Original Article

Relationships among foot position, lower limb alignment, and knee adduction moment in patients with degenerative knee osteoarthritis

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Abstract. [Purpose] The aim of this study was to determine the relationships among the foot progression angle, foot rotation angle, lower limb alignment, and knee adduction moments in patients with degenerative knee osteoarthritis (OA). [Subjects] Forty-eight patients diagnosed with degenerative knee OA (Kellgren-Lawrence grades 2 and 3) were included. [Methods] To assess the lower extremity alignment and weight-bearing ratio, static radiographic measurement was used. Foot progression angle, foot rotation angle, and knee adduction moments were measured by using a three-dimensional motion analysis system. [Results] The results of this study were as follows: the foot progression angle in the early and late stance phase was significantly correlated with the first and second peak knee adduction moments; the weight-bearing ratio was significantly correlated with the first and second peak knee adduction moments; and the tibiofemoral angle was significantly correlated with the first and second peak knee adduction moments. [Conclusion] The results of the present study indicated that as the foot progression angle and the foot lateral rotation angle increased, the knee adduction moment decreased. The weight-bearing ratio and tibiofemoral angle assessment with mechanical axis alignment were correlated with the knee adduction moments. These parameters may be helpful for selecting therapeutic options for patients with degenerative knee OA.
Key words: Knee osteoarthritis, Knee adduction moment, Foot rotation angle

INTRODUCTION

Osteoarthritis (OA) is the most prevalent disease associated with significant morbidity, and it is one of the most common causes of functional limitation and dependency. Knee OA is particularly disabling because of symptoms such as pain, stiffness, and muscle weakness[1, 2]. It causes difficulty in climbing stairs, rising from a seated position, and walking, eventually leading to physical disability and decreased quality of life[3, 4].

In many previous studies, associations between the mechanical axis alignment of the lower limb and OA severity were found[5–9]. Malalignments of the knee joint make individuals more susceptible to developments of knee OA[7], and valgus or varus alignment increase the risk of knee OA occurrence[6, 10]. Varus alignment, in particular, resulted in the largest stresses at the medial compartment of the knee[5].

The adduction moment at the knee during gait is the primary determinant of the medial-to-lateral distribution[11]. Measurement of the knee joint moments provides an indication of the actual knee joint loads related with the progression of OA[12]. The knee adduction moment is mainly determined by the ground reaction force and its lever arm. The line of action of the ground reaction force is directed to the medial side and the center of the knee during gait, and its lever arm is the perpendicular distance from this force vector to the knee joint center. The knee adduction moment tends to adduct the knee into a varus position, which is significantly correlated with disease severity[11].

An altered kinematic pattern of the ankle joint can also influence lower extremity function[13–18], and the foot progression angle is related to the knee adduction moment during gait[19–22]. During the late stance phase in the gait cycle, the ground reaction force passes through the forefoot, and medial to lateral disturbances caused by foot rotation influence knee kinetics[23]. Thus, patients with knee OA tend to rotate their foot in order to reduce their adduction moments[24].

Most previous studies on foot position and knee adduction moment have focused on foot progression[19, 22]. Only a few studies have examined the relationship between the foot rotation angle and knee adduction moment. Therefore, the purpose of this study was to investigate the relationships among the foot progression angle, foot rotation angle, lower limb alignment, and knee adduction moments in patients with degenerative knee OA.

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Table 1. General characteristics of the subjects (N=48)

Parameters	Values	
Kellgren-Lawrence radiographic criteria (n)	2nd grade	(21)
	3rd grade	(27)
VAS (scores)	6.5 ± 1.6	
Age (years)	70.5 ± 4.7	
Height (cm)	154.2 ± 4.9	
Weight (kg)	64.7 ± 8.4	
Foot length (cm)	22.8 ± 0.9	
Foot breadth (cm)	10.2 ± 0.7	
Cadence (steps/min)	121.8 ± 9.1	
Gait speed (cm/s)	118.9 ± 10.5	
Step length (cm)	117.5 ± 11.7	
Stride length (cm)	8.9 ± 1.8	

Values are means ± SD. VAS: Visual Analogue Scale

Table 2. Foot position, knee adduction moment, and lower limb alignment of the subjects (N=48)

