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Original Article

Increase in medial meniscal extrusion in the weight-bearing position observed on ultrasonography correlates with lateral thrust in early-stage knee osteoarthritis

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ABSTRACT

Background: Lateral thrust is known to be risk factors for knee osteoarthritis progression. Medial meniscus extrusion is also known to be risk factors for knee osteoarthritis progression; moreover, the amount of change in medial meniscus extrusion from non-weight bearing to weight bearing is an important factor for the progression of knee osteoarthritis. This study aimed to investigate the correlation between lateral thrust and the change in medial meniscus extrusion.

Methods: In total, 44 knees from 44 patients (mean age, 68.9 years) with knee osteoarthritis were divided into two groups according to the Kellgren–Lawrence grade: early-stage osteoarthritis (Kellgren–Lawrence = 2) and severe osteoarthritis (Kellgren–Lawrence = 3 or 4). The lateral thrust during gait, represented as the lateral acceleration peak immediately after heel strike, was recorded by an inertial sensor. The amount of change in medial meniscus extrusion, which was the difference between weight-bearing (unipedal standing) and non-weight-bearing (supine) conditions, was evaluated using ultrasonography.

Results: The mean value of the lateral acceleration peak in the severe osteoarthritis group was higher than that of the early-stage osteoarthritis group ($p < 0.05$). The non-weight-bearing and weight-bearing medial meniscus extrusion in the severe OA group were significantly higher than those of the early-stage osteoarthritis group ($p < 0.001$). However, the amount of change in medial meniscus extrusion in severe osteoarthritis group was significantly lower than in the early-stage osteoarthritis group ($p < 0.05$). The amount of change in medial meniscus extrusion showed a significant correlation with the lateral acceleration peak in the early-stage osteoarthritis group ($r = 0.56$, $p < 0.001$). On the other hand, there was no significant correlation in the severe osteoarthritis group.

Conclusion: The lateral thrust shows a positive correlation with the amount of change in medial meniscus extrusion by weight bearing in patients with early-stage knee osteoarthritis.

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1. Introduction

Knee osteoarthritis (OA) is one of the most common musculo-skeletal disorders. Severe knee OA usually affects physical function

and patients' activities of daily living [1]. Knee OA progression is believed to be associated with increasing mechanical stress due to pathological structural changes in joint compartments [2–4].

Knee lateral thrust is an abnormal lateral knee motion frequently observed in patients with OA. The lateral thrust indicates dynamic knee instability in the frontal plane during the initial stance phase of the gait cycle [2]. Several studies have reported that lateral thrust leads to increased mechanical stress in the medial compartment [5,6]. Moreover, a cohort study showed that the presence of lateral

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thrust was associated with three-fold increased odds of progression of medial knee OA [2]. Therefore, these studies indicate that the lateral thrust is a risk factor for progression of knee OA owing to increased mechanical stress in the medial compartment.

On the other hand, the meniscus is an important knee structure; the normal medial meniscus has a neutral alignment and plays a role in shock absorption and joint lubrication as well as providing stability for protecting the articular cartilage from tibiofemoral joint stress [7]. However, the medial meniscus frequently undergoes changes such as degeneration and tears, which lead to medial meniscus extrusion (MME) [8,9]. Previous studies reported that MME increases the mechanical stress to the medial compartment [10,11].

Moreover, several studies demonstrated that the degree of MME increased in weight-bearing condition than in non-weight-bearing condition [12,13], and that this difference in MME between the two conditions (Δ MME) was correlated with cartilage loss in the tibiofemoral joint [14]. Importantly, a previous study found that a larger Δ MME was observed in patients with early knee OA, with greater subsequent progression [15]. These studies suggest that Δ MME could also be an important factor for the progression of knee OA; however, whether the Δ MME correlates with lateral thrust is still unclear.

Previous studies demonstrated that the lateral thrust and MME vary in patients with varying severities of OA [5,16,17]. It was reported that the lateral thrust and MME gradually worsen with increasing Kellgren–Lawrence (K/L) grade, although the Δ MME decreases [5,13,16,17]. Thus, the K/L grade could affect lateral thrust, MME, and Δ MME. However, correlations between lateral thrust and MME and Δ MME in each K/L grade are still unknown.

