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Relation	

Medial Meniscus Extrusion during Gait is Associated with decrease in Knee Rotation in Early-stage Knee Osteoarthritis

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Abstract

Background: In patients with medial knee osteoarthritis (OA), medial meniscus extrusion during gait is aggravated by mechanical stress, such as knee adduction moment (KAM). Conversely, the decrease in the range of knee rotation during stance phase is also one of the important issues in early knee OA, whereas the correlation between medial meniscus extrusion and knee rotation during gait are unclear.

Research question: To investigate the correlation between increase in medial meniscus extrusion and range of knee rotation during gait in patients with early- and late-stage of knee OA.

Methods: Forty patients with medial knee OA were enrolled and divided into early- and late-OA group by Kellgren-Lawrence grading scale. During gait tasks, the extent of medial meniscus extrusion was measured using ultrasonography and kinetic/kinematic data were measured using three-dimensional motion analysis system. The correlation between medial meniscus extrusion and the range of knee rotation or KAM were evaluated in the overall, early-, and late- OA groups.

Results: A significant negative correlation was observed between an increase in medial meniscus extrusion and range of knee rotation angle in early-OA group only. However, an increase in medial meniscus extrusion significantly correlated with the second KAM peak in the overall and early-OA groups.

Significance: The decrease in range of knee rotation during stance phase may be associated with the increase in medial meniscus extrusion during gait in patients with early knee OA.

Keywords: *medial meniscus extrusion · range of knee rotation angle · medial knee osteoarthritis · ultrasonography*

1. Introduction

Medial knee osteoarthritis (OA) is among the most common degenerative musculoskeletal disorders. Lesions or degeneration of medial meniscus causes medial meniscus extrusion (MME) which leads to the progression of medial knee OA [1]. The increase in MME under weight-bearing condition indicates dysfunction of load distribution and associated with progression of knee OA [2,3]. In particular, a marked increase in MME during gait has been observed in knee OA [4]. Therefore, elucidating the factors of MME aggravation during gait include valuable information to prevent the progression of knee OA from an early stage.

As for kinetical factor, external knee adduction moment (KAM) is associated with the progression of knee OA [5,6]. KAM is used as index of measuring mechanical stress to the medial tibiofemoral joint [7]. A previous study showed that the second KAM peak correlated with increase in MME during gait [8]. However, various pattern of MME waveform was observed during stance phase, and not all waveforms correlated with KAM [9]. Therefore, kinetic mechanisms alone might not account for the increase in MME during gait.

In kinematic factors during gait, the decrease in range of knee rotation was already observed in patients with the early knee OA, while the decrease in the ranges of motion on other plane was not [10]. Further, internal knee rotation bias was associated with cartilage thinning on medial compartment of the knee [11]. Although it has shown that the medial meniscus moved accompanying internal/external knee rotation in static weight-bearing condition [12], the correlation between MME and knee rotation during gait is unclear.

Further, the extent of MME, knee rotation and KAM during gait varies based on the severity of knee OA or varus deformity [6,13,14], and investigating these correlations in various severity subgroups of knee OA would offer deeper insights into the factors of MME aggravation during gait.

This study aimed to evaluate the correlation between MME and range of knee rotation during stance phase in patients with early- and late-stage knee OA. We hypothesized that the aggravation of MME is associated with a decrease in knee rotation.

1. Materials and Methods

2.1. Participants

Forty participants with medial knee OA, receiving treatment at our institution, were enrolled for this study (mean age, 65.6 ± 11.8 years; females, $n = 20$). An orthopedic specialist evaluated the severity of knee OA using Kellgren-Lawrence (K/L) grading scale. In addition, the varus alignment was measured using femorotibial angle (FTA) which was defined as an anatomic axis on the frontal plane, and hip-knee-ankle angle (HKA-A) which was defined as mechanical axis on the frontal plane. Both parameters indicated that there was significantly severe varus alignment in late-OA group. Patients who were diagnosed with primary tibiofemoral knee OA and had the ability to walk without any support were included. Participants were excluded if they had (1) FTA < 174° or > 190°, (2) age < 40 years, (3) a history of surgical treatment of the knee joint, or (4) neurological disorders.

Participants were divided into two groups: the early-OA group (K/L grade I or II; n = 21) and the late-OA group (K/L grade III or IV; n = 19) based on the severity of knee OA.

This study was approved by the Ethical Committee for Epidemiology of Hiroshima University, Hiroshima, Japan (No. E449-4). All participants provided written informed consent.

