptomatic ACDs alter their gait patterns to unload the involved compartment which may serve to protect remaining cartilage.

The purpose of this study was to determine the compartment-specific loading patterns, quantified as joint reaction forces (JRF), of individuals with knee ACDs compared to healthy individuals during gait. We hypothesized that individuals with ACDs would unload the affected compartment during walking at self-selected speed. Specifically, we hypothesized that: (1) individuals with PF ACDs will demonstrate lower PF joint reaction force (PF-JRF) on the involved limb during gait compared to healthy individuals, (2) individuals with TF ACDs will demonstrate lower TF joint reaction force (TF-JRF) on the involved limb during gait compared to healthy individuals, and (3) individuals with a PF and TF ACD in the same knee (both PF and TF ACDs (MIX)) will demonstrate lower PF-JRF and TF-JRF on the involved limb during gait compared to healthy individuals. We also evaluated the role of secondary variables (i.e., quadriceps strength, gait speed, knee pain and function, activity level) in joint loading patterns, as a preliminary analysis of the associations between clinical presentation and joint loading.

Methods

Sample

Individuals seeking consultation and treatment for symptomatic ACDs were recruited from a local orthopedic practice (D. C. F.) to participate in this cross-sectional study from 2012 to 2015. Individuals were included if they were age 18–55 years and were diagnosed with a unilateral, full thickness knee ACD confirmed with magnetic resonance imaging or knee arthroscopy. Individuals were excluded if they had a body mass index greater than 35 kg/m^2, recent lower extremity surgery (reconstructive surgery within previous year, cartilage biopsy with debridement within the last 3 months) or other injury, history of spine surgery, current low back pain or lower extremity pain unrelated to the ACD, history of neurological injury/pathology, symptom duration less than 1 month, or any other factor unrelated to the ACD that may affect walking. Available knee radiographs were graded (Kellgren–Lawrence (KL) grade) by a non-treating orthopedic surgeon who was blinded to ACD location to evaluate for knee osteoarthritis (unavailable for two participants). Individuals without knee pain or history of knee injury (and meeting all exclusion criteria) were recruited from the community for a healthy control (HC) group. The study was approved by the University Institutional Review Board, and all participants provided informed consent.

Group allocation

Individuals with ACDs were divided into groups according to defect location. The PF group consisted of individuals with ACDs in the PF compartment only (on the patella or trochlea). Likewise, the TF group consisted of individuals with ACDs in the TF compartment only (on the femoral condyles or tibial plateaus). The MIX group consisted of individuals with a PF and TF ACD in the same knee. In individuals with ACDs, the involved limb was defined as the limb with a confirmed ACD (unilateral in all individuals). For the HC group, the involved limb was randomly assigned.

Data collection

Motion analysis

In a one-time visit to a biomechanics laboratory, individuals underwent three-dimensional gait analysis, strength testing and knee function assessment. Gait was analyzed during five trials of over ground walking at self-selected speed. During the trials, motion was captured with a 10-camera passive optical motion analysis system at 150 Hz (Vicon Nexus, MX-F40 cameras, Oxford, UK), and synchronized with ground reaction force data from six independent force plates (Bertec Corp, Columbus, OH) embedded into and flush with the floor, collecting at 1500 Hz. Sixty-three retro-reflective markers were placed on the participant's trunk and lower extremities using a point cluster mesh configuration[17]. The hip joint center was estimated from a functional star-arc task[18], while the knee and ankle joint centers were determined as the midpoint of markers placed on the medial femoral condyles (MFC) and lateral femoral condyles (LFC) and malleoli, respectively. Cluster markers on the anterior thigh and shank, as well as markers on the foot, pelvis, and trunk tracked the position of the segments during walking[19].

Knee symptoms, knee function, and activity level

The Knee Injury and Osteoarthritis Outcome Score (KOOS) is a common self-report questionnaire that is used to evaluate pain, symptoms, and function of individuals with knee injury, including individuals with ACDs[20]. The KOOS consists of five subscales: Pain, Symptoms, Activities of Daily Living (ADL), Sports and Recreation (Sports), and Quality of Life (QoL). Each subscale of the KOOS is scored independently from 0, indicating maximal deficits, to 100 indicating no deficits. The Tegner Activity Scale[21] is an 11-point scale that categorizes an individual's highest level of self-reported activity and is a common measure of activity level.

Quadriceps strength

Quadriceps strength was quantified as peak knee extension torque normalized to body mass during a maximal volitional isometric contraction. An isometric measure of quadriceps strength was chosen to minimize friction caused by the ACD in the joint, and to minimize the potential for symptom aggravation during the testing session[12]. For testing, the subject was seated in an isokinetic dynamometer (Biodex System III, Shirley, NY) with the hip and knee positioned approximately at 90 and 60 degrees of flexion, respectively. The axis of rotation for the dynamometer was aligned with the knee joint center and the lower leg was secured to the dynamometer arm. The maximum knee extension torque from three maximal knee extension trials was used to reflect peak knee extension torque.

Data reduction

Marker and ground reaction force data were both filtered using a fourth order low-pass Butterworth filter with cutoff frequency of 6 Hz. Visual 3D software (C-Motion Inc., Germantown, MD) was used to calculate Euler joint angles (X–Y–Z), and joint moments were calculated using standard inverse dynamics equations for the hip, knee, and ankle. Initial contact of the stance phase was defined by a vertical ground reaction force >10 N, and toe off was defined by a vertical ground reaction force <10 N. For each trial, gait speed (m/s) was calculated by the three-dimensional motion analysis system as the center of mass velocity while the participant was walking at steady state over the force plates, and averaged over all trials for each participant.