We hypothesize that there is a specific correlation between lateral thrust and Δ MME according to the knee OA severity. This may provide useful information to elucidate the mechanisms of knee OA progression and develop appropriate interventions for preventing it. The aim of this study was to examine the correlation between the lateral thrust and the difference in the MME using an inertial motion sensor and ultrasonography in each knee OA severity.

2. Material and methods

2.1. Participants

This study was approved by our institutional review board, and informed consent was obtained from each participant. Forty-nine knees from 44 patients were radiographically diagnosed as primary unilateral or bilateral knee OA. The Bilateral knee OA patients were chosen to one knee which had a more severe and painful knee to minimize the bias caused by the similarity between the knees of the same patient; finally, 44 knees were included in this cross-sectional study (mean age, 68.9 ± 9.6 years; % female, 50%). All participants could walk independently without any support. Participants with a history of surgical treatment, trauma, or neurological disorder were excluded. Kellgren–Lawrence (K/L) score and femorotibial angle (FTA) were determined through radiological assessment. The participants were divided into two groups: early-stage OA group (K/L = 2, $N = 23$) and severe OA group (KL = 3 or 4, $N = 21$).

The demographic data of participants are shown in Table 1. The mean value of FTA in the severe OA group was higher than that of the early-stage OA group ($p < 0.001$).

2.2. Medial meniscus extrusion assessment

MME was measured using an ultrasonography device (Hivision Avius, Hitachi ALOKA, Japan) with a 6–18 Hz linear-array probe. The probe was longitudinally placed in the medial joint space of the

Table 1
Demographic data of participants.

	Whole	KL = 2	KL = 3/4	P value
Knees	44	23	13/8	
K/L (II, III, IV)	23, 13, 8	23, 0, 0	0, 13, 8	
Gender (% female)	50	39	62	
Age (years)	68.9 ± 9.6	68.0 ± 11.2	69.9 ± 7.3	0.53
Height (cm)	159.8 ± 7.5	160.8 ± 7.0	158.6 ± 7.5	0.35
Weight (kg)	64.4 ± 10.7	64.3 ± 9.5	64.4 ± 12.0	0.97
BMI (kg/m^2)	25.1 ± 3.1	24.8 ± 2.7	25.5 ± 3.5	0.48
FTA ($^\circ$)	178.3 ± 2.5	177.1 ± 2.0	179.8 ± 2.2	$p < 0.001$

K/L, Kellgren–Lawrence grade; BMI, Body mass index; FTA, femorotibial angle. Values represent means \pm standard deviation. p value shows the difference between early-stage and severe OA group.

extended knee, and the medial meniscus appeared as a triangular, echogenic structure between the medial femoral condyle and the tibial plateau [18,19]. Valgus stress was applied to improve imaging during dynamic scanning, and an image was acquired when the border between the medial meniscus and the medial collateral ligament was most clearly visible (Fig. 1). MME was quantified as the distance from the medial tibial plateau cortex to the outermost edge of the medial meniscus, based on previous studies [12,20], and it was measured using image processing software (Image J ver19, NIH, US). MME was measured in two conditions: non-weight-bearing (supine) and weight-bearing (unipedal standing). Images were collected three times for each condition. The average value of the three measurements for each condition was used in the statistical analyses. Differences in MME between the weight-bearing and non-weight bearing conditions were calculated as Δ MME.

In this study, a single examiner performed ultrasonography in a blinded manner to evaluate the K/L grade of patients and demonstrated the reliability of ultrasonography for evaluating MME at around one week in 10 patients.

2.3. Lateral thrust

The lateral thrust was assessed using two inertial motion sensors, including triaxial accelerometers and gyrosensor (WAA-010, ATR-Promotions, Japan). The two sensors were fixed on the tibial tubercles and dorsal surface of the foot by elastic bandages and tape. Data were low-pass filtered with a 10-Hz cutoff, and calculated using MATLAB software (MATLAB 2017b, MathWorks, Japan). Joint axes were defined so that the z axis was oriented in an anteroposterior direction, the x axis in a mediolateral direction, and the y axis in a longitudinal shank direction. For the foot sensor, the y axis was oriented in an anteroposterior direction, the x axis in a mediolateral direction, and the z axis in a longitudinal foot direction. Participants were instructed to walk at a comfortable speed along a 10-m walkway twice. Data during gait was collected at a sampling frequency of 100 Hz. The gait cycle was defined as starting with initial foot contact with the ground and ending with the next initial contact with the same foot. The initial contact was detected using a peak value of positive sagittal angular velocity in foot sensor [21]. Each gait cycle was time-normalized to 100 data points, and the lateral thrust was defined as the first lateral acceleration peak in the tibial tubercle sensor after the beginning at around 10% of the gait cycle [22,23] (Fig. 2). The lateral thrust was represented as a mean value of lateral acceleration peak for five continuous stable strides during gait.