Parameters	Values
Foot progression angle (°)	
Early stance phase	8.95 ± 5.81
Late stance phase	10.25 ± 6.13
Foot rotation angle (°)	
Early stance phase	1.14 ± 1.03
Late stance phase	0.41 ± 1.07
Knee adduction moment (Nm/kg)	
1st peak value	0.55 ± 0.13
2nd peak value	0.47 ± 0.16
Weight-bearing ratio (%)	32.0 ± 12.2
Tibiofemoral angle (°)	3.60 ± 2.22
Femoral valgus angle (°)	
Medial	5.19 ± 1.49
Lateral	4.16 ± 1.90
Patellofemoral Q angle (°)	8.79 ± 5.46
Patellotibial Q angle (°)	9.23 ± 5.40

Values are means ± SD

SUBJECTS AND METHODS

We included 48 female patients aged 65 years and older who were diagnosed by radiography with degenerative knee OA (Kellgren-Lawrence grades 2 and 3). We excluded patients who received more than 7 points in a physical therapy evaluation, which included an assessment of sensation, circulation, range of motion, muscle strength of the lower limbs, and problems concerning the feet and balance[25]. Additional exclusion criteria were as follows: cardiovascular disease, diabetes, peripheral nervous disease, history of lower extremity surgery, difficulties with visual or auditory function, and cognitive disorder (Korean Mini-Mental State Examination score ≤24). The purpose of the study was explained to the participants, and informed consent was obtained. The study protocol was approved by the institutional review board of Sahmyook University, Seoul, Republic of Korea.

To assess the lower extremity alignment and weight-bearing ratio, a static radiographic measurement system (Shimadzu 500 mA and 35.56 × 91.44 cm cassette; Shimadzu Seisakusho, Ltd., Kyoto, Japan) was used. To minimize errors during knee angle assessment, the focus-film distance was set at 183 cm. The examiner conducted anterior-posterior radiography while subjects stood with their knees straight and their big toe and heel aligned with a marked line. The examiner measured the knee angle radiographically using a goniometer and ruler.

The foot progression angle, foot rotation angle, and knee adduction moments were measured by using a three-dimensional motion analysis system (Orthostat 6.29; Motion Analysis, Inc., Santa Rosa, CA, USA) composed of two force plates (piezoelectric force plate, 600 × 900 mm; Kistler Corp., Winterthur, Switzerland), six infrared cameras, and 25 mm reflective markers. The reflective markers were attached to the right and left of the center of the sacrum, anterior superior iliac spine, middle point between the greater trochanter and lateral femoral condyle, lateral femoral condyle, middle point between the femoral condyle and lateral malleolus, lateral malleolus, calcaneus, and 2nd metatarsal bone.

After a warm-up walk, the assessment was conducted five times, and the subjects were asked to walk as usual and had a 2 min rest during the intervals between the assessments.

The foot progression angle and foot rotation angle were measured at the point of the first peak knee adduction moment in the early stance phase and during the second peak knee adduction moment in the late stance phase. Additionally, we measured lower limb alignment and the first and second peak knee adduction moments.

The SPSS version 12.0 software (SPSS, Inc., Chicago, IL, USA) was used to perform statistical analyses. Descriptive statistics were used for general features. To determine the relationships among foot position, lower limb alignment, and knee adduction moments in the subjects, we used Pearson's correlation coefficient. The level of statistical significance was $p < 0.05$.

RESULTS

The general characteristics and gait analysis results of the subjects are described in Table 1. The foot position, knee adduction moments, and lower limb alignment of the subjects are summarized in Table 2.

In the early and late stance phases, the foot progression angle was significantly correlated with the first and second peak values of the knee adduction moments ($p < 0.05$) (Table 3). The weight-bearing ratio was significantly correlated with the first and second peak knee adduction moments. The tibiofemoral angle was significantly correlated with the first and second peak knee adduction moments ($p < 0.05$) (Table 4).

