Original Article

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Delayed Onset Time of Gluteus Medius Muscle and Frontal Mechanics of Trunk and Pelvis in Individuals with Medial Knee Osteoarthritis

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Abstract:

Objective: An increased strengthening of hip abductor muscles helps to improve pain and functional activity in medial knee osteoarthritis (OA). However, the mechanism analysis of the functional benefits is still incomplete. The objective was to compare the function of the gluteus medius (GMed) muscle, the contralateral pelvic drop, and ipsilateral trunk lean between the with and without knee OA groups.

Material and Methods: Twenty individuals participated in the study. Kinematics and kinetics were recorded during level walking using a 10-camera Vicon™ Nexus system and a force plate. GMed activity was recorded using a Delsys Trigno system. The data of 2 participants were excluded because they were incomplete. Finally, 18 data (9 knee OA and 9 asymptomatic) were reported. Independent T-test and the Mann-Whitney U test were used for statistical analysis.

Results: A delayed time of GMed muscle (32.73±30.42 ms) was significantly (p-value=0.006) exhibited in individuals with knee OA after foot contact. A lower knee injury and OA outcome score was noted in individuals with knee OA. No significant difference in manual muscle strength test, contralateral pelvic drop, lateral trunk lean, and average GMed muscle activity was observed between the groups.

Conclusion: A significant delay of GMed activation was noted in individuals with knee OA who had moderate severity in the current study, and it might be a sensitive indicator for the observation of neuromuscular deficits. In future studies, interventions aimed at improving the onset time of GMed should be investigated in individuals with knee OA in order to assess the clinical implications.

Keywords: contralateral pelvic drop, frontal movement control, knee osteoarthritis, lateral trunk lean, muscle activity, muscle onset time

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Introduction

Knee osteoarthritis (OA) is a degenerative disease, and its progression depends on the load applied to the knee joint[1,2]. The global prevalence of knee OA was 22.9% in individuals aged 40 years and over, totaling around 654 million individuals; women are more susceptible to knee OA than men[3]. In 2012, Wise et al.[4] reported the prevalence of knee OA in the United States, finding a higher medial knee OA (29.5%) among 5,202 individuals with knee OA.

Frontal trunk and pelvic movements influence medial knee loading[5]. Increased ipsilateral lateral trunk lean (toward the stance limb) and knee adduction movement (KAM) were reported during gait assessments in individuals with medial knee OA[5]. The KAM increased from contralateral pelvic drop and ipsilateral trunk lean during single-leg standing in healthy subjects[6,7]. Tanaka et al.[8] found that bilateral knee OA showed a pattern of trunk lean toward the swing limb. They suggested that contralateral pelvic drop and ipsilateral trunk lean could affect the center of mass shifting, which could lead to KAM alteration. Chang et al.[6] proposed that increased hip abduction moment caused by hip abductor function could potentially slow down the progression of medial knee OA. This suggests that hip joint strengthening exercises should be recommended for the rehabilitation of individuals with knee OA, possibly due to this mechanism[9,10]. However, some studies did not show the importance of hip abductor function on medial knee loading[11]. While hip strengthening may not directly reduce the KAM[12], previous studies have indicated that hip abductor strength contributes to the improvement of pain and functional activity in individuals with knee OA[9,10]. Consequently, hip strengthening exercises continue to be recommended for individuals with knee OA. Nevertheless, there is an incomplete understanding and intriguing aspect to the mechanism analysis regarding the benefits derived from hip abductor strengthening and function. Good muscle strength may not guarantee optimal function during activities, as neuromuscular control is also essential. Studying and quantifying muscle activity could help to better understand muscle function in dynamic tasks.

A change of lower extremity muscle function was reported in individuals with knee OA[11,12]. To the best of our knowledge, few studies have investigated hip abductor muscle function, especially the gluteus medius (GMed) muscle in terms of timing. The GMed muscle is activated from the early stance to the late stance phase in order to control body rotation[13]. Additionally, the GMed muscle plays a role in controlling pelvic motion. However, there is a lack of studies that have simultaneously examined the function of the GMed muscle along with the movement of trunk lean and pelvic drop in individuals with knee OA. Therefore, the current study aimed to investigate the function of the hip abductor muscles and the kinematics in the frontal plane of the pelvis and trunk during level walking in individuals with and without medial knee OA. We hypothesized that individuals with knee OA would show less activity and a delayed onset time of GMed muscle during the stance phase of level walking. Additionally, we anticipated observing greater ipsilateral trunk lean and contralateral pelvic drop in the knee OA group. These findings aim to contribute to a better understanding of the differences in trunk and pelvic compensatory movements in individuals with knee OA compared to those without knee OA. Alteration in GMed function during walking should be of concern. Furthermore, restoring GMed function may also be a goal in future rehabilitation.