2.4. Statistical analysis

The mean values of lateral acceleration peak, weight-bearing MME, Δ MME and demographic data were compared in each

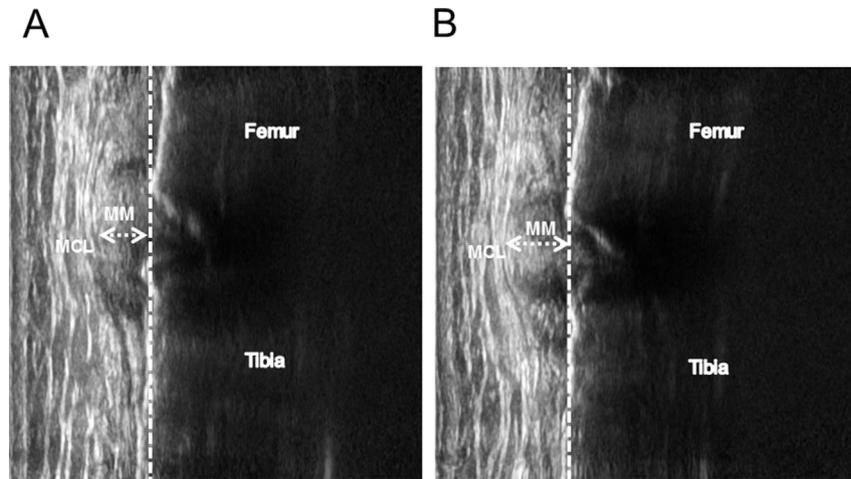


Fig. 1. Representative images of medial meniscus extrusion in the supine position (A) and unipedal standing position (B). MM, Medial meniscus. MCL, Medial collateral ligament. The arrow shows the value of medial meniscus extrusion.

group by using the two-sample *t*-test. Comparison between non-weight-bearing and weight-bearing MMEs was analyzed using paired *t*-test. As Shapiro–Wilk test demonstrated heterogeneity only in the non-weight-bearing MME in the early-stage OA group, the non-weight-bearing MME was analyzed using Mann–Whitney *U* test and Wilcoxon signed-rank test.

Univariate analyses were performed to confirm the correlation of lateral acceleration peak with MME in each group. Only the non-weight-bearing MME in the early-stage group was assessed using Spearman's rank correlation coefficient. The other MME was evaluated using Pearson's correlation coefficient. The significance level was set at 5%. All statistical analyses were conducted using SPSS ver. 23 (IBM, Japan).

3. Results

3.1. Reliability of MME

The intra-rater reliability was shown as intra-class correlation coefficient (ICC) [95% confidence interval; CI]. The ICC (1, 1) was 0.98 [0.923; 0.995] for non-weight-bearing MME ($p < 0.001$), 0.96

[0.866; 0.991] for weight-bearing MME ($p < 0.001$), and 0.87 [0.549; 0.965] for Δ MME ($p < 0.001$).

3.2. Correlation between lateral acceleration peak and MME

The mean value of the lateral acceleration peak in the severe OA group was higher than that of the early-stage OA group ($p < 0.05$, Table 2). In both groups, MME was significantly increased in weight-bearing when compared to the non-weight-bearing condition. The non-weight-bearing MME and weight-bearing MME in the severe OA group were significantly higher than those of the early-stage OA group ($p < 0.001$). On the other hand, the value of Δ MME in severe OA group was significantly lower than in the early-stage OA group ($p < 0.05$) (Table 2).

The Δ MME was significantly correlated with lateral acceleration peak in the early-stage OA group ($r = 0.56$, $p < 0.001$), but not in the severe OA group. Lateral acceleration peak was significantly correlated with non-weight-bearing MME ($r = 0.54$, $p < 0.05$) and weight-bearing MME ($r = 0.58$, $p < 0.001$) in the severe OA group. However, we could not observe any such correlations with these parameters in the early-stage OA group (non-weight-bearing MME: $r = -0.01$, $p = 0.998$; weight-bearing MME: $r = 0.28$, $p = 0.201$) (Table 3) (Fig. 3).