2.2. Study protocol

First, the static kinematics data were measured using a three-dimensional motion analysis system while the patients were standing. Second, participants were instructed to take 5m-walk at a self-selected normal speed, and three-dimensional motion analysis system and ultrasonography were used for kinetic/kinematic and meniscal assessment. Three gait trials were conducted, and the average of three trials were used for evaluation. Participants walked barefoot during the experiment.

2.3. Dynamic MME evaluation

An ultrasound system (SNiBLE, Konica Minolta, Inc., Japan) with a prototype 3- to 11-MHz flat shaped linear-array transducer (Konica Minolta, Inc., Japan) was used to evaluate the extent of MME during gait [4]. A probe was fixed longitudinally in the medial tibiofemoral joint space with a stretchable belt to obtain the medial collateral ligament and medial meniscus images (**Fig. 1A**). Ultrasound images were recorded during gait trial in the video mode at 30 fps. The ultrasonography and motion analysis system were synchronized via an external signal which allowed the timing of gait cycle to be detected in ultrasonic video data. Then, the approximately 20 images were acquired during a stance phase. The extent of MME was calculated from the ultrasound images during stance phase using video annotation software (v0.8.27, Kinovea open-source project). The extent of MME was calculated as the distance between medial tibial cortex and the medial edge of medial meniscus (**Fig. 1B**) [4], and the MME waveform during stance phase was normalized to 100 data point. The maximum (MME $_{max}$) and minimum (MME $_{min}$) value of MME, and the differences between them (ΔMME) in the stance phase were calculated (**Fig. 1C**). In previous study, the intraclass correlation coefficient (ICC) of ΔMME during gait were evaluated [8]. The ICC (1, 3) and the ICC (2, 3) were 0.93 (confidence interval (CI): 0.986–0.726, P = 0.001) and 0.78 (CI: 0.957–0.236, P = 0.001), respectively.

2.4. Gait analysis

Kinematic data were captured using a three-dimensional motion analysis system (VICON MX, Vicon Motion Systems, Oxford) at 100 Hz with 16 infrared cameras. Kinetic data were captured using eight force plates (AMTI, Watertown, Mass) at 1000 Hz. Thirty-four reflective markers were attached to the leg. In the static standing trials, twelve markers were attached to the bony prominences of the affected side (ASIS, PSIS, iliac crest, greater trochanter, medial/lateral femoral epicondyle, medial/ lateral tibial plateau, lateral/medial malleolus, fifth metatarsal head, heel). The thigh or shank cluster system were defined from measurements obtained by placing nine markers on the thigh and six markers on the shank [15]. During gait analysis, the markers attached to the medial knee joint were removed to avoid any interferences with the ultrasound probe fixed at medial joint space (**Fig. 1A**).

Point Cluster Technique (PCT) was used to calculate the knee angle (flexion/extension, internal/external rotation of the knee) [15]. The internal/external knee rotation was defined as the tibial axial angle relative to femur. Inverse Dynamics was used to calculate the KAM (Nm/kg). The ground reaction force data were low-pass filtered at 10Hz. Marker trajectory data were not low-pass filtered according to a previous study [16]. The timing of heel contact and toe-off was defined as the z-axis of GRF threshold of 20 N. Gait speed (m/s) was calculated by the length and the time of one gait cycle. The kinetic/kinematic data was obtained during a stance phase and normalized to 100 data point. The parameters of kinetic/kinematic data were calculated as follows. The range of flexion angle during loading response phase (flex LR) and mid-stance phase (flex Mst) was calculated according to a previous study [17]. The range of rotation angle was calculated as the difference between the most external and internal rotation angle measured during the stance phase. To define the kinetic parameters, the stance phase was divided into two phases: the first half (0–50%) and the latter half (51–100%) of the stance phase. The KAM peak in the first and the latter half of the stance phase was defined as the first and second KAM peak, respectively.

2.5. Statistical analysis

Data analysis was performed using MATLAB R 2022b (MathWorks). The mean value of the three stance phases in for all participants were used for MME and kinetic/kinematic measurement during gait. The normality of MME and kinematic/kinetic data was analyzed by Shapiro-Wilk test. The Student's t-test or Mann-Whitney U-test were used to compare the parameters between the early- and late-OA groups. The mean difference was represented with 95% confidence interval (CI). To remove the effect of age, body mass, and static varus alignment, the correlation between MME and kinetic/kinematic data was analyzed using Pearson's (r) or Spearman's (ρ) partial correlation controlling for age, BMI, and HKA-A in the overall, early-, and late-OA groups. The significance level was set at 0.05. All statistical analysis were conducted using SPSS statistical software (version 23; IBM, USA).