Material and Methods

This study was the cross-sectional research and explored females with and without medial knee OA. Data collection was conducted in the motion analysis laboratory, Faculty of Physical Therapy, Mahidol University.

Participants

Twenty individuals with and without knee OA (10 per group) voluntarily participated in the study. The study protocol was explained and all participants signed an informed consent form before participating in the study. The study protocol was approved by Mahidol University Central Institutional Review Board (MU-CIRB 2019/101.1106).

The sample size for the present study was determined based on GMed onset data obtained from a pilot study (5 per group) and calculated using G-power software. Given that GMed onset was the primary variable of focus in this study, it was chosen as the basis for calculating the sample size in order to achieve 95% power. At least 6 participants per group were needed to observe a significant difference (effect size=2.169).

Ten individuals with unilateral or bilateral knee OA exhibited a knee varus deformity (≥5cm intercondylar distance[14]), knee pain experience >3 months, and ≥3 criteria of the American College of Rheumatology classification criteria[15,16]. Participants were excluded if they had a history of lower extremity fracture or surgery, experience of intra-articular corticosteroid or intra-articular hyaluronic acid injection within 6 months before testing, a BMI of 35 kg/m^2 or more, neurological problems, or were unable to walk without gait aid. These criteria were established to prevent confounding factors from affecting the results.

In the control group of 10 asymptomatic individuals, age range (±5 years) and body mass index (BMI) (±3 kg/m^2) were matched to the knee OA group. They had no history of knee OA or neurological problems.

Procedures

Before the walking test, a general physical examination was conducted, which included observation, palpation, and manual muscle testing. The Thai version of the knee injury and osteoarthritis outcome score (KOOS) was utilized to assess the functional outcome measure[17]. Participant preparation and maximum voluntary isometric contraction (MVIC) test.

The Trigno™ Wireless electromyography system (EMG) (Delsys, USA, Inc.) was used for recording GMed muscle activity at a frequency of 1000 Hz. The skin was prepared by cleaning it with an alcohol wipe. EMG electrodes were then placed on the GMed muscles on both sides according to the surface EMG for the non-invasive assessment of muscles recommendation (50% on the line from the crista iliaca to the trochanter)[18].Before testing, observation of the EMG signal quality and crosstalk checking were performed during the manual muscle strength test of the hip abductor muscle.

Then, EMG data during MVIC tests were collected in the side-lying position (Figure 1A).

The participants were in the neutral anatomical side-lying position, and the test leg was above the opposite limb (Figure 1A). Participants were asked to perform hip abduction and resist the belt with maximum effort. To ensure that abductor strength was tested and that the lower limbs did not rotate externally, participants were asked to ensure that their toes were pointing horizontally during contraction. Then, participants were asked to resist the belt (toward the ceiling) with a maximum of 5 seconds' effort. EMG data during the MVIC test were used as max EMG for %MVIC calculation. Each side was measured 3 times and a 90-second rest was allowed between the trials.

A motion analysis system with 10 video cameras (Vicon™ Nexus, Oxford Metric Ltd., Oxford, UK) was used for capturing the kinematic data, including trunk and pelvic motions during level walking. The sampling frequency of video capture was 100 Hz. Before the level walking test, reflective markers were attached to the bony prominences on both sides (Figure 1B-D). The marker model of calibrated anatomical system technique was used in the

study. Five clutter sets of 4 markers were attached at the T7 spinal level, the lateral thighs, and the lateral shanks. Reflective markers were placed on the bony prominences of both sides, including acromio-clavicular joints, anterior superior iliac spines, posterior superior iliac spines, greater trochanters, lateral pelvic brims, medial and lateral femoral condyles, medial and lateral malleolus, 1st metatarsal head, 5th metatarsal heads and bases, and calcaneus. After marker attachment, all participants were asked to perform a level walking test in the motion analysis laboratory.