3.3. Correlation between lateral acceleration peak and Δ MME

There was a positive correlation between Δ MME and lateral thrust in the early-stage OA group ($r = 0.56$, $p < 0.001$). The Δ MME in the early-stage OA group is higher than that in the severe OA group. Additionally, the acceleration peak value is higher than the

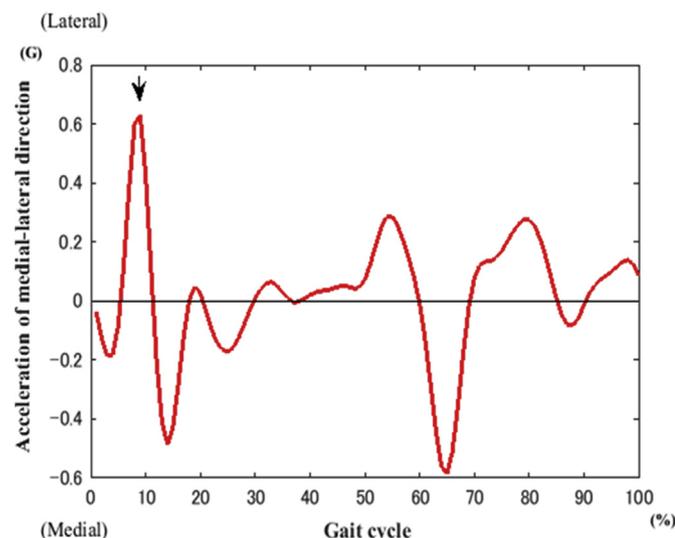


Fig. 2. Representative accelerographs during one gait cycle. The black arrow shows the first lateral acceleration peak (e.g., the lateral acceleration peak is 0.62 G).

Table 2

Comparison in lateral acceleration peak and medial meniscus extrusion between groups.

	Whole	KL = 2	KL = 3/4
Lateral acceleration peak (G)	0.66 ± 0.30	0.58 ± 0.26	0.76 ± 0.32*
Non-weight-bearing MME (mm)	4.09 ± 2.17	2.67 ± 1.44	5.65 ± 1.72*
Weight-bearing MME (mm)	4.90 ± 2.09	3.60 ± 1.48	6.32 ± 1.71*
Δ MME (mm)	0.81 ± 0.41	0.93 ± 0.43*	0.67 ± 0.35

Δ MME, change in the value of medial meniscus extrusion from non-weight-bearing to weight-bearing. Values represent means ± standard deviation. * Shows a significant difference between early-stage and severe OA group, $p < 0.05$.

Table 3
Correlation coefficients between lateral acceleration peak and medial meniscus extrusion in each group.

MME	Group		
	Whole	KL = 2	KL = 3/4
Non-weight-bearing MME	0.45*	-0.01	0.54*
Weight-bearing MME	0.52*	0.28	0.58*
Δ MME	0.24	0.56*	0.19

Non-weight-bearing MME, value of medial meniscus extrusion in supine; Δ MME, change in the value of medial meniscus extrusion from non-weight-bearing to weight-bearing. Values represent correlation coefficient. * shows a significant correlation with lateral acceleration peak, $p < 0.05$.

average in the early-stage OA group (Fig. 4C: 0.8 G; average: 0.58 G) (Fig. 4).

On the other hand, there was no correlation between Δ MME and lateral thrust in the severe OA group. The value of MME does not change much from the supine to the unipedal standing position, although the acceleration peak value is not so different compared to the average in the severe group (Fig. 5C: 0.82 G; average: 0.76 G) (Fig. 5).

4. Discussion

To our knowledge, this is the first study to investigate the correlation between lateral thrust and the Δ MME, especially when in the early stages of knee OA.

Our results revealed that the values of the lateral acceleration peak and non-weight-bearing MMEs in the severe OA group were greater than those in the early-stage OA group, although the Δ MME in the early-stage OA group was smaller than that in the severe OA group. These results are in line with the results of some previous studies that evaluated the effect of the severity of OA on lateral

thrust and MME [5,13,16,17], and indicate that evaluation of the lateral acceleration peak and MME can depict the change in lateral thrust and meniscal extrusion according to the stage of knee OA.

