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# Relations between external moment and movement of the knee joint during the stance phase in patients with severe knee osteoarthritis

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ABSTRACT

*Background:* The relations between external knee moment and the knee joint movement during stance phase of the patients with knee osteoarthritis is unknown well. This study try to clarify the relations between external knee moment and the knee joint movement during stance phase of the patients with knee osteoarthritis.
*Methods:* Subjects comprised 15 patients who had 23 knees with severe osteoarthritis. The knee joint movements and external knee moments while walking were measured using a motion analysis system and a floor-mounted force plate. We then calculated the change in knee joint angles, first and second peak external knee adductions, and maximum flexion – extension moments during the stance phase. Pearson's product – moment correlation coefficient was used to confirm the relation between the external moments and knee movements.
*Results:* The first peak external knee adduction moment was moderately positively correlated with the maximum knee varus angle at the early stance phase and was moderately negatively correlated with the amount of change in the knee valgus direction angle at mid-stance. The peak external knee extension moment at the early stance phase was strongly positively correlated with the knee flexion angle at foot-strike and the maximum knee flexion angle at the early stance phase and was negatively correlated with the external rotation angle at foot-strike.
*Conclusion:* An effective rehabilitation approach to decrease the load of knee joint must combine both to strength the muscles around the knee joint, particularly quadriceps, and to device for controlling the knee movement.

## 1. Introduction

Prior studies have reported that the external knee adduction moment adds a dynamic load to the medial surface of the knee joint with knee osteoarthritis.[1] Because the medial knee load cannot be measured directly in vivo without using invasive methods, the external knee adduction moment during the stance phase has been used to characterize the dynamic medial knee load.[2] In contrast, walking analyses to help identify medial knee osteoarthritis have been reported problems not only for varus movement in the frontal plane but also for flexion in the sagittal plane.[3] It was also shown that the external knee adduction moment was not sufficient to predict joint loading at the stance phase, and the sagittal plane movement contributed substantially to the knee contact force.[4] Knee joint movement during the stance phase of patients with medial knee osteoarthritis have a pattern different from that of unimpaired persons due to destruction of the joint architecture,[5] thereby causing restriction and instability of joint movement, which are thought to be factors contributing to changes in mechanical loads on the knee. It was reported that a double knee action during the stance phase of normal walking and rotational movement with flexion-extension of the knee joint, so called “screw home movement” decreased and disappeared with knee osteoarthritis patients.[6] In addition, the rotational movement of the knee joint at the initial stance phase may increase the load on the medial compartment of the tibia, making it difficult to absorb the impact.[7] However, the relations between external knee moment and the three dimensional knee joint movement during stance phase of the patients with knee osteoarthritis is unknown well.

This study try to clarify the relations between external knee moment and the three dimensional knee joint movement during stance phase of the patients with knee osteoarthritis. Particularly, the authors reported the relationship between varus thrust and rotational movement of the knee joint during the stance phase in the past,[7] but not well known the

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relationship between external moments. By clarifying the relationship between kinematics and kinetics during stance phase of the patients with knee osteoarthritis, it will help to treat the KOA.

The purpose of this study was to clarify the relationship between external knee moment and the three dimensional knee joint movement during stance phase of the patients with knee osteoarthritis, and we hypothesized that kinematics change of not only the sagittal and frontal planes but also the horizontal plane of the knee joint gave the effect to the external knee moments of the stance phase.

## 2. Materials and methods

### *2.1. Subjects*

Altogether, 15 patients participated in this study. Among them, we evaluated 23 knees with severe osteoarthritis (rated ≥3 on the Kellgren–Lawrence radiographic scoring system.[8] Each underwent plain radiography, which was performed by a radiology technician using Rosenberg's 45° flexion load-bearing view. One orthopedic surgeon interpreted all of the radiographs of all of the patients, thereby avoiding the inter-human judgment factor and potential differences of opinion. Grade 3 knee osteoarthritis was diagnosed if multiple osteophytes and definite narrowing of the joint space were present. Grade 4 was diagnosed if large osteophytes and marked narrowing of the joint space were present.

