■ ORIGINAL ARTICLES

Medial knee contact force and dysfunction in the elderly

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ABSTRACT:

OBJECTIVE: The tissue destruction around knee joint is considered to involve medial knee contact force overload. However, no report has examined the relationship between the medial knee contact force and dysfunction. In this study, we investigated the medial knee contact force during gait in elderly subjects using musculoskeletal model-based simulation analysis and revealed its connection with pain and dysfunction.

METHODS: We separated 122 elderly participants into 2 groups, the pain group and non-pain group, according to the existence of knee pain. Medial knee contact force was calculated based on the previously published inverse dynamics solution for normal walking. The muscle and joint reaction forces were used to determine the medial knee contact force during the stance phase. Japanese knee osteoarthritis measurement was used to assess the severity of symptoms for knee pain subjects.

RESULTS: The medial knee contact force was significantly correlated with total Japanese knee osteoarthritis measurement scores and subscale dysfunction scores for pain subjects, although there was no difference in the medial knee contact force between the 2 groups.

CONCLUSION: An increased medial knee contact force during gait might relate to dysfunction among elderly individuals with knee pain.

Key words: dysfunction, medial knee contact force, gait

INTRODUCTION

Many elderly individuals experience knee functional disorder, which is manifested clinically as pain, limited mobility, and knee joint deformity. Adverse mechanical loading, including repetitive and excessive joint load, is believed to contribute to joint deformation, such as subchondral bone damage, soft tissue irritation by osteophytes, and joint effusion caused by inflammation[1], which leads to knee pain or dysfunction[2]. Even in healthy elderly individuals, a certain level of damage is present in the cartilage and periarticular soft tissues around the knee, and some of them feel somewhat uncomfortable symptom, i.e. dull pain during exercise or difficulty in deep knee bending[3]. The structural destruction in knee joint develops predominantly in the medial compartment of the tibiofemoral joint[4], and thus it would be valuable to examine the mechanical contact force in this compartment (medial knee contact force) for knee dysfunction.

The identification of medial knee contact force might be an indicator of knee joint damage risk. Larger medial contact force is considered a risk factor for knee symptoms due to tissue damage around the knee. There are many studies to investigate the relation between adduction moment and knee function such as knee pain[5,6], however, no study has focused on elderly to investigate the relation between the medial knee contact force and knee function. Unfortunately, the medial knee contact force is impossible to measure non-invasively. However inverse simulation analysis enables the calculation of muscle tension from the joint angle and joint moment based on a musculoskeletal model[7]. It also provides a method to predict joint contact force in a non-invasive manner. We reported that the medial knee contact force calculated by using the model was correlated to both external adduction moment, which has been used as an index to burden on medial knee joint, and flexion moment, which lead to quadriceps force[8]. Adduction moment cannot fully explain the burden at the medial knee joint. Therefore, we examined the medial knee contact force during gait in elderly subjects using musculoskeletal model-based simulation analysis and investigated the correlation between the medial knee contact force and pain or dysfunction in this study.

SUBJECTS AND METHOD

Participants

One hundred twenty-two community-dwelling elderly individuals (31 men and 91 women) participated in this study. Subjects were aged 73.8 ± 6.3 years, 1.54 ± 0.08 m in height, and weighed 51.1 ± 7.4 kg. Inclusion criteria were (1) no cognitive impairment that prohibited understanding of instructions, (2) no serious neuromuscular impairment that would prevent measurements, (3) no difficulty in independent ambulation, and (4) no need for daily life assistance. Written informed consent was obtained from each subject. The study was approved by the Ethical Review Board.

Subjects were divided into 2 groups, the pain group and non-pain group, according to the existence of pain at the medial side of the knee. Subjects who had experienced continuous knee pain for more than 3 months in the last 1 year were classified as the pain group; those who had experienced knee pain caused by an accidental injury lateral knee pain were excluded in this study.

Knee function measurement

The Japanese knee osteoarthritis measurement (JKOM) was used to assess the self-reported knee function of subjects in the pain group[9]. The JKOM is a measurement of patient-based outcomes and health-related quality of life in the context of a Japanese sociocultural background. The JKOM consists of 4 major categories: (1) knee pain and stiffness, (2) condition in daily life, (3) general activity, and (4) health condition. The JKOM consists of 25 questions. For each question, a score of “5” designates the most severe disability, and the worst total score (full marks) is 125. The pain and stiffness subscale was used as a measure of the pain score and the condition in daily life subscale was used as a measure of dysfunction score. The reliability and validity of the JKOM have been established previously[9].