In this study, there was a positive correlation between the lateral acceleration peak and Δ MME. This result indicates that the lateral thrust correlates with the greater change of MME under weight-bearing. The lateral thrust has been known as coronal instability of tibiofemoral joint during the stance phase of the gait cycle [2,4]. Enokida et al. found that the lateral thrust correlates with greater MME using magnetic resonance imaging (MRI) [24]. However, they only evaluated MME in a supine position. The medial meniscus experiences compressive and shear forces during the stance phase of the gait cycle, and their stress are distributed by hoop function in circumferential structure. In the present study, we evaluated the MME under weight-bearing by ultrasonography and presented the change in meniscus extrusion under weight-bearing as Δ MME. Barile et al. demonstrated the existence of medial meniscus instability under arthroscopic evaluation and suggested that the Δ MME correlates with meniscus instability in knee OA [25]. Thus, our results follow the trend of previous studies in that the structural instability of the knee under biomechanical stress might correlate with the dynamic knee instability during gait.

We also confirmed the effect of OA severity on the correlation between lateral thrust and Δ MME. It was shown that the lateral acceleration peaks positively correlated with the Δ MME in early-stage OA group but not in severe OA group. Although, the lateral acceleration peak in severe OA was greater than that in early-stage OA, the value of Δ MME was lower in severe OA group. These results suggest that the lateral thrust is independent on Δ MME in a severe case. Some studies report an increase in MME when going from a non-weight-bearing to a weight-bearing condition [12,13,20]. However, Patel et al. reported the effect of OA severity on meniscus extrusion during weight bearing. They showed that meniscus

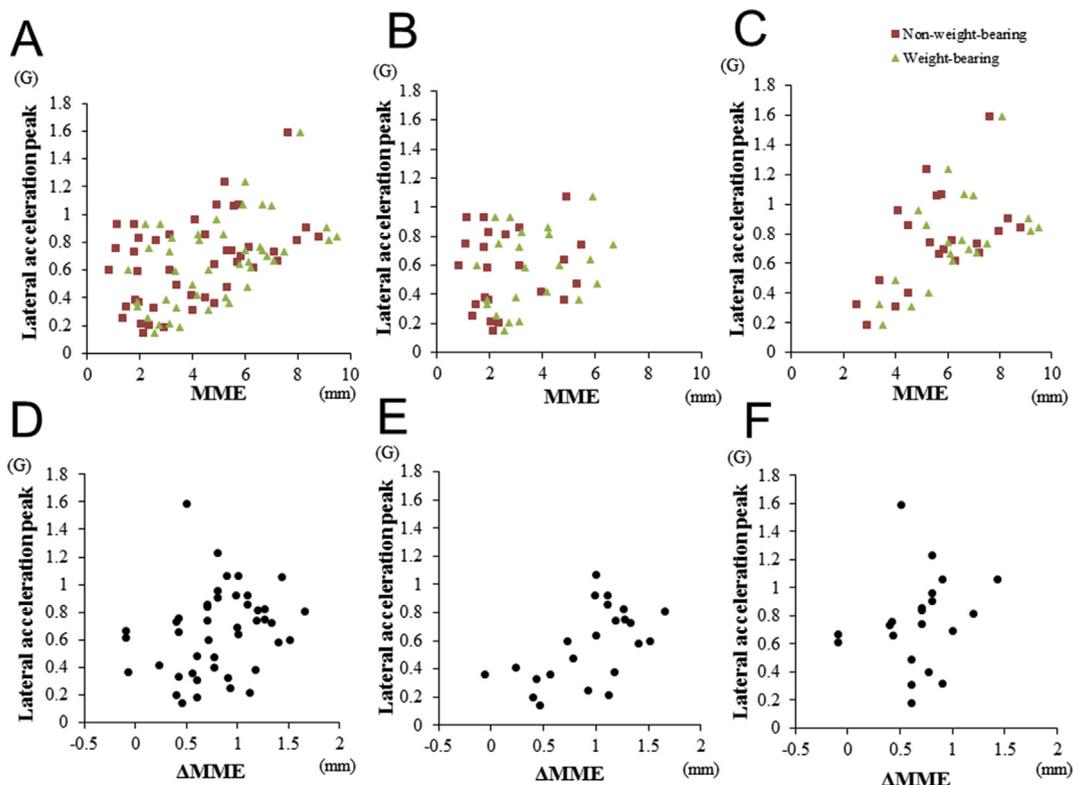


Fig. 3. Scatter plots representing the relationship between MME (A–C) or Δ MME (D–F) on the x-axis and lateral acceleration peak on the y-axis in each group. The whole (A, D), K/L = 2 (B, E), K/L = 3/4 (C, F).