3. Results

3.1. Demographic data

The participants' demographic data are summarized in **Table 1**. FTA was significantly larger in the late-OA group ($p < 0.01$; mean difference, -3.5; 95%CI -5.2, -1.9). HKA-A was significantly smaller in the late-OA group ($p < 0.01$; mean difference, 3.9; 95%CI 2.3, 5.5). The groups did not differ significantly in terms of any demographic characteristics, except for FTA and HKA-A.

3.2. MME and kinetic/kinematic waveforms and variables

The average waveform of the MME, knee rotation and KAM are shown in **Fig. 2**. The MME $_{\text{min}}$ and MME $_{\text{max}}$ occurred at 8.2 ± 9.5 % and 75.8 ± 7.3 % of stance phase, respectively. The maximum knee external and internal rotation occurred at 30.1 ± 40.1 % and 63.2 ± 18.2 % of stance phase, respectively. The first and the second KAM peak occurred at 31.9 ± 6.5 % and 71.1 ± 6.2 % of stance phase, respectively. MME and kinetic/kinematic parameters are shown in **Table 2**. MME $_{min}$ ($p < 0.01$; mean difference, -1.4; 95%CI -2.1, -0.6) and $_{max}$ ($p < 0.01$; mean difference, -1.3; 95%CI -2.1, -0.5) were significantly larger in the late-OA group.

3.3. Correlation between MME and KAM

The correlations between MME and KAM parameters are shown in **Table 3**. No significant correlations were observed between MME $_{max}$ and KAM parameters. The ΔMME was significantly positively correlated with the second KAM peak in the overall and the early-OA groups.

3.4. Correlation between MME and knee rotation

The correlations between MME and knee rotation parameters during gait are shown in **Fig. 3**. The MME $_{max}$ significantly negatively correlated with the knee internal rotation angle in overall patients with knee OA ($r = -0.39$, $p < 0.05$; **Fig. 3A**), but not in the early- and late-OA groups (early: $r = -0.34$, $p = 0.17$; late $r = -0.30$, $p = 0.27$; **Fig. 3B, C**). The ΔMME significantly negatively correlated with the range of knee rotation angle in the early-OA group but not in the overall or late-OA group (overall: $\rho = -0.32$, $p = 0.05$; early: $\rho = -0.49$, $p < 0.05$; late: $r < 0.01$, $p = 0.99$; **Fig. 3D-F**).

4. Discussion

This study investigated the correlation between the increase in MME and the range of knee rotation during stance phase in knee OA. In the knee OA, ΔMME was not significantly correlated with the range of knee rotation angle, but the ΔMME positively correlated with the second KAM peak. Conversely, in the early-OA group, ΔMME and the range of knee rotation angle exhibited significant negative correlations, suggesting that the extent of increase in MME during gait could be due to a decrease in knee rotation in patients with early knee OA.

Firstly, in overall knee OA, the second KAM peak significantly positively correlated with the ΔMME, which was similar to those of previous studies [8,18]. Further, this study showed that $\mathrm{MME}_{\mathrm{max}}$ negatively correlated with knee internal rotation angle. Since $\mathrm{MME}_{\mathrm{max}}$ and the maximum value of knee internal rotation were observed at the mid to terminal stance phase, MME and knee rotation are likely associated. However, in term of the ΔMME, the range of knee rotation was not associated with the extent of an increase in MME in the overall knee OA. Therefore, the second KAM peak may be an important factor for MME increase compared to the range of knee rotation angle in the overall participants with knee OA.

Interestingly, in the early-OA group, an increase in ΔMME significantly correlated with the decrease in the range of knee rotation. A previous study reported that the decrease in the range of knee rotation during gait occurred in early knee OA [10]. Although it was reported that the internal rotation bias was associated with cartilage thinning [11], there is no consensus that the decrease in the range of knee rotation induces the aggravation of medial contact pressure or MME in the knee joint. On the other hand, it has reported that the medial meniscus posterior root tear, which induced MME, led to increase the external knee rotation angle compared to that in the intact knee [19]. Therefore, it is unclear if the decrease in the range of knee rotation induces the increase in MME during gait, or the opposite causal relationship exists. However, ΔMME and the range of knee rotation were not significantly correlated in patients with late knee OA. In this study, HKA-A was significantly larger in late-OA group, which indicated that the varus deformity was more severe in late-OA group. Moreover, a previous study reported that the several gait kinematic patterns were observed in late knee OA [20]. Accordingly, in patients with late knee OA, morphologic or kinetic/kinematic data would influence intricately on the increase in MME during gait, and hence no specific parameters which directly influence on the ΔMME was observed in late-OA group. Therefore, a decrease in the range of knee rotation could be one of the factors for an increase in MME during gait in patients with early knee OA only.

