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Original Article

Differences in onset time between the vastus medialis and lateralis during stair stepping in individuals with genu varum or valgum

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Abstract. [Purpose] We investigated the difference in onset time between the vastus medialis and lateralis according to knee alignment during stair ascent and descent to examine the effects of knee alignment on the quadriceps during stair stepping. [Subjects] Fifty-two adults (20 with genu varum, 12 with genu valgum, and 20 controls) were enrolled. Subjects with > 4 cm between the medial epicondyles of the knees were placed in the genu varum group, whereas subjects with > 4 cm between the medial malleolus of the ankle were placed in the genu valgum group. [Methods] Surface electromyography was used to measure the onset times of the vastus medialis and vastus lateralis during stair ascent and descent. [Results] The vastus lateralis showed more delayed firing than the vastus medialis in the genu varum group, whereas vastus medialis firing was more delayed than vastus lateralis firing in the genu valgum group. Significant differences in onset time were detected between stair ascent and descent in the genu varum and valgum groups. [Conclusion] Genu varum and valgum affect quadriceps firing during stair stepping. Therefore, selective rehabilitation training of the quadriceps femoris should be considered to prevent pain or knee malalignment deformities.
Key words: Quadriceps muscle, Genu varum, Genu valgum

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INTRODUCTION

The quadriceps pulls the patella upward and laterally and generate high power through a mechanical advantage from the patella[1)]. The vastus medialis and lateralis provide both functional mobility and stability of the knee joint and maintain balance between the two muscles, so the degree of activation and temporal coordination of these two muscles are keys to providing safe movement of the knee joint[2)]. Imbalance between the vastus medialis and lateralis of the quadriceps leads to pain, as the patella glides abnormally[3)]. For example, patellofemoral pain syndrome occurs after patellar lateral subluxation because of the weakness and delay of the vastus medialis in genu valgum[4, 5)]. It is important to acquire balance and stability between the vastus medialis and lateralis for proper alignment of the patella and lower extremities[6)]. So many studies have been performed to increase the strength of the vastus medialis selectively[7–9)].

Previous studies[10–12)] reported that genu varum and valgum are common knee malalignment problems that affect the cross-sectional area, onset time, and activation of the vastus medialis and lateralis. Knee malalignment leads to imbalance between the vastus medialis and lateralis. In particular, studies that investigated the differences in contraction onset time between the vastus medialis and lateralis during isometric and isokinetic concentric exercise show that genu varum delays the vastus lateralis and genu valgum delays the vastus medialis[11, 12)].

Stair stepping is commonly used to investigate changes in the quadriceps femoris in patients with patellofemoral pain syndrome. The load on the knee joint increases during stair stepping, so it is used to study the activation of the quadriceps, kinetics of the knee joint, and effects of patellofemoral pain syndrome interventions. Stair stepping is a closed kinetic chain, functional activity because it changes the muscle activation pattern and joint moment, as the body is lifted against gravity. Thus, it is useful in identifying an activation imbalance between two muscles or a change in knee joint moment according to increased range of motion[13)]. However, previous studies[11)] measured the imbalance between the vastus medialis and lateralis during isometric contraction or an open kinetic chain. We hypothesized that the effect of knee alignment on these two muscles during stair stepping, or a closed kinetic chain, is different from the effect of that

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Table 1. Anthropometric data (M±SD)

	Control group	Genu varum group	Genu valgum group
N	20	20	12
Age (years)	21.4 ± 1.7	21.3 ± 1.5	23.7 ± 3.2
Height (cm)	165.4 ± 9.0	165.0 ± 7.5	171.7 ± 8.5
Weight (kg)	58.0 ± 13.1	55.4 ± 8.1	67.3 ± 14.1
Q-angle (°)**	13.2 ± 1.7	18.6 ± 1.3	7.3 ± 1.5
Distance†			
IC (cm)**	0.4 ± 1.5	5.1 ± 0.8	-
IM (cm)**	-	-	6.1 ± 1.0

M±SD: mean±standard deviation
**p<0.01
†Intercondylar distance of the knee in the genu varum group; intermalleolar distance of the ankle in the genu valgum group

during an open kinetic chain because these two muscles contract more simultaneously during a closed kinetic chain than during an open kinetic chain[14, 15]. Therefore, we compared the difference in onset time between the vastus medialis and lateralis during stair ascending and descending in people with genu valgum and varum and identified the effect on the quadriceps according to knee alignment during stair stepping.