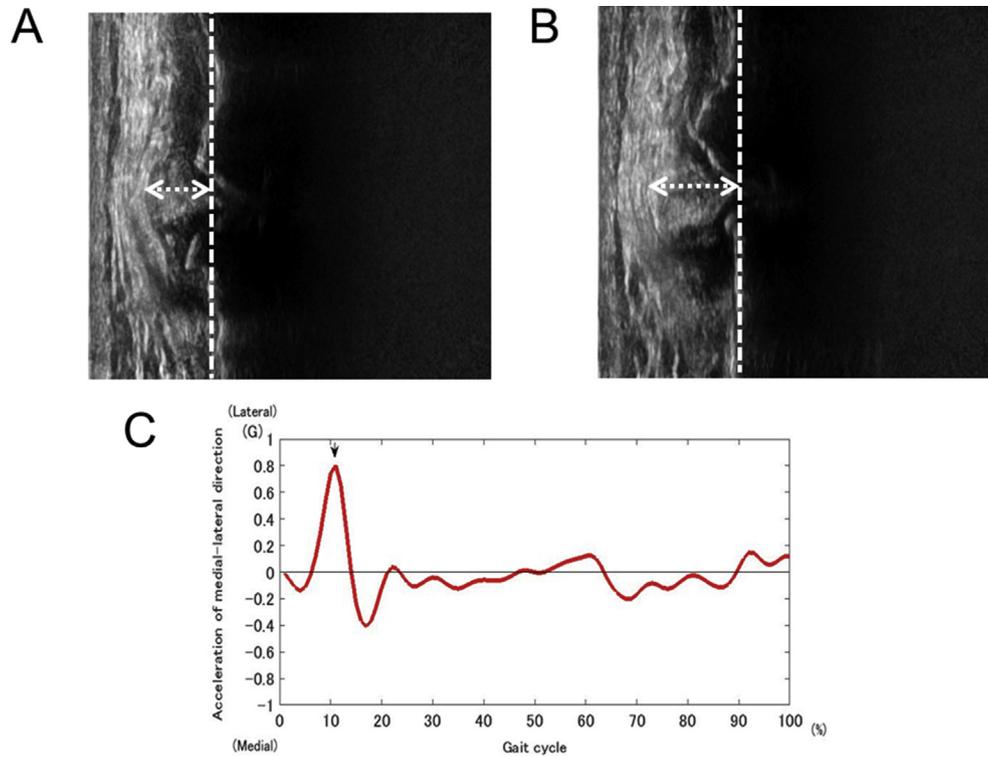


Fig. 4. Ultrasound images with and without weight bearing and accelerogram in an early-stage OA patient. Representative images of the medial meniscus in the supine position (A) and unipedal standing position (B), and the accelerogram during the one gait cycle (C).