Kinetic and kinematic data

Three-dimensional motion analyses and lower extremity muscle activity measurements were performed during static standing and gait conditions. For the assessments during static standing, subjects were instructed to keep both legs slightly apart with a relaxed posture as they stood on 2 force plates (Kistler, Switzerland) for more than 1 s. For the gait assessment, subjects were instructed to walk as usual on the force plates at normal speed. Each trial was performed twice.

For both static standing and gait conditions, three-dimensional coordinates of reflective markers and ground reaction force data were measured using the VICON MX motion analysis system (Vicon Motion, UK). The three-dimensional motion capture system consisted of 6 infrared cameras with a sampling rate of 100 Hz and 2 force plates with a sampling rate of 1000 Hz. Seventeen markers were attached to each subject skin at anatomical landmarks: anterior superior iliac spines, sacrum, greater trochanters, medial and lateral knees, medial and lateral ankles, heels and second metatarsal head referred to described elsewhere[10]. Low-pass Butterworth filters were applied to the reflective marker coordinates and ground reaction force data using cutoff frequencies of 5Hz and 15Hz, respectively.

The center of the ankle joint was defined as the midpoint between the lateral and medial malleolus markers, and the center of the knee joint was defined as the midpoint between the medial and lateral knee markers. The center of the hip joint was calculated from pelvis markers[11]. The joint angle was calculated from the joint center positions according to the International Society of Biomechanics recommendation on definitions of joint coordinate systems[12]. Each segment length was calculated from the data computed for static standing, and the segment mass and moment of inertia were calculated as described previously[13]. Inverse dynamics was performed to calculate the joint moments and joint reaction forces using the Newton–Euler equation.

Musculoskeletal model

The previously described musculoskeletal model[14] was used in this study. This model consists of 4 rigid segments of the pelvis, thigh, shank, and foot. The 3 joints of the ankle, knee, and hip have 2, 1, and 3 rotational degrees of freedom, respectively. The model has 42 muscle-tendon units, and the optimal length, tendon slack length, and pennation angle were decided based on data from a previous report[15]. The segment lengths were used to scale the simulation model to the subject which included scaling of the anatomical position, optimal length and tendon slack length. The physiological cross-sectional area of each muscle was determined based on Horsman’s data[16]. The maximum muscle stress was extracted from the literature[17]. Hill’s model[18] was used to calculate the muscle force while considering the effects of velocity and length in accordance with a previous study[19].

The net joint moments were decomposed into individual muscle forces by solving a minimization problem of the cubic sum of muscle activations at each sampling instance[20].

The knee contact force was calculated as a point load acting on the tibial plateau. The moment vector $\vec{m}_{muscle}(j)$ generated by the muscle j was expressed by

$$\vec{m}_{muscle}(j) = \vec{f}(j) \times \vec{r}(j) \quad j = 1, 2, \cdots, N \tag{1}$$

where $\vec{f}(j)$ and $\vec{r}(j)$ are the muscle tension force vector and moment arm vector of the muscle j, and N is the number of muscles crossing the knee joint. The muscle tension force vector $\vec{f}(j)$ was decomposed into the knee contact forces $F(j)$ by the muscle j, the parallel component along the long axis of the shank. The net knee contact force F_{net}, which is the sum of the medial and lateral knee contact forces F_m and F_l, were calculated as the sum of the external force (joint reaction force) F_{ext} and the contact forces generated by muscle tension forces $F(j)$.

$$F_{net} = F_m + F_l = \sum_{j=1}^{N} F(j) + F_{ext} \tag{2}$$

That is, the equilibrium of adduction/abduction moment of the knee joint is written as

$$F_m d_m - F_l d_l = \sum_{j=1}^{N} M_{muscle}(j) + M_{ext} \tag{3}$$

where d_m and d_l are the mediolateral moment arm lengths, i.e., the distances from the center of the knee joint to the point of the contact forces acting on the medial and lateral compartments, respectively, $M_{muscle}(j)$ is the external knee adduction moment in $\vec{m}_{muscle}(j)$, and M_{ext} is the external knee adduction moment. The mediolateral moment arm lengths, d_m and d_l, were fixed at 25% of the knee joint diameter, as described previously[6].