Level walking tests

All participants were asked to walk with bare feet at a self-selected speed in the 10-meter walkway for 5 trials. They were instructed to contact forceplates (AMTI, Advance Mechanical Technologies Inc., USA) (1,000 Hz), which were located in the middle walkway and synchronized with the motion analysis system. Walking trials with clear-foot contact on the forceplate were included for data analysis. Then, the onset time and average EMG of GMed muscle, ipsilateral trunk lean angle, and contralateral pelvic drop angle were extracted for comparison between the groups. Before testing, participants were given time to familiarize themselves with the test and the environment.

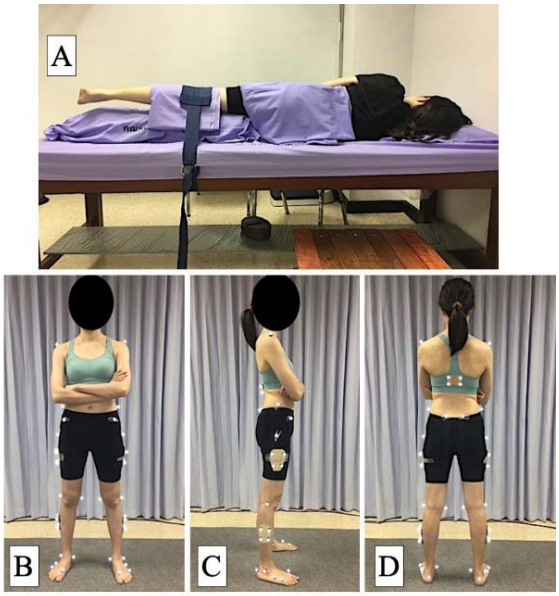
Data acquisition and statistical analysis

The EMG data were filtered with a bandpass Butterworth filter (20-450 Hz). Then, full-wave rectification was performed. The onset time of the GMed muscle was the time period of muscle activation before foot contact with the forceplate. A greater than 10N of vertical ground reaction force was defined as the starting point of initial contact. The threshold for onset time was determined when EMG amplitude was greater than 3 time the standard deviation of EMG's baseline[19]. The EMG baseline (Resting EMG) was measured during the resting period in the supine position. The EMG data (Test EMG) from 100 ms before and 100 ms after the peak contralateral pelvic drop were selected to average for analysis. Muscle activity was reported as a percentage of MVIC using the formula presented, as shown in the equation below[20]. Both the onset time and the percent MVIC were averaged across 5 walking trials.

$$\%\text{MVIC} = \frac{\text{Test EMG} - \text{Resting EMG}}{\text{Max EMG} - \text{Resting EMG}} \text{ x } 100$$

For the kinematic data, cubic spline interpolation and the copy pattern technique were used to fill the gap in the marker trajectory. A low-pass zero-lag Butterworth filter (4th order) was used to reduce the noise, and the cut-off frequency was 6 Hz. Then, Visual 3D software (C-Motion, Rockville, MD, USA) was used to construct the 3D model. The study represents contralateral pelvic drop and ipsilateral trunk lean (toward the stance limb) angles as the excursion of pelvic and trunk body segments during the stance phase on the more symptomatic limb in the knee OA group (Figure 2). In the asymptomatic group, data for the matched side were reported. The excursion angle was calculated by measuring the angle from heel strike to the maximum angle during the stance phase. Average values of excursion angles for contralateral pelvic drop and ipsilateral trunk lean were reported and analyzed.

The statistical analysis was performed using the SPSS program version 18. The Shapiro-Wilk test was used for data distribution testing. Excursion data of pelvic and trunk angles had a normal distribution. Then, an independent T-test was used for the analysis. Data of GMed muscle activity had a non-normal distribution. The Mann-Whitney U test was used to statistically analyze the GMed onset time between the groups. The level of statistical significance was set at (p-value) less than 0.05.



