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Original Article

Functional electrostimulation therapy for vastus medialis decreases the varus thrust during gait

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Abstract. [Purpose] This study aimed to investigate whether modification of vastus medialis activity can delay the varus thrust. [Participants and Methods] Ten participants (Kellgren–Laurence grades I: n=2, II: n=6, and III: n=2) diagnosed with knee osteoarthritis were enrolled. The intervention involved free walking on a 10-m walkway at any speed after donning a functional electrical stimulation set to contract the vastus medialis before heel contact. Using a Vicon Nexus ground reaction force meter and a wireless electromyograph DELSYS, varus thrust, maximal knee extension angle, maximal knee adduction moment, and vastus medialis onset time were assessed both before and after intervention. [Results] A significant difference in varus thrust was detected from before to after the intervention (2.7 ± 1.1° vs. 2.2 ± 1.3°). Both the vastus medialis activation time (−0.06 ± 0.09 vs. −0.21 ± 0.1) and the knee-joint extension angle (8.7 ± 5.1° vs. 5.5 ± 5.9°) decreased following intervention, whereas the knee adduction moment significantly increased (0.50 ± 0.20° vs 0.56 ± 0.18°). [Conclusion] Wearing the functional electrical stimulation set caused the vastus medialis to act earlier in response to heel strike, thereby improving the knee-joint extension angle and suppressing varus thrust.
Key words: Vastus medialis, Maximal knee extension angle, Knee osteoarthritis

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INTRODUCTION

Approximately 30 million people in Japan are estimated to have latent knee osteoarthritis (knee OA), while a further 10 million patients are symptomatic[1)]. Conservative therapy, including weight loss, muscle strengthening exercises, education, and aerobic exercise, is the first choice for knee OA according to the guidelines of the National Institute for Health and Clinical Excellence, developed under the jurisdiction of the United Kingdom National Health Service[2)]. In a previous longitudinal study of 700 patients, varus thrust was shown to affect the onset and progression of knee OA[3–5)], suggesting that it may be a therapeutic target for knee OA. However, the relationship between the abovementioned first-choice treatments and varus thrust has not been clarified. Factors influencing varus thrust include knee joint laxility and knee joint varus alignment[4, 6)], among which the delay in the timing of activity of the vastus medialis (VM) during walking can be controlled by the patients

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themselves[7]. For those who did not recognize varus thrust, the VM was active before heel contact while walking, whereas for those who recognized varus thrust, the VM was activated after heel contact. The VM stabilizes the knee joint by extending it and pulling the patella inward[8]; in this vein, a previous study showed that the flexion angle of the knee joint in the initial stage of neutral walking in healthy individuals was approximately 5°, whereas that in patients with knee OA was approximately 20°[9]. This flexion angle is defined as the angle at which the medial and lateral collateral ligaments relax and the knee joint sways in the varus and valgus directions[10]. It was therefore presumed that a delay in the VM activity during walking brings about heel contact at an angle that triggers varus/valgus movement of the knee joint, leading to knee joint sway. Delay in VM activity is classified as a state of learned disuse during walking caused by long-standing pain in patients with knee OA. Functional electrical stimulation (FES) is often applied in patients with central nervous system disorders, and the effects of functional improvement on muscles in a state of learning disuse have been confirmed, in addition to reciprocal inhibitory effects on the activation of the cerebral cortex and disinhibited nerves[11]. As such, it has been suggested that FES may suppress rapid varus movement by correcting the timing of VM activity in the learned disuse state before heel strike.

This study aimed to investigate whether gait training using FES suppresses varus thrust to improve VM onset time in patients with knee OA. We hypothesized that gait training using FES would accelerate VM onset time and suppress varus thrust. The results of this study may have clinical significance, helping promote gait training using FES, as a new preventive treatment for knee OA.

PARTICIPANTS AND METHODS

This study was an open-label single-intervention before-and-after study.

The inclusion criteria were as follows: knee OA patients diagnosed with Kellgren–Lawrence grade I–III and with a cognitive function of 21 points or higher on the Hasegawa Simple Cognitive Assessment Scale. The exclusion criteria were patients with diseases or symptoms in other joints, neuromuscular diseases, or internal medicine diseases that affected continuous walking for 10-m or more. Participants who were found to be unsuitable for the study, such as those who used medical electrical devices implanted in the body (cardiac pacemakers or metal implants) and those with a history of or suspected epilepsy, were further excluded. Finally, 10 patients were enrolled.