The subjects had the following general characteristics, expressed as the mean (SD): 76.3 (7.7) years of age; 1.53 (0.09) m height; 59.3 (12.7) kg weight; 25.0 (3.4) $kg/m^2$ body mass index. The orthopedic surgeon measured the femorotibial angle (FTA) on radiographs. Varus deformity was defined as a measured FTA of > 180°. All 23 knees met this criterion for varus deformity, with a mean (SD) FTA of 184.4° (4.3°). The mean (SD) knee range of motion of all subjects was for extension −6.5° (8.5°) and for flexion 128.7° (12.3°). Subjects with prior knee replacement surgery, rheumatoid arthritis, and/or peripheral or central neurologic disease were excluded. Ethical approval for this study was obtained from the Ibaraki Prefectural University of Health Sciences Ethics Committee.

### *2.2. Gait analysis and data acquisition*

To measure walking, kinematics and kinetics data were obtained at 200 Hz using an eight-camera motion analysis system (Vicon Nexus; Vicon, Oxford, UK). Ground reaction force data were recorded at 200 Hz using a floor-mounted force plate (Kistler Instruments, Winterthur, Switzerland). This method to measure walking parameters was based on a protocol used in a prior report.[7] In this study, reflective markers of 9.5 mm diameter were affixed to the following anatomic landmarks: bilateral anterosuperior and posterosuperior iliac spines, bilateral greater trochanters, lateral and medial femoral epicondyles, lateral and medial tibial condyles, lateral and medial malleoli, the calcaneus, and the top of the foot at the base of the second metatarsal. In addition, rigid plates with three attached reflective markers were placed on the lateral side of the thighs and shanks to reduce errors caused by skin movement artifacts. After attaching the reflective markers and prior to measuring the walking parameters, each subject underwent a single static calibration while in the standing position. The anatomic landmarks represented by the rigid plates of the thighs and shanks were the greater trochanter, the lateral and medial femoral epicondyles, the lateral and medial tibial condyles, and the lateral and medial malleoli. These anatomic landmarks were estimated using software (Body Builder, Vicon, Oxford, UK) provided with the motion analysis system.

After the static trial, the subjects walked barefoot along an 8-m walkway at their own, self-selected, habitual speeds. The subjects were instructed to step on a floor-mounted force plate with the lower limb targeted for measurement. They were allowed to perform several preparation trials. Each participant performed three successful walking trials, the data for which included all of the markers and were used for analyses. The knee joint angles and external knee moments while walking were measured using the coordinate values of the anatomic landmarks estimated by the thigh and shank clusters. The knee joint angle during the stance phase was calculated by defining the thigh and shank coordinate systems using the joint coordinate system. External knee flexion − extension and adduction moments were calculated using inverse dynamics techniques. In this study, body segment parameter coefficients specific to the Japanese population, as previously reported, were used when calculating joint moments.[9] The external moments were normalized to body weight (Nm/kg). Foot-strike and toe-off were determined using the force plate data, and all calculated data were normalized to 100% of the stance phase (foot-strike to toe-off = 100%) using spline interpolation. We defined the stance phase of the gait as four periods (early stance: 0–16% of stance; mid stance: 17–50%; terminal stance: 51–83%; pre-swing: 84–100%).[10]

### *2.3. Statistical analysis*

For kinetics data, the first and second peak external knee adduction moment and the maximum flexion − extension moment were calculated from longitudinal data. For kinematics data, knee joint angles (flexion − extension, varus-valgus, external − internal rotation) at foot strike and the maximum values of those angles were analyzed during early stance phase, and the amount of change in knee joint angles (flexion − extension, varus-valgus, external − internal rotation) were analyzed at the completion of every fourth period.

Pearson's product − moment correlation coefficient was used to confirm the relation between the eternal moments and knee movement. Values of $p < 0.05$ were considered to indicate statistical significance. All statistical analyses were performed using SPSS software version 19.0 (IBM, Tokyo, Japan).

## 3. Results

The longitudinal data of knee joint angles and the external knee moments during stance phase are shown in Figs. 1 and 2. The first peak external knee adduction moment was at mid-stance (0.42 ± 0.19 Nm/kg). It was moderately positively correlated ($r = 0.468$, $p = 0.024$) with the maximum knee varus angle at the early stance phase (15.66 ± 6.00°). In addition, the first peak external knee adduction moment was moderately negatively correlated ($r = -0.511$, $p = 0.013$) with the amount of change in the knee valgus direction angle at mid-stance (−1.76 ± 3.93°). The second peak external knee adduction moment was at pre-swing during the last stance phase (0.39 ± 0.19 Nm/kg). It was not correlated with the knee joint angles.