MVIC=maximum voluntary isometric contraction

Figure 1 Participant preparation. (A) starting position during MVIC test of the hip abductor muscle, (B) markers attached from the front view, (C) markers attached from the side view, (D) markers attached from the posterior view

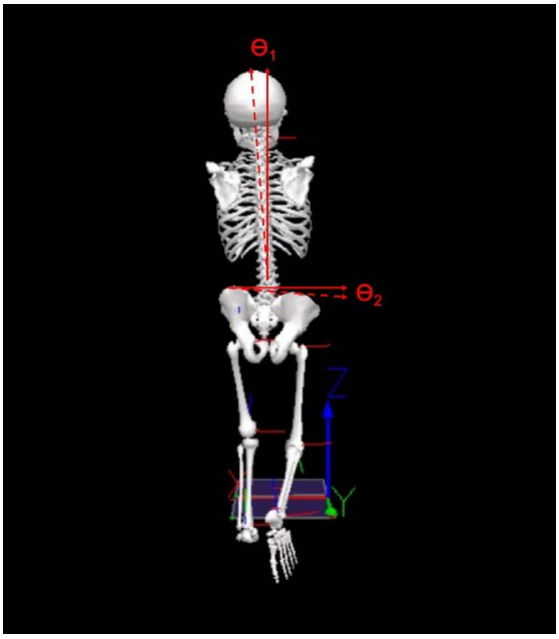


Figure 2 Schematic of trunk, pelvis, and lower extremity in posterior view. This illustration shows an example of the left-stance phase during level walking. Ø1 represents the angle of the lateral trunk lean toward the stance limb and Ø2 represents the angle of contralateral pelvic drop relative to the stance limb.

Results

A total of 20 participants were included in the study. The data of 2 participants were incomplete due to a missing marker, and as a result, the completed 3D model could not be constructed. Therefore, the data of 18 participants were reported and analyzed. All participants in the OA group had bilateral knee OA; 4 participants had more severe symptoms in the left knee, while 5 participants had more symptoms in the right knee. Characteristics of the participants are shown in Table 1.

Excursion angle of contralateral pelvic drop and ipsilateral trunk lean

Contralateral pelvic drop and ipsilateral trunk lean excursions during the stance phase did not show a significant difference between the asymptomatic and knee OA groups (Table 2). Pelvic and trunk motions during level walking are shown in Figure 3.

GMed onset time and muscle activity

Delayed muscle activity was observed in the knee OA group. However, there was no significant difference in GMed muscle activity between the asymptomatic and knee OA groups (Table 3).

Table 1 Characteristics of the participants in asymptomatic and knee OA groups

Characteristics	Group		p-value
	Asymptomatic (n=9)	Knee OA (n=9)	
Age (years)	63.8±6.0	64.6±6.7	0.799[a]
Height (cm)	151.7±6.5	155.2±4.4	0.836[a]
Weight (kg)	57.1±11.9	61.0±6.5	0.397[a]
BMI (kg/m^2)	25.1±4.1	26.3±3.1	0.498[a]
Walking speed (m/s)	1.0±0.1	0.9±0.1	0.126[a]
GMed muscle strength	5.0	5.0	0.609[b]
Total KOOS score (%)	96.33±1.58	51.89±16.94	<0.001[b]
Symptoms & stiffness (%)	100.00	55.22±19.66	<0.001[b]
Pain (%)	100.00	64.33±17.23	<0.001[b]
Function in daily living (%)	99.89±0.33	77.22±15.87	<0.001[b]
Function in sport (%)	81.67±7.91	31.67±23.45	<0.001[b]
Quality of life (%)	100.00	32.00±18.28	<0.001[b]

[a]Tested with independent T-test, [b]Tested with Mann-Whitney U test, mean±S.D. was reported, except for GMed muscle strength, which is presented as a median value. S.D.=standard deviation, OA=osteoarthritis, BMI=body mass index, GMed=gluteus medius, KOOS=knee injury and osteoarthritis outcome score, cm=centimeter, kg=kilogram

Table 2 Contralateral pelvic drop and ipsilateral trunk lean angles during level walking (mean±S.D.)

Excursion	Group		p-value
	Asymptomatic (n=9)	Knee OA (n=9)	
Contralateral pelvic drop (°)	4.47±1.13	3.51±1.46	0.139
Ipsilateral trunk lean (°)	5.75±1.45	7.32±4.4	0.336

S.D.=standard deviation, OA=osteoarthritis

Table 3 GMed muscle function during level walking (mean±S.D.)