Increase in MME under weight-bearing conditions induces the progression of knee OA [1,3]. Since gait is routinely repeated in daily living, it is important to understand the mechanisms related to an increase in MME during gait. In this study, the second KAM peak correlated with ΔMME in patients with knee OA. In previous studies, the gait modification which used for inhibiting KAM also reduced MME during gait [18,21]. On the other hand, there was no significant correlation between MME and KAM in late-OA group. In moderate to severe knee OA, the morphological changes, such as osteophyte width or varus alignment, was observed, and it aggravated the amount of MME [22,23]. The correlation between MME and KAM in the late-OA group may be distorted by these confounding factors. In this study, the internal rotation angle negatively correlated with

MME_{max} during gait in the knee OA. This is similar to the previous findings which show that a larger extent of external knee rotation deformity and MME was observed in severe knee varus deformity [13,24]. Moreover, there was a significant correlation between the range of tibial rotation and the aggravation of ΔMME in patients with early knee OA only. Our study results have shown that the decrease in knee rotation could be a factor for an increase in MME during gait in early stage of knee OA. However, the causal relationship between the range of knee rotation and ΔMME remains unclear. Therefore, to clarify the association between MME and knee rotation, future research would like to focus on the lesion of medial meniscus or intervention affecting the knee rotation, and the investigate the causal relationship between MME and knee rotation during gait.

The study had several limitations. First, MME was only evaluated at the medial compartment, although knee rotation occurred in the horizontal plane. Previous studies have used ultrasonic evaluation of MME was conducted at the medial compartment [3,4,25]. Since this study was the first step to evaluate the correlation between MME and knee rotation during gait, MME was also evaluated at medial compartment in accordance with the previous studies. MME evaluation at another compartment is required to identify the MME dynamics in detail. Second, the sample size of the study was small in the early- and late- OA group. Also, we included patients who can walk without any support and have no remarkable degree of varus or valgus knee alignment. Therefore, this study cannot be generalized in patients with varying degrees of knee OA. Third, we did not recruit the healthy control volunteer because we focused on the difference in the correlation of MME with knee rotation between knee OA severity. Further investigations are needed to clarify the association of MME with knee rotation in knee OA by comparing with healthy control. Last, this study was a cross-sectional study and the consequences of the kinetic/kinematic data on MME remain unclear. Longitudinal studies are needed to improve our understanding of the cause of an increase in MME during gait in patients with knee OA.

5. Conclusions

The decrease in the range of knee rotation is correlated with the extent of increase in medial meniscus extrusion during gait in early knee OA, but not in late knee OA. The range of knee rotation could have some association with aggravation of medial meniscus extrusion in early knee OA.

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Declaration of interest

Yosuke Ishii and Yuko Nakashima declare that they borrowed an ultrasound device from Konica Minolta, Inc. Saeko Okamoto, Yoshifumi Kono, Takato Hashizume, Riko Okinaka, Goki Kamei, Akinori Nekomoto, Makoto Takahashi and Nobuo Adachi declared that they have no conflicts of interest.

Autor Contributions

Saeko Okamoto: Data curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. **Yosuke Ishii:** Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Writing – review & editing. **Yoshifumi Kono:** Methodology, Software, Resources. **Takato Hashizume:** Investigation. **Riko Okinaka:** Investigation. **Yuko Nakashima:** Resources, Funding acquisition. **Goki Kamei:** Resources, Writing – review & editing. **Akinori Nekomoto:** Resources, Writing – review & editing. **Makoto Takahashi:** Writing – review & editing. **Nobuo Adachi:** Resources, Project administration, Writing – review & editing.