SUBJECTS AND METHODS

Fifty-two healthy adults who were over 20 years old and without any orthopedic, neurological, or knee pain history were enrolled in this study. The distance between the ankles and knees while standing up straight was measured to classify the subjects into three groups, the genu varum, genu valgum, and control group. Subjects with distance between the ankles > 4 cm were classified as the genu valgum group, those with distance between the knees > 4 cm were classified as the genu varum group, and the others were classified as the control group[10]. Age, height, weight, Q-angle, and the distances between the ankles and knees were measured as general characteristics of the subjects (Table 1). The subjects understood the experimental purpose and methods and agreed voluntarily to participate in the study. All the participants read and signed an informed consent form approved by the local ethics committee of the Catholic University of Daegu.

A WEMG-8 wireless surface electromyograph (EMG) was used, and the surface electrodes were attached to the vastus medialis, vastus lateralis, and rectus femoris of both legs but not the vastus intermedius, as it is difficult to measure its activity by surface EMG. The electrodes for evaluating the rectus femoris were attached 9–17 cm above the superior patella, and electrodes for the vastus medialis were attached 5 cm above the superomedial patella. The electrodes for the vastus lateralis were attached 15° in the diagonal direction, lateral to the midline, and 3–5 cm above the patella. The distance between two electrodes in one channel was maintained at 2 cm[16]. The EMG signal sampling rate for data collection was 1,024 Hz, with band-pass filtering of 13–430 Hz, a 60 Hz notch filter, and an EMG reduction filter. The EMG signals were converted to root mean square values.

Muscle onset time was the time during the first 25 ms of contraction when the signal exceeded a value three standard deviations above the mean EMG baseline signal measured 200 ms before an isometric contraction[17]. The value obtained by subtracting the vastus lateralis onset time from the vastus medialis onset time was the difference in onset time between the vastus medialis and lateralis[13, 18].

The three wooden sets of stairs (120 cm wide, 28 cm long, 18 cm high, gradient of 30°) used in this experiment were manufactured according to the Korea Research Institute of Standards and Science.

The EMG surface electrodes were attached, and the subjects practiced stair stepping with a natural gait. Subjects ascended and descended the stairs three times to measure the difference in onset time between the vastus lateralis and medialis, and the mean value was used for analysis. Ascending stairs is a closed kinetic chain exercise, and concentric contraction of the quadriceps occurs after the foot makes contact with stairs; on the other hand, descending stairs is a closed kinetic chain exercise, and eccentric contraction of the quadriceps occurs when the knee starts to flex while the other foot starts to descend stairs. Thus, the onset time was measured after the foot touched the stairs during stair ascent for the closed kinetic chain exercise and concentric contraction of the quadriceps and after the other foot started to descend the stairs for the closed kinetic chain exercise and eccentric contraction of the quadriceps.

The Kruskal-Wallis test was used to analyze the differences in onset time between the vastus medialis and lateralis among the three groups. Tukey's and Duncan's post hoc tests were performed after converting the values to ranks; hence, one-way analysis of variance was used. The Wilcoxon signed-rank test was used to analyze the difference between ascending and descending stairs. Statistical analyses were performed using PASW ver. 18.0 for Windows (SPSS Inc., Chicago, IL, USA), and p-values < 0.05 were considered significant.

Table 2. Difference in onset time (VM-VL) during ascent and descent of stairs (ms) (M±SD)

	Control	Genu varum*	Genu valgum*
Stair ascend**	11.25 ± 0.12	−9.69 ± 0.06	33.43 ± 0.16
Stair descend**	8.80 ± 0.03	−4.72 ± 0.04	12.70 ± 0.03

M±SD: mean±standard deviation
VM: vastus medialis; VL: vastus lateralis
*p<0.05; **p<0.01

RESULTS

Significant differences were detected in onset time between the vastus medialis and lateralis during ascent and descent of stairs among all three groups. The onset time was less than 0 in the genu varum group, whereas it was greater than 0 in the genu valgum group, indicating that the vastus medialis contracted faster than the vastus lateralis in the genu varum group; on the other hand, the vastus lateralis contracted faster than the vastus medialis in the genu valgum group (Table 2).