GMed muscle	Asymptomatic (n=9)		Knee OA (n=9)		p-value
	Mean±S.D.	Median	Mean±S.D.	Median	
Muscle activity (%MVIC)	8.28±5.87	7.21	6.31±3.74	5.20	0.412
Onset time (ms)	-6.91±29.17	-12.20	32.73±30.42	21.80	0.006*

*statistically significant difference, negative and positive values of onset time mean GMed activation before and after foot contact, respectively. MVIC=maximum voluntary isometric contraction, OA=osteoarthritis, GMed=gluteus medius, S.D.=standard deviation

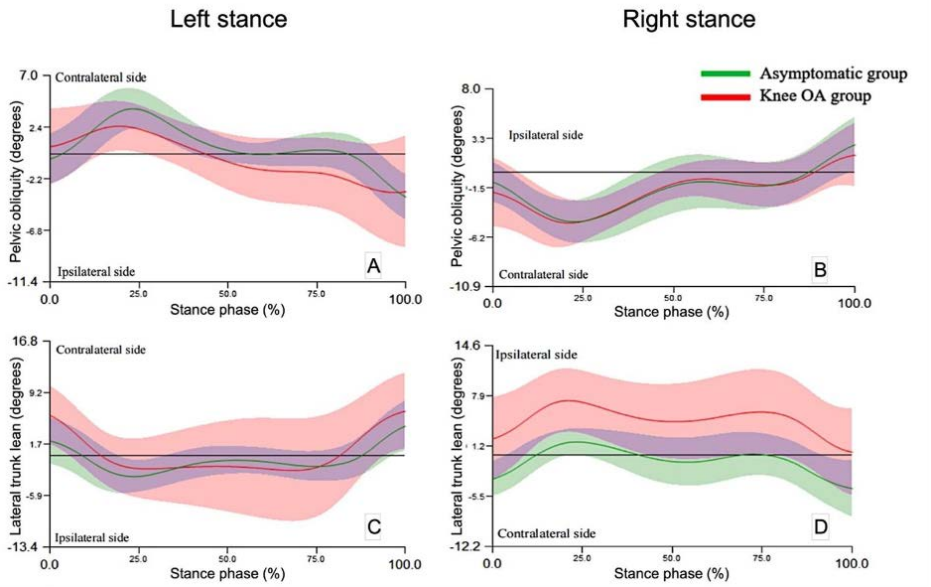


Figure 3 Pelvic and trunk motions during level walking. (A) averaged pelvic motion during left stance, (B) averaged pelvic motion during right stance, (C) averaged trunk motion during left stance, (D) averaged trunk motion during right stance

Discussion

This cross-sectional observational study was conducted in a motion analysis laboratory. The aim was to compare contralateral pelvic drop, ipsilateral trunk lean, GMed onset timing, and average GMed activity between individuals with and without medial knee OA. None of the participants reported knee pain during the gait assessment. Therefore, the study's findings present trunk and pelvic movements, as well as GMed activity during level walking, without interference from knee pain.

There were no significant differences in age, BMI, and gait speed between the asymptomatic and knee OA groups (Table 1). The scores of the Thai version of the KOOS questionnaire were noticeably different between the 2 groups, as shown in Table 1. Upon observing the KOOS scores, the asymptomatic group exhibited a higher score

(96.33%) than the knee OA group (51.89%), as expected. The KOOS scores in this study are consistent with those of a previous study[21]. Hálfdanardóttir et al.[22] reported KOOS scores in individuals with moderate medial knee OA, including 64.1% for pain, 68.3% for symptoms, 71.8% for daily activities, 31.5% for sport/recreational activities, and 38.4% for quality of life. It is assumed that the findings of the present study may be representative and applicable to individuals with moderate severity of medial knee OA.

No significant difference in contralateral pelvic drop between the groups was observed in the present study. Similar to the previous study's results, the contralateral pelvic drop was less than 5 degrees during level walking[23]. A previous study[24] showed a positive relationship between contralateral pelvic drop and the odds of medial knee OA, which was evaluated with radiography (Kellgren and Lawrence grade ≥2), but did not show up in the ipsilateral trunk lean parameter. However, this study used a two-dimensional measurement tool to evaluate the kinematic data. In the current study, greater ipsilateral trunk lean was observed in the knee OA group (7.32°) than in the control group (5.75°). However, there was no significant difference between the 2 groups. In 2012, Bechard et al.[25] found no significant difference in contralateral pelvic drop. However, significant ipsilateral trunk lean was noted in mild to moderate knee OA. In contrast, Hálfdanardóttir et al.[22] found no significant difference in ipsilateral trunk lean and contralateral pelvic drop between the asymptomatic and moderate severity of the knee OA group in the walking task. Hunt et al.[26] found ipsilateral trunk lean in severe knee OA was significantly higher than the asymptomatic control group, but contralateral pelvic drop did not exhibit a significant difference. They suggested that skin tension and artifacts could be the possible reason why the contralateral pelvic drop value in the knee OA group was less than that of the control group. Interestingly, ipsilateral lateral lean may be noted in individuals with moderate knee OA, as reported by Bechard[25] and the current study. However, it is worth noting that the current study's small participant size may have limited the detection of significant changes in ipsilateral trunk lean and contralateral pelvic drop excursions. Recruiting a larger number of participants would be necessary to confirm these observations.