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Table 1

Demographic data of the participants

	OA patients	early-OA	late-OA	mean difference (95% CI)	p value
Knees	40	21	19		
K/L (I, II, III, IV)	4, 17, 14, 5	4, 17, 0, 0	0, 0, 14, 5		
sex (% female)	50	57.1	42.1		
age (years)	65.6 ± 11.8	63.5 ± 13.4	66.8 ± 9.5	-2.6 (-10.3, 5.1)	0.50
height (cm)	162.0 ± 8.1	160.4 ± 8.4	163.8 ± 7.4	-4.1 (-9.2, 1.1)	0.12
weight (kg)	65.6 ± 11.8	64.9 ± 11.9	68.9 ± 11.9	-5.7 (-13.4, 2.0)	0.14
BMI (kg/m^2)	25.2 ± 3.6	24.7 ± 4.3	25.8 ± 3.2	-1.6 (-4.0, 0.9)	0.21
FTA (°)	179.2 ± 3.1	177.5 ± 2.3	181.0 ± 2.3	-3.5 (-5.2, -1.9)	< 0.01
HKA-A (°)	-5.1 ± 3.1	-3.3 ± 2.5	-7.2 ± 2.3	3.9 (2.3, 5.5)	< 0.01

K/L grade, Kellgren-Lawrence grade; BMI, body mass index; FTA, femorotibial angle on the frontal plane, HKA-A, hip-knee-ankle angle on the frontal plane. The values are presented as means ± standard deviations. Mean differences were calculated from the difference between early- and late-OA group with 95% confidence interval (CI). P values are the results of t-tests comparing the early and late OA groups.

Table 2

Medial meniscus extrusion and kinetic/kinematic data during gait

	OA patients	early OA	late OA	mean difference (95% CI)	p value
gait speed (m/s)	0.8 ± 0.2	0.8 ± 0.2	0.8 ± 0.2	0.01 (-0.1, 0.1)	0.89
$\mathrm{MME}_{\mathrm{max}}$ (mm)	4.5 ± 1.4	3.9 ± 1.5	5.2 ± 0.9	-1.3 (-2.1, -0.5)	< 0.01
$\mathrm{MME}_{\mathrm{min}}$ (mm)	3.7 ± 1.4	3.0 ± 1.4	4.4 ± 1.0	-1.4 (-2.1, -0.6)	< 0.01
ΔMME (mm)	0.84 ± 0.16	0.86 ± 0.17	0.84 ± 0.15	-0.02 (-0.09, 0.12)	0.73
external rotation angle (°)	7.9 ± 4.6	6.9 ± 4.6	8.9 ± 4.6	-2.0 (-5.0, 1.0)	0.18
internal rotation angle (°)	0.2 ± 4.5	1.4 ± 4.8	-0.8 ± 4.0	2.2 (-0.8, 5.1)	0.14
range of knee rotation (°)	8.1 ± 3.1	8.1 ± 3.6	8.1 ± 2.8	0.03 (-2.0, 2.1)	0.46
flex LR (°)	7.0 ± 2.8	6.6 ± 2.8	7.5 ± 3.0	-0.9 (-2.7, 1.0)	0.34
flex Mst (°)	8.4 ± 4.6	9.2 ± 4.8	7.5 ± 4.4	1.7 (-1.3, 4.6)	0.26
first KAM peak (Nm/kg)	0.52 ± 0.14	0.49 ± 0.14	0.55 ± 0.13	-0.06 (-0.15, 0.03)	0.16
second KAM peak (Nm/kg)	0.50 ± 0.15	0.49 ± 0.14	0.55 ± 0.13	-0.05 (-0.14, 0.05)	0.33

$\mathrm{MME}_{\mathrm{max}}$ and $\mathrm{MME}_{\mathrm{min}}$, the maximum and minimum value of medial meniscus extrusion, respectively; ΔMME, increase in medial meniscus extrusion during stance phase; external/internal rotation angle, the maximum external/internal tibial rotation angle relative to femur; flex LR and Mst, the range of flexion angle during loading response and mid stance, respectively. Values are presented as means ± standard deviations. Mean differences were calculated from the difference between early- and late-OA group with 95% confidence interval (CI). P values are the results of t-tests comparing the early and late OA groups.

Table 3

Correlation coefficient between medial meniscus extrusion and knee adduction moment

	first KAM peak		**second KAM peak**	
	r	p	r	p
MME max				
OA patients	0.13	0.43	0.15	0.37
early-OA group	0.13	0.60	0.16	0.53
late-OA group	0.06	0.83	0.13	0.65
ΔMME				
OA patients	0.20	0.23	0.37	<0.05
early-OA group	0.36	0.14	0.50	<0.05
late-OA group	0.37	0.16	0.47	0.64

Partial correlation coefficients controlling for age, BMI, and HKA-A between MME and KAM parameters in the overall, early- and late-OA groups. MME_{max}, the maximum value of MME; ΔMME, the increase in MME during stance phase. r, correlation coefficient; p, p value.