Data analysis

The data for the affected knee were analyzed for pain group subjects and the data for both knees were analyzed for non-pain group subjects. In the case of bilateral knee pain, the data for the most strongly affected side were used. Each external joint moment was normalized by the subject's height and body weight (BW), and the contact force was normalized by the subject's BW. The medial knee contact force was represented as the waveform throughout the 101 percentage points of the stance phase (%SP). The first and second peaks were identified from the waveform data of the medial knee contact force. We defined the first peak of the medial knee contact force as the maximum value of the medial knee contact force during 0−50 %SP and the second peak as the maximum value of the medial knee contact force during 51−100 %SP.

The *t*-test and Chi-square test were used to examine the difference between the pain and non-pain groups. The correlations between the medial knee contact force, total JKOM score, subscale pain and dysfunction scores, and gait speed were examined using Spearman's rank correlation coefficient. A *p*-value less than 5% was considered significant.

RESULTS

There were 44 subjects in the pain group and 78 subjects in the non-pain group (Table 1). There was no significant difference between these 2 groups in age, height, weight, sex distribution, and gait speed. The median total JKOM score of pain group subjects was 7.5 (range, 1−37).

The maximum values of the external joint moment and medial contact force are shown in Table 2 and the medial knee contact force throughout the stance phase is shown in Figure 1. The first peak of the medial knee contact force did not differ significantly between the 2 groups. The mean value of the second peak of the medial contact force was slightly larger in pain group, but this difference was not significant.

The correlation coefficient between the total JKOM score and the peaks of the medial knee contact force are shown in Table 3. The total JKOM score was significantly correlated with the first peak of the medial knee contact force (correlation coefficient, 0.32, p <0.05). The pain score did not have significant correlations with the first and second peaks of the medial contact force; however, the dysfunction score was positively correlated with both the first and second peaks of the medial contact force. Gait speed was not significantly correlated with the total JKOM score (r = -0.22, p = 0.16), pain score (r = -0.09, p = 0.59), or dysfunction score (r = -0.15, p = 0.34).

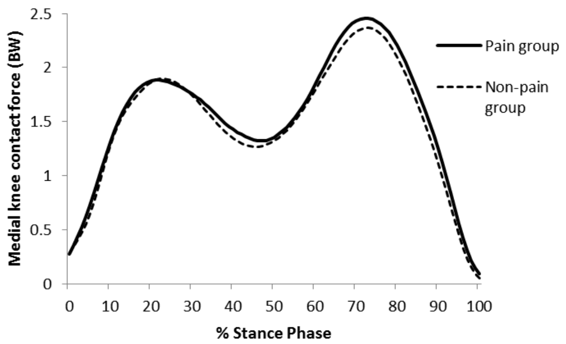

Figure 1. Mean medial knee contact force of the study groups

Table 1. Data of the study subjects

	Pain group	Non-pain group
Age (years)	74.8 ± 6.4	73.4 ± 10.5
Height (m)	1.53 ± 0.06	1.55 ± 0.08
Weight (kg)	51.3 ± 7.5	50.8 ± 7.3
Sex	7 men, 37 women	24 men, 54 women
Gait speed (m/s)	1.28 ± 0.17	1.29 ± 0.18
JKOM (total)	7.5 (1−37)	

Age, height, weight and gait speed are represented as mean ± standard deviation.
Japanese knee osteoarthritis measurement (JKOM) scores are represented as median values (minimum − maximum).
T-tests were used to examine statistical differences in age, height, weight, and gait speed.
The chi-square test was used to examine the statistical difference in sex distribution.
No differences were observed between the 2 groups.

Table 2. Maximum external knee moments and medial knee contact force

	Pain group	Non-pain group
External knee moment (Nm/%BW*height)		
Flexion	3.23 ± 1.89	2.83 ± 1.54
Extension	4.50 ± 2.21	4.58 ± 2.29
Adduction	2.97 ± 1.06	2.78 ± 1.38
Medial knee contact force (%BW)		
First peak	2.12 ± 0.47	2.07 ± 0.63
Second peak	2.64 ± 0.83	2.51 ± 0.89

Data are represented as mean ± standard deviation.
No difference was observed between the 2 groups.

