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Smoothness of the knee joint movement during the stance phase in patients with severe knee osteoarthritis

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ABSTRACT

Background: Patients with knee osteoarthritis can significantly affect the function of the knee joint in terms of joint range and mobility and have a stereotypical pattern of knee stiffness during gait, caused by an increased resistance in the muscles and soft tissues during the stance phase of knee joint movement. Smoothness in movement, such as during walking and running, is assumed to be attained by adulthood; however, disruptions in gait pattern due to injury or performance enhancement can alter the smoothness of the movement, and this is often quantified in terms of "jerk". A higher jerk value is linked with a decrease in smoothness. However few have reported to evaluate the smoothness of the knee joint movement during walking in patients with knee osteoarthritis. The purpose of the present study was to quantify the smoothness of the knee joint movement during walking in people with knee osteoarthritis.
Methods: Patients were classified as having early or severe knee osteoarthritis. There were eight patients in each group (16 knees; three males, five females). The normalized angular jerk was calculated as an indicator of the walking knee joint smoothness in each of the four periods of the stance phase. Two-way ANOVA was performed to compare the smoothness of knee joint movement between groups and between each period of the stance phase.
Results: The angular change in the sagittal plane of those with severe knee osteoarthritis was smaller than that of those with early knee osteoarthritis in all periods of the stance phase. Normalized angular jerk did not significantly differ between groups in all periods. In both groups, the normalized angular jerk in the sagittal plane was significantly larger in the mid-stance and terminal stance periods than in the early stance and pre-swing periods. Only in patients with severe knee osteoarthritis, there was a significantly larger jerk in the frontal plane in the mid-stance period.
Conclusion: The present results revealed that the smoothness of joint movement decreases during the single leg supporting phase of the stance phase in the frontal plane with severe knee osteoarthritis, although there is no difference in smoothness of joint movement according to the severity of knee osteoarthritis The instability during single leg support due to increase of the knee joint load and destruction cause the impaired smoothness of the knee joint movement.

Introduction

Patients with knee osteoarthritis (KOA) have a stereotypical pattern of knee stiffness during gait.[1] Typically, KOA is an age-related degenerative disease that causes by an increased resistance in the muscles and soft tissues during the early stance phase of knee joint movement.[2,3] The movement of the knee joint during walking depends on joint force, ligaments, and muscles, rather than just the bony structure,[4] and thus KOA can significantly affect the function of the knee joint in terms of joint range and mobility. In normal walking, there are slight variations in joint movement during the gait cycle, and a decrease in this normal variability may lead to joint destruction.[5] Therefore, adequately varied joint movement may be useful for the redistribution of joint loading.[6] A previous study reported that a softer landing during

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foot strike can improve the smoothness of a gait pattern, which in turn, helps to reduce loading on the joint.[7]

Smoothness in movement, such as during walking and running, is assumed to be attained by adulthood; however, disruptions in gait pattern due to injury or performance enhancement can alter the smoothness of the movement, and this is often quantified in terms of "jerk".[8,9] Jerk is defined as a change in the acceleration rate of a movement, and is the third derivative of displacement, with the smoothest movement having the lowest jerk. Several previous reports have sought to use the smoothness of joint movement to explain, coordinate, or alter joint movement.[9–11] Newton's second law states that acceleration is proportional to force, assuming that mass is constant. Therefore, jerk, as a derivative of acceleration, can be defined as a change in force; as jerk is an index of gait smoothness, jerk is therefore linked with smoothness and force. In other words, a lower jerk value is associated with a smoother movement and a smaller change in force, whereas a higher jerk value is linked with a decrease in smoothness and a larger change in force. Several previous reports have used jerk as a measure to evaluate the smoothness of joint movements,[9–13] however few have reported to evaluate the smoothness of the knee joint movement during walking in patients with KOA.

The purpose of the present study was to quantify the normalized angular jerk of the knee joint movement during walking in people with KOA. We hypothesized that the smoothness of the joint movement in patients with severe KOA would be altered due to a restricted range of motion in the joint angle during the stance phase, and that the instability during single leg support would cause the impaired smoothness of the knee joint movement.