Table 3. Relationship between foot position and knee adduction moment (N=48)

| Foot position | Knee adduction moment | |
	1st peak value	2nd peak value
Foot progression angle (°)		
Early stance phase	−0.30[a]*	−0.45*
Late stance phase	−0.33*	−0.48*
Foot rotation angle (°)		
Early stance phase	0.08	0.31*
Late stance phase	0.14	0.38*

[a]Pearson's correlation coefficient. *p<0.05

Table 4. Relationship between lower limb alignment and knee adduction moment (N=48)

| Lower limb alignment | Knee adduction moment | |
	1st peak value	2nd peak value
Weight-bearing ratio (%)	−0.58 [a]*	−0.62*
Tibiofemoral angle (°)	0.57*	0.59*
Femoral valgus angle (°)		
Medial	0.39	0.27
Lateral	0.08	0.23
Patellofemoral Q angle (°)	−0.06	0.22
Patellotibial Q angle (°)	−0.01	0.30

[a]Pearson's correlation coefficient. *p<0.05

DISCUSSION

The results of the present study indicated that as the foot progression angle and foot lateral rotation angle increased, the knee adduction moment decreased. In addition, the weight-bearing ratio and tibiofemoral angle assessment with mechanical axis alignment were correlated with the knee adduction moments. We found that a higher foot progression angle was correlated with a reduction in knee adduction moments. A study by Lin et al. demonstrated a reduced peak knee adduction moment when out-toeing during normal walking[22]. Additionally, a study by Teichtahl et al. showed that subjects who walked with their feet externally rotated reduced their knee adduction moment during the late stance phase[23]. Guo et al. suggested that walking with a toe-out strategy may be beneficial for persons in the early stages of medial knee OA, because the toe-out foot position can transfer ground reaction force to the outside of the foot, resulting in a reduction in knee adduction moment[20].

Our results showed that the foot rotation angle was higher in the second knee adduction moment. Similarly, Teichtahl et al. described that the foot rotation position was more related to the late stance phase than the early stance phase because of the ground reaction forces distributed to the forward, inside, and outside parts of the foot[23].

Anatomical lower limb alignment assessment of the knee measured on standard knee radiographs is widely used to investigate the relationship with the knee adduction moment[5, 10, 26] and to detect the progression of degenerative knee OA[23, 27–30]. The anatomical tibiofemoral angle of the knee obtained using a short cassette (35.56 × 43.18 cm) is more widely used because of its economical and practical benefits. However, a limitation of this measurement is its wide variation due to exclusion of the hip and ankle joints[28]. Thus, we used a measurement method that assessed the mechanical tibiofemoral angle and the weight-bearing ratio using the hip, knee, and ankle angles with full-limb radiographs using a long cassette (35.56 × 91.44 cm).

The weight-bearing ratio is calculated by measuring the distance from the medial edge of the proximal tibia to the point where the weight-bearing line intersects the proximal tibia and then dividing the measurement by the entire width of the proximal tibia; the percentage is calculated by multiplying this ratio by 100%. By definition, a weight-bearing line of <50% indicates varus alignment of the lower extremity, and a line >50% indicates valgus alignment[19]. In our results, the weight-bearing ratio was significantly correlated with the first knee adduction moment and the second knee adduction moment, meaning that as the knee adduction moment in the early and late stance phase increased, the inside of the knee joint loading increased.

In the present study, the tibiofemoral angle of the subjects was 3.60° ± 2.22°, which was greater than that of a normal person (1.2–2.2°)[30], because the subjects had knee OA with varus alignment. Regarding the relationship between the tibiofemoral angle and the knee adduction moment, the first and second knee adduction moments were significantly correlated with the valgus alignment angle.

The femoral valgus angle was 5.19° at the time of measurement of the medial tibiofemoral angle and was 4.16° at the time of measurement of the lateral tibiofemoral angle. These values were less than that of the normal group (6°)[31], because the subjects with knee OA had varus alignment. Therefore, there was no relationship between the femoral valgus angle and the knee adduction moment in our subjects. The normal anatomical Q angle is 15 ± 3°[30], but in our subjects, the patellofemoral Q angle was 8.7°, and the patellotibial Q angle was 9.2°, both of which were less than the normal range due to the varus deformity of the knee joints. Additionally, there was no significant relationship between the Q angle and the knee adduction moment.

In conclusion, we found that as the foot progression angle and foot lateral rotation angle increased, the knee adduction moment decreased. The weight-bearing ratio and tibiofemoral angle assessment with mechanical axis alignment were correlated with the knee adduction moments. However, the femoral valgus angle and anatomical Q angle may not be relevant to the knee adduction moment. Therefore, the mechanical tibiofemoral angle is more appropriate for assessing patients with knee OA than anatomical lower limb assessment. These findings may be helpful for selecting therapeutic options for patients with degenerative knee OA.

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