As intervention, muscle activity reeducation training was performed while walking using FES. Electrodes were attached to the participant's VM, and an external stimulus was applied at a level that allowed the VM to contract efferently from 10% before the heel strike to 10% after the heel strike throughout the entirety of the gait cycle. Walking practice was performed for 20 min while an external stimulus was applied to each walking cycle. Participants were subjected to sound feedback that matched the electrical stimulation to strengthen their awareness of muscle activity timing and practice so that the same muscle activity could be reproduced even without FES.

The following assessments were performed (Fig. 1). The kinematic and dynamic data during walking were measured using the VICONMX (Vicon Motion Systems, Oxford, UK) three-dimensional motion analysis system, with 16 infrared cameras at a sampling frequency of 200 Hz. Infrared markers were attached to 35 points on the entire body, according to the plug-in-gait model. The floor reaction force was measured using eight floor reaction force meters (AMTI, Watertown, MA, USA) at a sampling frequency of 1,000 Hz. For each participant, we calculated the varus thrust value by subtracting the minimum knee varus angle from the maximum varus angle in the load response period. We also calculated the knee extension angle and knee adduction moment (KAM). The heel contact was defined as the time at which the vertical component of the floor reaction force was 20 N or more.

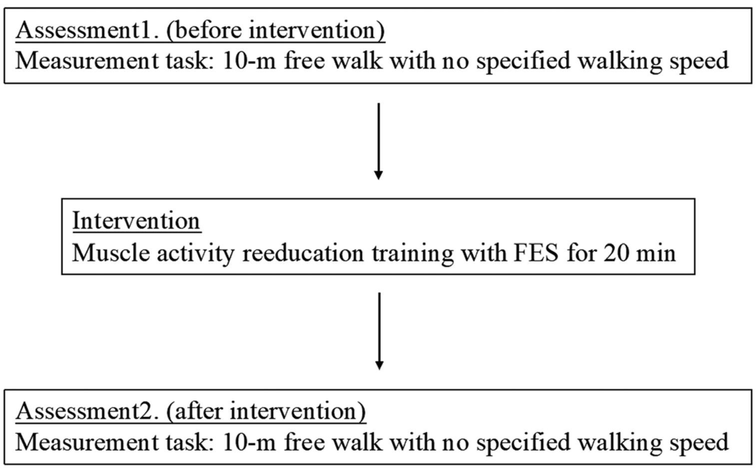

Fig. 1. Flowchart of assessment and intervention.

A surface electromyograph (Trigno Wireless System; Delsys Inc., Boston, MA, USA) was applied to measure muscle activity patterns at a sampling frequency of 1,000 Hz. The VM was used as the test muscle, and electrodes were placed longitudinally on the belly of the muscle following the standard skin treatment according to the method described by SEINAM[12]. The recorded raw EMG waveforms were full-wave rectified, a root mean square of 100 ms was obtained, and the maximum muscle activity by MMT of the VM was normalized to 100%. Using the average muscle activity in a quiet sitting position of 100 ms as the baseline, the time when the muscle activity started exceeding 2 SD from baseline at time 0 was calculated, and the VM activity onset time to the heel contact point obtained from the ground reaction force meter was calculated.

The measurement task was a 10-m free walk with no specified walking speed. It was conducted twice, before and after the intervention, during which measurements of varus thrust values, vastus medialis activation and knee joint extension angle, KAM were undertaken. For each parameter, the median value of the three trials was adopted and compared for each task.

All statistical analyses were performed using SPSS (v23, IBM, Tokyo, Japan), and the data were assessed for normality prior to performing analyses at an alpha level of 0.05. Varus thrust, knee extension angle, VM onset time, and maximum KAM were all compared before and after the intervention using t-tests.

This study was approved by the Hiroshima University Clinical Research Ethics Review Committee (implementation plan number: jRCTs062180071). All participants were informed of the purpose and content of the study in writing, and measurements were only performed after obtaining written informed consent.

RESULTS

The demographic characteristics of the study participants are summarized in Table 1. Overall, 10 knees of 10 participants were included (Table 1).