No differences in onset time were observed between ascending and descending stairs in the control group. However, significant differences in onset time were found between ascending and descending stairs in the genu varum and valgum groups. The value was near 0 while subjects descended stairs in both the genu varum and valgum groups, indicating that the vastus medialis and lateralis contracted more simultaneously while subjects descended stairs than when they ascended stairs (Table 2).

DISCUSSION

The difference in onset time between the vastus medialis and lateralis was determined by subtracting the vastus lateralis onset time from the vastus medialis onset time[13]. If the value was less than 0, the vastus medialis contracted faster than the vastus lateralis, whereas if the value was greater than 0, the vastus medialis contracted later than vastus lateralis. When the value was close to 0, it indicated that the two muscles contracted more simultaneously. The value was less than 0 in the genu varum group during both ascent and descent of stairs, so contraction of the vastus lateralis was more delayed than that of the vastus medialis in the genu varum group, whereas the value was greater than 0 in the genu valgum group; thus, contraction of the vastus medialis was more delayed than the vastus lateralis in the genu valgum group. These results indicate that the firing patterns of the vastus medialis and lateralis in genu varum and valgum groups were different from that in the control group. This result was similar to that of a previous study[11] reporting an imbalance in onset time between these two muscles during isometric contraction. Thus, the firing pattern of muscle contraction seems the same between open and closed kinetic chain exercise.

The vastus medialis and lateralis provide functional mobility and stability to the knee joint, as they maintain the appropriate balance of contraction. The degree of activation and temporal coordination of these two muscles are keys to providing stability of the knee joint[2]. An imbalance between these two muscles is often observed in patients with patellofemoral pain syndrome, and pain is caused by lateral dislocation of the patella due to weakness of the vastus medialis. However, studies about delayed vastus medialis activation have been performed, and this argument about the results has been made consistently. Wong[4] reported that the number of studies[19–21] reporting that patellofemoral pain syndrome results in delayed activation of the vastus medialis was similar to the number of studies[22–26] reporting no difference in onset timing between patellofemoral pain syndrome and control groups. He emphasized that the onset time of firing does not indicate displacement of the patella.

However, significant differences in the degree of activation and temporal coordination between the vastus medialis and lateralis in genu varum and genu valgum groups were reported by Park et al[11, 12]. The onset time of the vastus lateralis was delayed during isometric contraction in their genu varum group, but that of the vastus medialis was delayed in their genu valgum group[11]. In addition, the vastus lateralis was weaker than the vastus medialis in their genu varum group, whereas the vastus medialis was weaker than the vastus lateralis in their genu valgum group during isometric contraction. These studies support our results showing delayed firing of the vastus medialis in the genu valgum group and delayed firing of the vastus lateralis in the genu varum group.

No difference in onset time was detected between ascending and descending stairs in the control group, which coincided with the results of Bennell et al.[27], who reported that a difference in onset time between the vastus medialis and lateralis does not affect stair stepping in healthy adults. However, significant differences in onset time were observed between ascending stairs and descending stairs in the genu varum and valgum groups. The onset time was closer to 0 while subjects descended stairs than when they ascended stairs in both the genu varum and valgum groups. This result shows that the vastus medialis and lateralis contracted more simultaneously when subjects descended stairs than when they ascended stairs. The quadriceps generates a large amount of power while ascending stairs to lift all of the body weight, so a stronger muscle would contract faster than a weaker muscle. However, the quadriceps control the descent velocity of the mass of gravity through eccentric contraction to absorb the impact to the knee joint while descending stairs[1], so these two muscles contracted simultaneously. Thus, it may be more effective to contract the muscle eccentrically while descending stairs than while ascending stairs as rehabilitation training through two muscles contract simultaneously.

A limitation of this study was that the subjects were

young and healthy with no pain. Future studies should investigate patients with knee pain or an unstable knee joint. Moreover, the number of subjects differed among the three groups, and there were more males than females in the genu valgum group. However, no gender differences were detected because the onset time was compared between the two muscles within each subject; the onset time was not compared between individuals. Future studies should control the gender raio.

In summary, genu varum and valgum affected the quadriceps firing onset time due to malalignment of the lower extremities during stair stepping. Moreover, the onset times of the two muscles in the genu varum and valgum group were different from that in the control group. Therefore, selective quadriceps rehabilitation should be considered to prevent knee pain or deformities in knee alignment.

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