Impaired neuromuscular function could be noted in individuals with knee OA. A previous study investigated the H-reflex of the soleus muscle in individuals with knee OA and found that the H-reflex had changed in the knee OA group. They mentioned that the H-reflex of the soleus muscle had a higher significance (6.6%) than the control group in the initial contact phase in order to prepare for weight bearing on the knee joint[27]. To our knowledge, the present study is the first to investigate the timing of GMed activation related to the heel strike phase in medial knee OA. We observed that the knee OA group exhibited a 32.73 ms delay in GMed activation after foot contact during level walking, whereas the control group demonstrated a 6.91 ms earlier activation of the GMed muscle before foot contact. The delay of GMed activation may reflect the change of movement plan from the feedforward to the feedback mechanism in individuals with knee OA. The result of this study showed that an average of the onset timing in the asymptomatic group had significant activation before foot contact during level walking compared with the knee OA group. We thought that the timing impairment of GMed activation could be noted even though there was no change in contralateral pelvic drop in moderate knee OA compared with asymptomatic individuals during walking. Additionally, it is plausible that the neuromuscular parameter of muscular onset time is particularly sensitive to observation in individuals with mild to moderate knee OA. Therefore, future investigations with longitudinal studies would be intriguing if they could observe the development and changes in knee OA over time.

To control the body's center of mass in the frontal plane, the GMed muscle has the important role of pelvic level stabilization during walking[6]. Average EMG activity around peak contralateral pelvic drop could correspond to the control peak contralateral pelvic drop during level walking rather than the average through the stance phase. We found that less muscle activation in the knee OA group (6.31% MVIC) was noted than in the control group (8.28% MVIC). However, there was no significant difference of average GMed amplitude and manual muscle strength test between the groups.

Lower hip muscle strength was shown in people with knee OA in the previous study[28]. Ling et al.[12] studied muscle activities in individuals with knee OA and found that the activity of knee and calf muscles in the knee OA group was different, such as quadriceps, gastrocnemius, and hamstrings, compared with the healthy subjects. The results of Rutherford et al.[29] and Alkjaer et al.[28] showed that the change of EMG amplitude was observed in the medial knee OA group. We found no significant difference in average GMed activity in 200 ms around peak contralateral pelvic drop or approximately at 25% gait cycle during the stance phase. There was no significant difference in GMed muscle activation over the peak contralateral pelvic drop, which might represent that there is no difference in GMed work between individuals with and without knee OA in the current study. However, this finding may imply that individuals with moderate knee OA, according to the patient characteristics of this study. It would be interesting for further analysis to investigate the details of EMG in specific phases during stances, such as the early and late phases.

Conclusion

A significant delay in GMed onset was observed in individuals with moderate knee OA severity in the current study. The delayed onset time of GMed might be a sensitive indicator for the observation of neuromuscular deficits in individuals with knee OA, even when pelvic obliquity, lateral trunk lean, and average GMed activity did not show any significant differences between the groups. The findings of the current study align with previous evidence supporting the fact that GMed exercise programs, particularly those focusing on onset time, facilitate GMed function. In any future study, adding an intervention that helps to improve the onset time should be investigated in individuals with knee OA for the clinical implications.

Ethics approval

The research protocol was approved by the Mahidol University Central Institutional Review Board for Human Research (MU-CIRB 2019/101.1106). The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments, or comparable ethical standards.

Informed consent statement

All participants provided written informed consent for study participation and for the publication of this study prior to data collection. Trial Registration is not applicable because this article does not contain any clinical trials.

Data availability

All data from this study are available upon reasonable request to the corresponding author.

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Conflict of interest

The authors declare no conflict of interest.

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