The statistic analyses revealed significant differences in all assessed parameters. The varus thrust value, the vastus medialis activation time and the knee joint extension angle decreased following the intervention. Conversely, the KAM significantly increased after intervention (Table 2).

DISCUSSION

The present study is the first to show that the modification of activity initiation in the VM during gait reduces mechanical stress. Our results show that the onset of VM activation occurs approximately 0.15 s earlier, resulting in a 0.5° decrease in varus thrust and an approximately 3° knee extension angle.

In healthy individuals without knee OA, the VM is active approximately 10% before heel contact in the gait cycle[13]; however, this activity is delayed in individuals with varus thrust[7]. Furthermore, the flexion angle of the knee joint in the initial stance, defined as the angle at which the relaxed knee joint oscillates in the direction of the varus/valgus[9], was approximately 5° in healthy individuals, whereas that in patients with knee OA is approximately 20°[10].

Overall, the results of this study suggest that early heel-strike activity in the VM improved the knee extension angle at heel-strike to 5°, triggered a gain in structural stability, and reduced the varus thrust.

Table 1. Demographic characteristics of the study participants

Characteristics	n=10
KL (I, II, III)	2, 6, 2
Sex (male:female)	2:8
Age (years)	68.6 ± 12.5
BMI (kg/m^2)	24.2 ± 3.2

Values represent the means ± standard deviations.
KL: Kellgren–Lawrence grade; BMI: body mass index.

Table 2. Comparison of knee dynamic motion parameters before and after the intervention

	Before	After
Varus thrust [°]*	2.7 ± 1.2	2.2 ± 1.3
VM onset time [sec]**	−0.06 ± 0.09	−0.21 ± 0.1
Knee extension angle [°]**	8.7 ± 5.1	5.5 ± 5.9
Knee adduction moment [Nm/BW]*	0.50 ± 0.20	0.56 ± 0.18

*p<0.05, **p<0.01.
Values are shown as the means ± standard deviations.
VM: vastus medialis.

An intervention studies investigating varus thrust have been previously conducted. One such study showed that quadriceps strength training leads to increased muscle strength and improved symptomatic and functional outcomes but does not change the quadriceps or knee joint biomechanics during walking[14]. This may be because traditional quadriceps strength training aims primarily to increase the quantity of muscle output, rather than to target the biomechanical contributors to the medial compartment knee load[15].

A previous study showed that neuromuscular and quadriceps strengthening exercises did not affect knee adduction moment (KAM) in patients with moderate varus malalignment and mostly moderate-to-severe medial knee OA. However, it should be noted that varus thrust was not considered in this study[16]. Dixon et al. previously investigated the relationship between periarticular muscle activity patterns and varus thrust, showing that a greater joint contraction of the quadriceps and hamstrings resulted in a greater varus thrust[17].

Although there have been several intervention studies for varus thrust, no clear results have yet been obtained. The results of the present study showed that KAM, a typical index of mechanical stress on the knee joint, increased significantly on the other hand varus thrust decreased. Sosdian et al.[18] previously showed that the KAM increased in a group with a large varus thrust, which contradicted the results of the present study. The fact that the KAM increased despite the varus angle decreasing immediately after the heel strike is presumed to be due to an increase in the floor reaction force component. KAM is clinically related to the knee joint mechanical stress index and pain[19–21]. In addition to the joint load and clinical symptoms, varus thrust is a known risk factor for knee OA[22]. As such, further longitudinal studies are required to determine how our results affect the future progression of knee OA.

This study had several limitations. First, motion-capture techniques can introduce errors estimated to be less than 5° in systematic reviews[23]. In contrast, the varus thrust difference obtained in the present study was 0.5°, which is within the margin of error. However, because our method calculates any thrust movement as the actual excursion of all movements (i.e., peak-to-trough or trough-to-peak), the direction and amount of knee movement are conserved. Second, the risk factors for the onset and progression of knee osteoarthritis other than mechanical stress include gender, obesity, range of motion, and muscle strength[1, 4, 24]. However, this study was unable to examine these risk factors.

In conclusion, the results of the present study confirmed our hypothesis; gait training using FES accelerates VM onset time and suppresses the varus thrust in patient with knee OA. However, it should be noted that the KAM also increased. Therefore, a long-term follow-up study is needed to clarify whether gait training using FES will be a preventive treatment for knee OA.

Preprint publication

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Conflict of interest

None.

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