Increased Variability of Knee Motion in Patients with Knee Osteoarthritis and Complaints of Instability

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Introduction: From a dynamical systems perspective, variability in the musculoskeletal system is necessary to complete daily tasks within changing environmental conditions while maintaining system health. [1] Disease states affecting the inherent variability of the musculoskeletal system can reduce the flexibility or stability of the system and may lead to compromised mechanics and pathology. For example, altered stride-to-stride variability of knee joint motion in patients with knee osteoarthritis (OA) has been previously hypothesized as a cause of increased pain and disease progression. [2] It has been theorized that the commonly observed knee stiffening gait pattern in patients with knee OA can decrease available degrees of freedom within the system to cause pathologic elevations in load distribution across the joint. [3] It could also be argued that self-reports of episodic joint instability observed in a subgroup of patients with knee OA [4] may be a sign of excessive system variability and inadequate control of the joint which may also be harmful. The objective of this work was to compare variability in knee joint kinematics and contact mechanics during the loading response phase of decline gait in three groups of older adults: 1) healthy subjects without knee OA or reports of instability, 2) knee OA patients without reports of instability, and 3) knee OA patients with episodic reports of joint instability. We hypothesized that compared to the control subjects, patients with knee OA without reports of instability will demonstrate decreased knee joint motion variability while patients with knee OA and concurrent reports of joint instability would demonstrate increased knee motion variability.

Methods: Forty-four subjects participated in the study and were stratified into 3 mutually exclusive groups: 1) Control: 24 older adults without knee OA or joint instability (age:69.6±7.5 yrs, BMI: 24.7±3.8 kg/m²); 2) OA Stable: 9 patients with knee OA and no reports of joint instability (age: 69.5±7.9 yrs, BMI: 27.5±5.0 kg/m²); and 3) OA Unstable: 11 knee OA patients with episodic reports of knee joint instability (age: 69.9 ± 8.2 yrs, BMI: 31.5±4.8 kg/m²). Subjects were included in the OA Stable and OA Unstable groups if they: 1) met the American College of Rheumatology classification criteria [5], 2) demonstrated radiographic medial compartment knee OA of at least grade II or higher according to the Kellgren and Lawrence radiographic severity rating scale [6] and 3) radiographic disease severity in the medial compartment was higher than the lateral compartment. Subjects in the OA Unstable group also had a self-reported knee instability rating of ≤ 3 on the knee stability scale indicating that the subjects’ perceived symptoms of instability affect their ability to perform activities of daily living. [4] Dynamic stereo x-ray techniques were used to image subjects’ knees during declined walking (7% grade, 0.75m/s) on an instrumented treadmill. Each subject completed three separate walking trials for analysis. Ground reaction forces were used to determine the loading response phase, defined as the first 20% of stance for each subject. CT images were used to create 3D models and anatomical coordinate systems for the femur and tibia. [7] Tibio-femoral joint rotations were then determined for each time frame. The location of the joint contact point was estimated using the distance-weighted centroid of the region of closest proximity between the bony surfaces in both medial and lateral compartments using a Cartesian coordinate system aligned with the tibial plateau. [8] Knee motion variability was calculated from a plot of knee joint rotations or translations vs. angular or linear velocities during the loading response phase of decline gait. Phase angles were calculated as the angle between the positive horizontal axis and the line connecting the origin (0,0) of each graph to the data point of interest for each successive data point during the loading response phase. [9] A knee joint “variability index” was then defined as the standard deviation of the average phase angles for identical time points during the loading response phase across the three trials for each subject. [10] The variability of the angular knee motion was calculated in the sagittal, coronal, and transverse planes. The variability of linear joint contact motion was calculated for anterior-posterior and medial-lateral motions of the medial and lateral tibiofemoral compartments for each subject. An ANOVA with Tukey’s correction (p≤0.05) was used to compare the variability index of joint kinematics and tibiofemoral contact motion between the three experimental groups.

Results: Variability index in the sagittal plane during the loading response phase of gait was significantly increased in the OA Unstable group (33.9±19.9) compared to the Control (17.1±10.9;p=0.008) and the OA Stable groups (12.5±15.5;p=0.006; Figure 1). No other significant group differences in variability of tibiofemoral joint kinematics were observed. Greater anterior-posterior contact variability index was also observed for the medial compartment in the OA Unstable group (48.3±19.5) compared to the Control (28.2±16.7;p = 0.01) and the OA Stable groups (28.0±20.1;p = 0.05; Figure 2).
**Discussion:** Consistent with our initial hypothesis, knee OA patients with episodic reports of instability demonstrated increased variability in their sagittal plane knee motion. This increased variability may be related to the diminished quadriceps strength or altered neuromuscular control of the quadriceps resulting from episodic exacerbation of joint symptoms which could lead to reflex inhibition and restriction of proper quadriceps activation. [10] However, as we did not measure quadriceps strength or activation in our subjects, this hypothesis will need further validation in future studies. Additionally, increased variability in the anterior-posterior joint contact motion in OA Unstable patients is similar to pathomechanics previously reported for patients with anterior cruciate ligament deficient knees, [11,12] which suggests diminished knee joint stability during dynamic weight bearing activities. This lack of control during a high-impact portion of gait could potentially cause regions of cartilage to be exposed to high loads that are unaccustomed to being loaded, thus contributing to the rate of disease progression. Inconsistent with our original hypothesis, however, knee OA patients without reports of instability did not demonstrate reduced knee motion variability compared to the Control group, an unexpected result given previous observations of knee-stiffening gait patterns in this patient population.

**Significance:** The results of this study demonstrate evidence of dynamic joint instability and a lack of joint control in patients with knee OA who experience episodic bouts of instability. Intervention focused toward reducing excessive knee joint variability such as bracing and neuromuscular training may be indicated in this patient population.

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Figure 1. Variability index for knee joint kinematics during the loading response phase of decline gait.

Figure 2. Variability index for medial and lateral compartment contact mechanics during the loading response phase of decline gait.

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