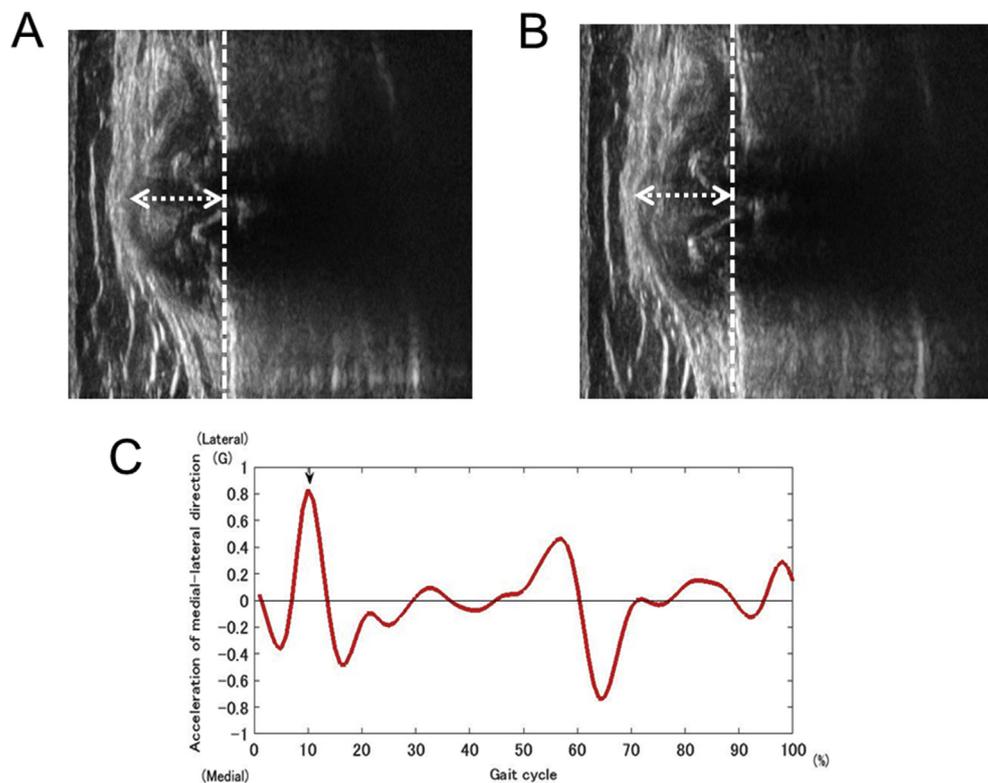


Fig. 5. Ultrasound images with and without weight bearing and accelerogram in a severe OA patient. Representative images of the medial meniscus in the supine position (A) and unipedal standing position (B) and the accelerogram during the one gait cycle (C).

extrusion in the weight-bearing condition increased when compared with that in the non-weight-bearing condition in whole-knee OA, but not in severe cases [13]. In addition, Kawaguchi et al. [16] reported the correlation between weight-bearing MME and non-weight-bearing MME in knee OA in their longitudinal study. Their results showed that the baseline weight-bearing MME value was close to the 1-year follow-up non-weight-bearing MME value, except in severe OA cases. These findings suggest that the Δ MME between weight-bearing and non-weight-bearing conditions gradually becomes smaller, indicating a loss of plasticity of the medial meniscus in severe OA. On the other hand, the lateral thrust has been known to gradually increase in the severe case [5,17]. Therefore, these studies might support our hypothesis that the lateral thrust is correlated with the larger value of Δ MME only in the early phase of knee OA, and that this affects the degree of knee OA progression.

With regard to meniscal evaluation, our results showed that the amount in the meniscal position change under weight-bearing condition was reflected in the abnormal gait motion in early-stage knee OA. This abnormal gait motion, defined as lateral thrust, has been known as a risk factor for the progression of knee OA [2]. Hence, it indicates that the evaluation of meniscal extrusion under weight-bearing condition is important to predict the progression of OA in each patient. In fact, several studies have evaluated the medial meniscus in non-weight-bearing condition using MRI [10,11,24]. Although MRI enables more detailed evaluation of morphological pathology of whole meniscal body [26], meniscal evaluation using MRI in various positions, such as the weight-bearing position, is difficult owing to limitations of the apparatus involved. On the contrary, ultrasonography is more feasible for the measurement of meniscal extrusion with the patient in various positions, and it has many advantages in that it is safe, noninvasive, not time consuming, and inexpensive [26,27]. Therefore, ultrasonographic evaluation of weight-bearing MME could be useful and effective in daily clinical practice.

The present study has several limitations. First, we evaluated the degree of lateral thrust using inertial motion sensor. With this apparatus, we could obtain the value of lateral acceleration without joint angle data and detailed gait cycle. However, precise and detailed gait parameters can be obtained using a 3-dimensional motion sensor or a ground reaction force platform. Second, we cannot conclude whether the lateral thrust causes medial meniscus pathology given the cross-sectional nature of the study. Other pathologies of joint compartments such as cartilage defect, ligamentous laxity, stiffness, or bone deformities affect the lateral thrust. Therefore, further research is required to examine the correlations between these parameters. Third, MME was measured only in a static condition, and not during dynamic motion which can increase meniscal stress. Furthermore, the results were obtained from limited loading condition in a correctional human study. Fourth, our results did not consider potential confounder such as age, sex, BMI and FTA because we had small sample size. Further studies are required to evaluate the meniscus in different joint angles and in various dynamic conditions in a cohort study.

In conclusion, we demonstrated that lateral thrust was positively correlated with Δ MME only in the early stage of knee OA. An increase in MME in the weight-bearing condition associated with abnormal mechanical stress might be an important parameter to predict future OA progression in the early of stages of knee OA.

Conflict of interest statement

There are no conflicts of interest to declare.

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