The peak external knee extension moments at the early stance phase (0.26 ± 0.22 Nm/kg) were strongly positively correlated ($r = 0.766$, $p < 0.01$ and $r = 0.831$, $p < 0.01$, respectively) with the knee flexion angle at foot-strike (17.01 ± 9.49°) and the maximum knee flexion angle at the early stance phase (24.74 ± 9.26°). In addition, peak external knee extension moment was negatively correlated ($r = -0.456$, $p = 0.029$) with the external rotation angle at foot-strike (7.94 ± 9.08°). The peak external knee flexion moment during the last stance phase (0.89 ± 0.21 Nm/kg) was not correlated with knee joint angles.

## 4. Discussion

When knee varus angle at the early stance phase is large, the first peak external knee adduction moment that occurs in the early stage of the mid stance tends to become large, and the control of the varus angle in the early stance was suggested the possibility of reducing the mechanical load of the knee joint by the external knee adduction moment. Also, the external knee extension moment generated in the early stance

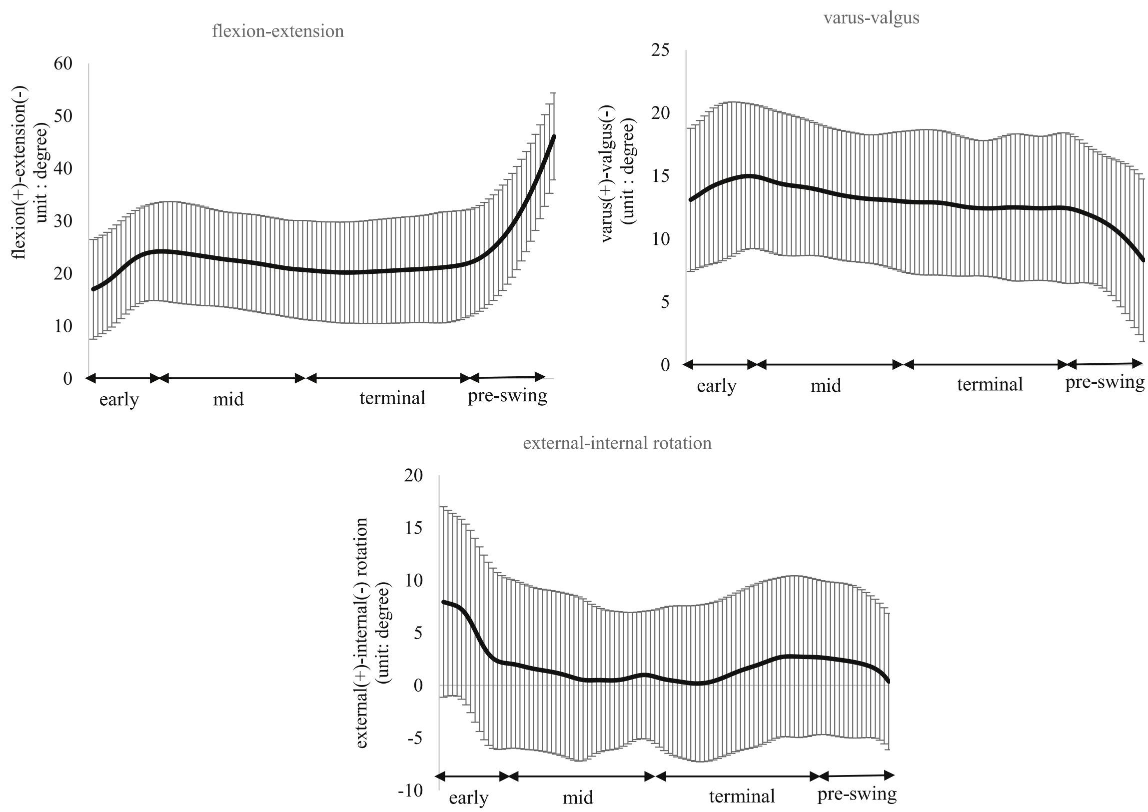


**Fig. 1.** Longitudinal data of the knee joint angle during the stance phase. Left. knee flexion – extension angle. Right. knee adduction – abduction angle. Below. knee external – internal rotational angle.

phase showed a tendency to increase with the increase of the knee flexion angle in the early stance phase, and the external knee extension moment tended to decrease as the external rotation movement increased. From these results, some of our hypotheses have been proved.