Table 3. Correlation between the Japanese knee osteoarthritis measurement (JKOM) score and medial knee contact force

Coefficient correlation	Medial knee contact force	
	First peak	Second peak
JKOM total score	0.32*	0.17
JKOM subscale		
Pain score	0.28	0.21
Dysfunction score	0.36*	0.31*

The correlation was examined using Spearman's rank correlation coefficient.
*$p < 0.05$

DISCUSSION

This study analyzed the relation between the medial knee contact force during the stance phase and knee pain and dysfunction in elderly subjects, using musculoskeletal simulation analysis and a self-reported knee function measure JKOM to have context of life style for Japanese elderly. The total JKOM score was reported to be 50–60 for patients with mild and moderate osteoarthritis (Kellgren and Lawrence grade I and II)[21, 22]. The median total JKOM score for our pain group subjects was 7.5 (range, 1–37); therefore, they had very mild knee dysfunction. The mean gait speed of the pain group subjects was nearly the same as that of the non-pain group subjects and was not correlated with pain or dysfunction scores. These results implied that slow walking caused by pain or dysfunction in order to reduce the medial contact force was not observed in this study.

The total JKOM score was positively correlated with the first peak of the medial knee contact force. This result indicated that subjects with more severe symptoms walk with a higher medial knee contact force. In particular, the dysfunction score was related to the first and second peaks of the medial knee contact force. For elderly individuals with knee pain, dysfunction score measurement might be used for prediction of medial knee contact force. The results of the present study suggested that the subjects who walked with a higher medial knee contact force tended to have some sort of disability. However, these findings did not agree with those of a previous study of moderate and severe osteoarthritis patients, which reported that the knee dysfunction score had no or a weak negative relation to adduction moment[23, 24]. This inconsistent result is likely explained by the intensity of symptoms, that is, moderate and severe patients might perform a compensatory gait to avoid pain, which is a source of disability for osteoarthritis patients, to minimize the medial knee contact forces. To decrease the medial knee contact force during walking, several strategies have been suggested, including reduction of gait speed, increase of toe-out, or increase of trunk lean[25]. Gait speed is closely related to the knee extension-flexion moment, and consequently to the quadriceps and gastrocnemius muscle activation[26]. The muscle force is a major contributor to the medial knee contact force, thus the gait speed is important factor that affects the medial knee contact force[27]. Indeed, 1.28m/s was similar speed as that for normal healthy elderly in aged 70s female[28]. Moreover, walking speed did not correlate with the dysfunction score in this study. Pain group subjects might not need to perform a compensatory slow gait to decrease the medial contact force because the intensity of their symptoms was very mild.

In contrast to the dysfunction score, the pain score was not significantly correlated with both the first and second peaks of the medial knee contact force. Pain is one of the most prominent symptom; however, the correlation between knee pain and radiographic severity is not strong[3]. Articular cartilage has no nociceptive fibers and thus cannot be the source of pain[2]. The exact cause of pain with degenerative joint disease is often passed unnoticed.

There were no significant differences in the medial knee contact force between the pain and non-pain groups. Medial knee contact force during the stance phase for 2 groups exhibited similar patterns, as shown in Figure 1. This result implies that the existence of medial knee pain within the past 1 year was not affected by the magnitude of medial knee contact force during the stance phase. The maximum joint moment was also not different between the 2 groups. In a previous study, patients with less severe osteoarthritis were reported to have similar knee adduction moment values as healthy subjects[29]; our study showed the same result. Therefore, the medial knee contact force during gait might not be related to the presence or absence of knee pain.

The limitation of this study was addressed in the method of group classification. We divided to subjects into 2 groups, according to the existence of pain at the medial side of the knee, and the pain group subjects were regarded elderly with knee symptom to implicit osteoarthritis. Approximately two-thirds of subjects, even those with radiographic changes of degenerative articular cartilage, did not feel knee pain[3]; thus, radiographic assessment would be required for the examination of osteoarthritis pathology. Moreover, our simulation model used in this study could not account for the co-contraction factor of antagonistic muscles, although a high level of co-contraction is necessary to stabilize joints during the early stance phase[30]. Thus, the contact force in the early stance phase might have been underestimated. Electromyographic measurement is required to assess the detailed information of the medial knee contact force. And more individual bony structural, we did not get information, might be relate to our result. For example the lever arm between knee joint center and contact point will be related to the magnitude of medial knee contact force.

We examined the association of the medial knee contact force, calculated using the musculoskeletal model-based analysis during gait, with the self-reported knee dysfunction and pain scores among the elderly subjects. The medial knee contact force during gait was moderately correlated with dysfunction, however this force was not significantly different from subjects with no knee pain. Our study implies the medial knee contact force during gait might contribute to dysfunction among elderly individuals with knee pain.

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