Figure 1

(A) Placement of the reflective markers and the prove of ultrasonography. (B) Measurements of MME. The dashed line reflects the cortex of the medial tibial plateau. (C) The waveform of MME during stance phase. The dashed line indicates the maximum and the minimum value of MME. The arrow is the increase in MME during stance phase (ΔMME).

MME, medial meniscus extrusion; MCL, medial collateral ligament.

Figure 2

The average waveforms of MME, knee internal rotation angle and KAM during stance phase; MME (A), internal tibial rotation angle relative to femur (B) and KAM (C). The gray line and the black dashed line indicate the average value in the early- and late-OA groups, respectively.

Figure 3

The scatter plots of MME and knee rotation angle. The correlation between the maximum value of MME and the knee internal rotation angle in the overall and the early- and late-OA groups (A-C). The correlation between ΔMME and the range of knee rotation in the overall and in the early- and late- OA groups (D-F). The knee rotation angle was defined as tibial rotation angle relative to femur.

Figure 1

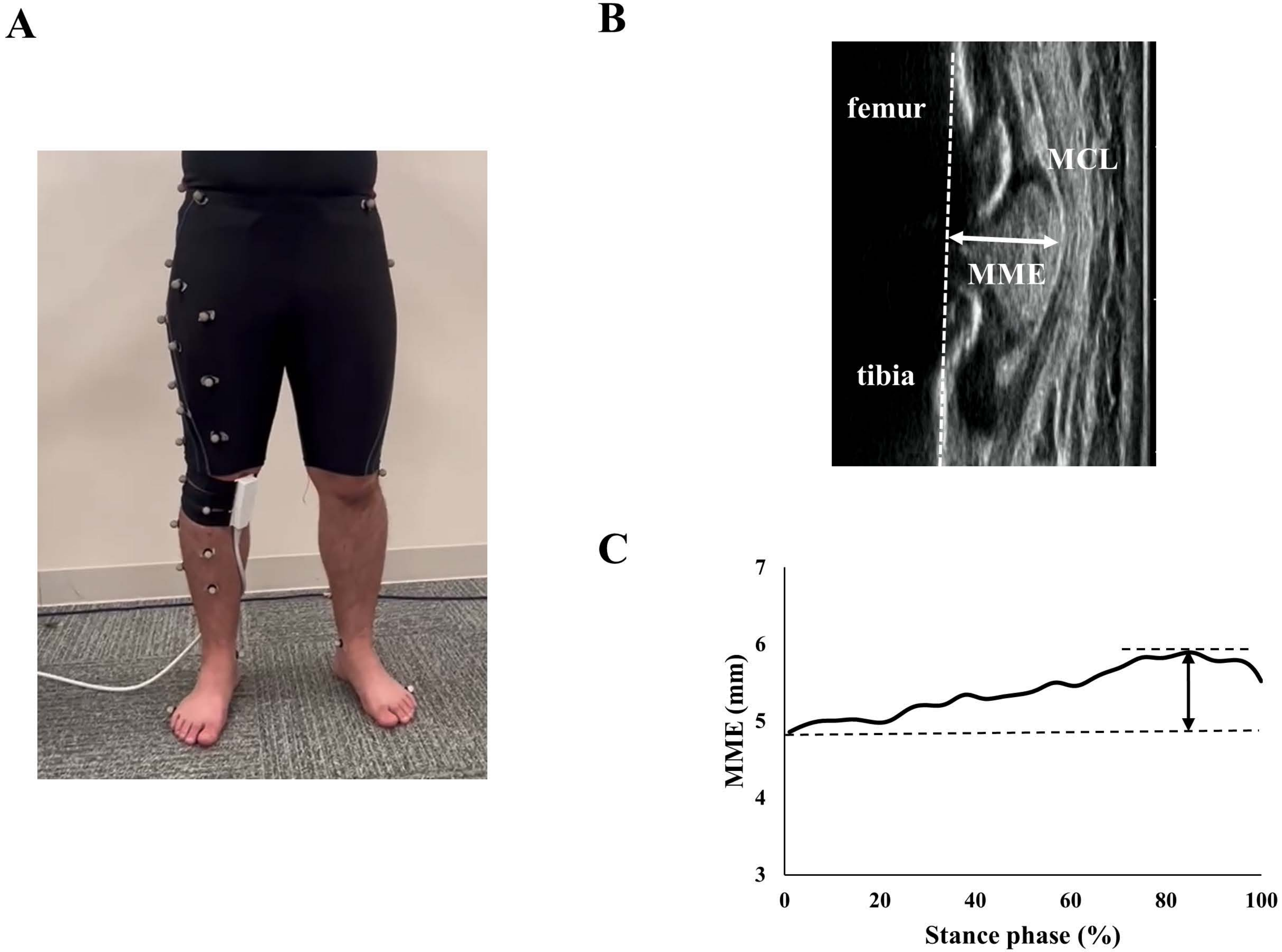

A
B
femur
MCL
MME
tibia
C
7
6
5
4
3
MME (mm)
0
20
40
60
80
100
Stance phase (%)