Materials and methods

Subjects

The participants enrolled in the present study were orthopedic patients who visited the hospital for outpatient treatment of medial KOA. All participants underwent Rosenberg view radiography by a radiological technologist, and an orthopedic surgeon classified the severity of KOA according to the Kellgren–Lawrence (KL) radiographic osteoarthritis grading system.[14] Grade 1 was defined as doubtful narrowing of joint space, possible osteophyte development, grade 2 was defined as definite osteophyte, absent or questionable narrowing of joint space, grade 3 was defined as the presence of moderate (multiple) osteophytes or a definite narrowing of the joint space, and grade 4 involved the presence of large osteophytes or marked narrowing of the joint space. Patients were then further categorized into two groups: KL grades 1 to 2 were classified as early KOA[15] (in this study, 4 knees were not underwent radiography but we classified them as early group because they recognized pain and disability in daily life as walking or stair climbing), and KL grades of 3–4 were classified as severe KOA. Each group included 16 knees from eight subjects (three males, five females). The patient characteristics are presented in Table 1. The exclusion criteria were prior knee replacement surgery, rheumatoid arthritis, unresolved injury to any lower extremity joint, prior bone injuries, and neurological problems. All participants provided written informed consent, and the study was approved by the ethical review board of our institution.

Table 1
Characteristics of the study participants.

	Early KOA		Severe KOA	
	Mean	SD	Mean	SD
Age (years)	73.38	±9.54	75.25	±5.51
Height (m)	1.54	±0.09	1.52	±0.06
Weight (kg)	56.00	±9.77	61.81	±7.69
BMI (kg/m^2)	23.57	±3.21	26.80	±3.05

Gait analysis

Participants walked barefoot along a level, 8-m-long walkway at a self-selected, habitual speed. Kinematic data were obtained at 200 Hz using an 8-camera motion analysis system (Vicon Nexus, Oxford, UK). Two floor-mounted force plates (Kistler Instruments, Winterthur, Switzerland) were used to obtain the ground reaction forces at a rate of 1200 Hz, and the data were synchronized with the motion capture data. The global coordinate system was defined with the X-axis as anterior-posterior, the Y-axis as lateral, and the Z-axis as vertical. The average of three gait trials was collected for each subject and used for analysis.

According to a lower extremity model of the Plug-In-Gait marker set,[16] which is a widely used standardized marker arrangement for three-dimensional motion analysis, 9.5-mm-diameter reflective markers were placed directly over the following bilateral anatomical landmarks: anterior and posterior superior iliac spines, lateral thighs, lateral femoral epicondyles, lateral shanks, lateral malleoli, calcanei, and the tops of the feet at the base of the second metatarsals. After the reflective markers were attached, each subject was instructed to stand barefoot for a single static calibration in the standing position before gait analysis. After the static calibration, participants were instructed to step onto a floor-mounted force plate with their targeted lower limb for a measurement, and were allowed to perform several trial steps in preparation before the measurements were taken. From the ground reaction force data, we defined the stance phase of the gait as four periods: early stance (0–16% of the stance), mid-stance (17–50%), terminal stance (51–83%), and pre-swing (84–100%).[17] Mid and terminal stance phases include the shingle leg supporting phase.[18] The markers and joint angles acquired from the Plug-In-Gait model, and the ground reaction forces were low-pass filtered at 6 Hz using a second-order, dual-pass Butterworth filter. The normalized angular jerk was calculated as the knee joint smoothness in each period of the stance phase, using the following formula:[10,11]

$$\text{Normalized angular Jerk (Knee joint smoothness)} = \int_{t2}^{t1} \left(d^3\theta/dt^3\right)^2 dt \times \frac{t_f{}^5}{D^2}$$

where θ is the knee joint angle, t_1 and t_2 are the initial time and final time of each period of the stance phase, t_f is the time of each stance phase period, and D is the amount of change in the knee joint angle during each stance phase period. A lower value of normalized angular jerk indicates that knee joint movement is smooth, while higher values represent lack of smoothness.

Statistical analysis

Two-way ANOVA was performed to compare the smoothness of knee joint movement between groups and between each period of the stance phase; when the main effect was observed, Bonferroni post hoc testing was performed. A *t*-test was conducted to evaluate the differences between the two groups in range of motion during the stance phase. *P*-values less than 0.05 were considered statistically significant. All statistical analyses were performed using SPSS software ver. 19.0 (SPSS Inc., Tokyo, Japan).