The maximum varus angle of the knee joint observed during the early stance phase in the frontal plane is thought to be related to the appearance of varus thrust. The presence of varus thrust during the early stance phase indicates dynamic instability and malalignment in the frontal plane of the knee,[11] and is thus a mechanical risk factor for progression of medial knee osteoarthritis.[12] Therefore, this study also proposed that a decreased load on the medial compartment of the knee joint by reducing the external knee adduction moment was needed to decrease varus thrust.

The knee extensor moment by the quadriceps muscle leads to greater knee joint compression and an elevated knee joint contact force.[13] Because of the higher external knee extension moment in this sthudy, the knee extensor moment was less necessary, which may result in the reduced activity of the quadriceps muscle seen in patients with knee osteoarthritis. The walking patterns of patients with knee osteoarthritis in this study were similar to the quadriceps avoidance gait observed in patients with an anterior cruciate ligament injury.[14] In contrast, the knee osteoarthritis patient might maintain this gait to decrease the shock from the ground reaction forces, thereby avoiding pain. As the increase in the external knee extension moment diminishes the knee extensor moment produced by quadriceps muscle activity, weakness of the quadriceps muscle may accelerate. In addition, in a past report,[15] the increased external knee extension moment during the early stance phase was thought to compensate by a forward shift of the center of mass via forward bending of the trunk.

The internal – external rotational angle of the knee joint at foot strike showed an interrelation with the external knee extension moment, and the external rotational angle was negatively correlated with

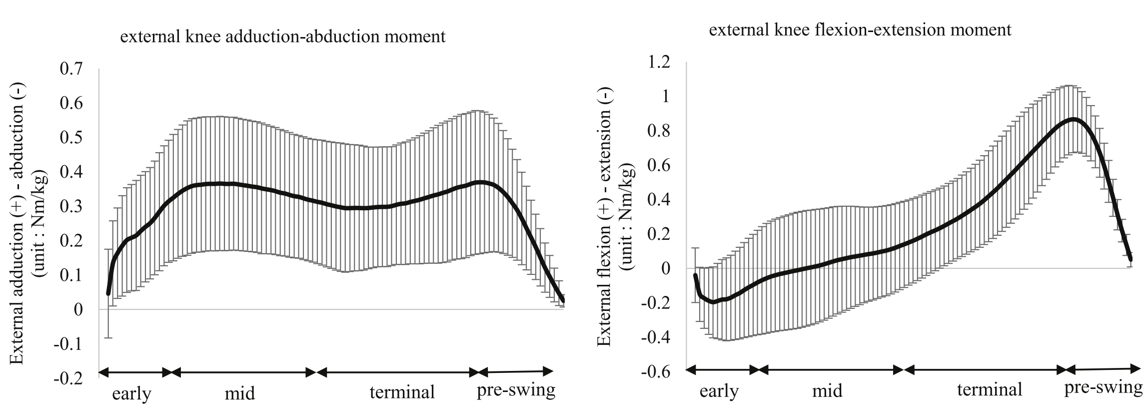


**Fig. 2.** Longitudinal data for the external knee moment during the stance phase. Left. External knee adduction moment. Right. External knee extension – flexion moments.

the external knee extension moment. Because the lateral condyle of the thigh rotates toward the back when the knee joint flexes, the knee joint shows a tendency to assume an internal rotational position. Based on the results of this study, the increase in the external knee extension moment was thought to be influenced by the combination of flexion and rotational movements of the knee joint.

This study had several limitations. Only a limited number of subjects were enrolled, and we lacked a control group. We therefore could not compare osteoarthritic and normal knee movements. But we could not ignore the influence of skin motion artifacts in the frontal and horizontal planes. Finally, this study was a cross-sectional study. In the future, we would include patients with mild knee osteoarthritis in our analysis.

In conclusion, findings from this study clarified the relation between the external knee moment and movement of the knee joint. An effective rehabilitation approach to decrease the load of medial compartment of knee joint must combine both to strength the muscles around the knee joint, particularly quadriceps, and to device for controlling the knee movement. In the future, we would include patients with mild knee osteoarthritis in our analysis, and propose a conservative treatment method to effectively prevent the progression of knee osteoarthritis that emphasizes ways to reduce dynamic load.

## Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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