Figure 2

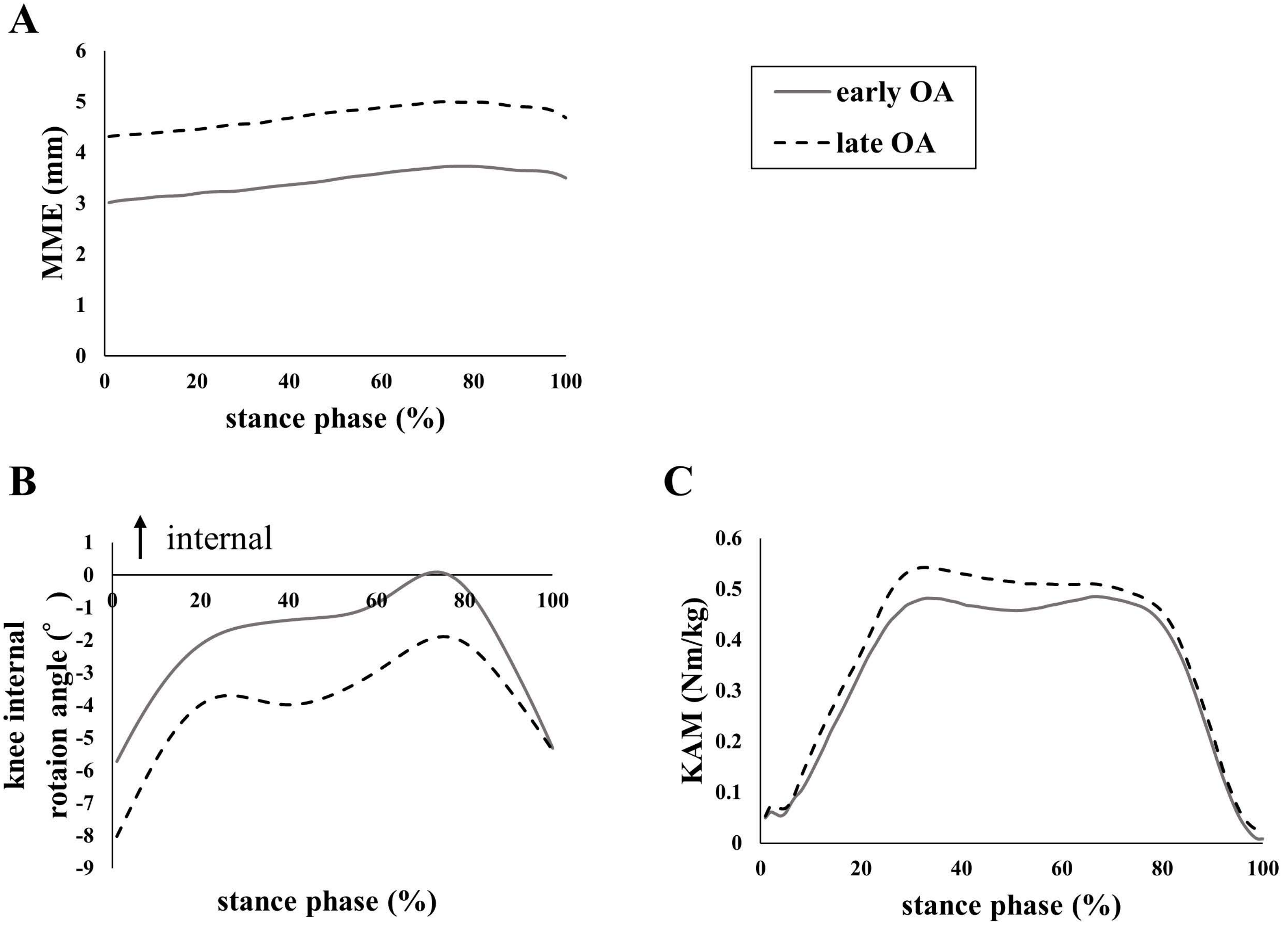
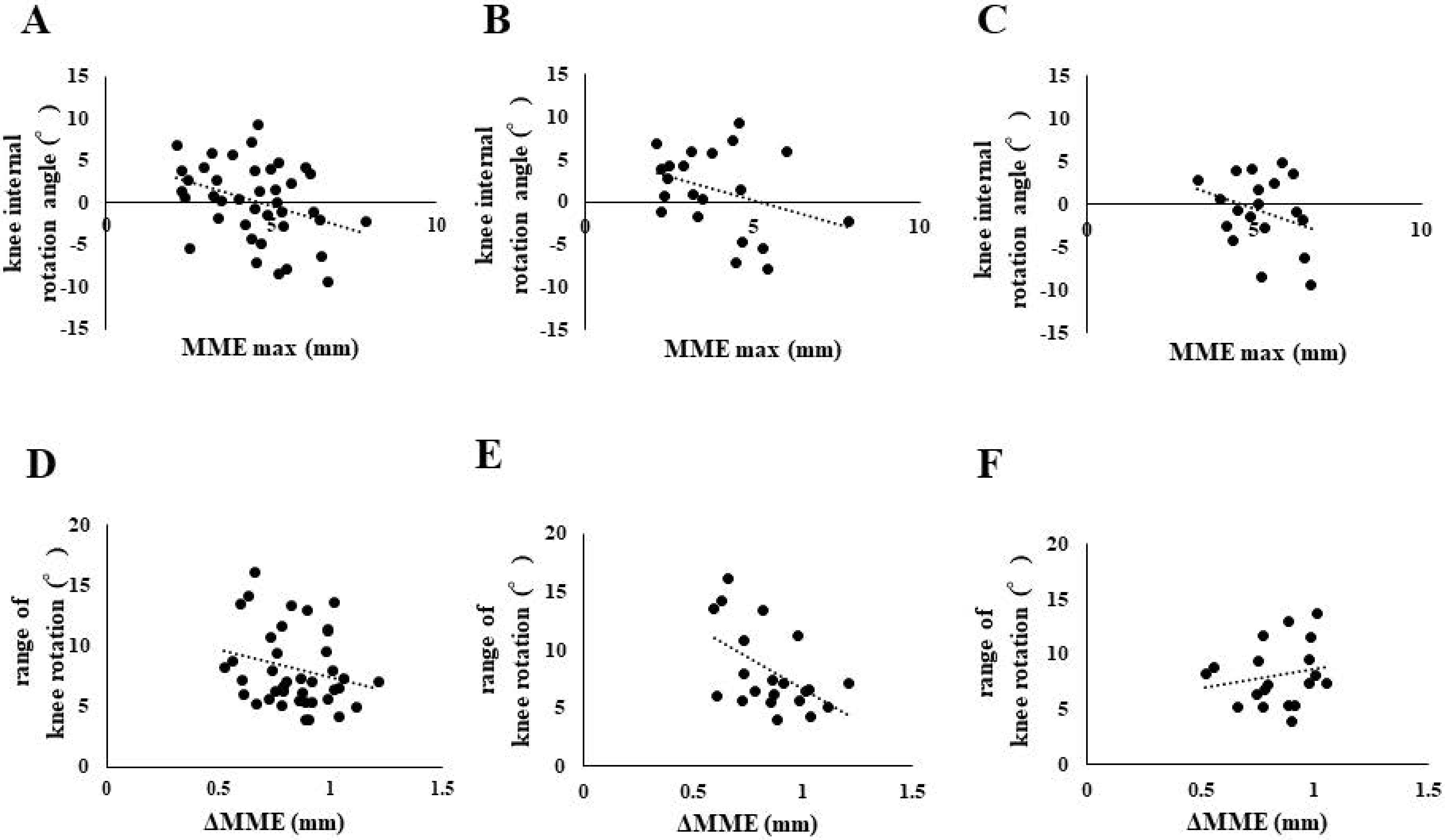

A
MME (mm)
6
5
4
3
2
1
0
0
20
40
60
80
100
stance phase (%)
early OA
late OA
B
internal
knee internal
rotaion angle (°)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
stance phase (%)
C
KAM (Nm/kg)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
stance phase (%)

Figure 3


A
B
C
knee internal rotation angle (°)
15
10
5
0
-5
-10
-15
0
5
10
MME max (mm)
D
E
F
range of knee rotation (°)
20
15
10
5
0
0
0.5
1
1.5
ΔMME (mm)