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Differences in onset timing between the vastus medialis and lateralis during concentric knee contraction in individuals with genu varum or valgum

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Abstract. [Purpose] The purpose of this study was to investigate the difference in onset timing between the vastus medialis and lateralis among the different knee alignments, as well as the best isokinetic angular velocity for an isokinetic concentric contraction. [Subjects] Fifty-two adults (20 with genu varum, 12 genu valgum, and 20 controls) were enrolled in this study. Subjects with > 4 cm between the medial epicondyles of the knee 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 concentric contractions at 30, 60, and 90°/sec. [Results] The vastus lateralis showed more delayed firing than the vastus medialis in the genu varum group, whereas vastus medialis firing was delayed more than that of the vastus lateralis in the genu valgum group. No differences in onset timing were observed between the vastus medialis and lateralis according the different angular velocities during concentric contractions in all three groups. [Conclusion] Genu varum and valgum affect quadriceps firing. 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

During concentric contraction, the quadriceps extends the knee which is commonly used to raise the center of mass, such as when running uphill, jumping, or standing from sitting. In particular, the quadriceps pulls the patella upward and laterally, and generates high power through a mechanical advantage from the patella[1)]. Knee pain occurs as the patella slides abnormally when there is imbalance between the quadriceps vastus medialis and lateralis during concentric contractions to extend the knee[2)]. This type of pain is referred to as patellofemoral pain syndrome[2–5)]. Therefore, both balance and stability between the vastus medialis and lateralis must be acquired to correct alignment of the patella[6)], and to prevent and treat patellofemoral pain syndrome. Some studies have analyzed differences in muscle activities or onset timing between the vastus medialis and lateralis[7–10)]. In particular, weakness is often observed in the vastus medialis, which is the first muscle to show weakness among the quadriceps muscles[11)]. Hence, many studies have attempted to suggest the best angular velocity during isokinetic exercise to selectively strengthen the vastus medialis.

A few studies based on knee alignment have been conducted on the mechanical characteristics of the quadriceps. Moreover, some studies have measured the cross-sectional areas of the vastus medialis and lateralis according to knee alignment and Q-angle[12, 13)], and the difference in onset timing between the vastus medialis and lateralis according to knee alignment during isometric contraction has also been investigated[14)]. A significant difference was observed between cross-sectional areas of the vastus medialis and the lateralis according to knee alignment measured by the Q-angle. More specifically, Sogabe[12)] reported that subjects with genu varum have a larger vastus medialis and a smaller vastus lateralis, Tsakoniti[13)] reported that subjects with a smaller Q-angle have a larger vastus lateralis and a smaller vastus medialis. Thus, knee alignment affects the imbalance between the vastus medialis and lateralis, and genu varum is related to a smaller Q-angle and genu valgum is related to a larger Q-angle. Therefore, the relationship between knee alignment or Q-angle and the quadriceps needs to be investigated. Supporting this notion, Park[14)] demonstrated that knee alignment affects onset timing between the vastus medialis and lateralis during isometric contraction. In addi-

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Table 1. Anthropometric data (M ± SD)

	Control	Genu varum	Genu valgum
N (Male: Female)	20 (7:13)	20 (5:15)	12 (8:4)
Age (years)	21.4 ± 1.73	21.3 ± 1.45	23.7 ± 3.22
Height (cm)	165.4 ± 8.95	165.0 ± 7.45	171.7 ± 8.51
Weight (kg)	58.0 ± 13.10	55.4 ± 8.05	67.3 ± 14.05
Q-angle (°)**	13.15 ± 1.66	18.60 ± 1.27	7.33 ± 1.53
Distance†			
IC (cm)†	0.42 ± 1.54	5.06 ± 0.75	-
IM (cm)†	-	-	6.13 ± 1.03

M ± SD: mean ± standard deviation.
*p < 0.05, **p < 0.01
†distance: intercondylar distance of the knee in the genu varum group, intermalleolar distance of the ankle in the genu valgum group

tion, balance training considering the knee alignment in term of the vastus medialis and lateralis can be used to relieve knee pain and strengthen the quadriceps. However, no studies have yet determined the onset timing during dynamic isometric contraction.

In this study, we investigated the difference in onset timing between the vastus medialis and lateralis, according to knee alignment, as well as the best isokinetic angular velocity for performing an isokinetic concentric contraction. The onset timing of the vastus medialis and lateralis in subjects with genu valgum or genu varum was measured during concentric contractions performed at three angular velocities using equipment for measuring isokinetic muscle strength.

SUBJECTS AND METHODS

Fifty-two healthy young adults with no orthopedic or neurologic diseases and no knee pain were enrolled, and they were classified into three groups according to their knee alignments. We measured intermalleolar and intercondylar distances with the subjects in the standing position. If a subject had > 4 cm intermalleolar distance, they were placed in the genu valgum group. If a subject had > 4 cm intercondylar distance, they were placed in the genu varum group. The remaining subjects comprised the control group[12]. We also determined age, height, weight, and Q-angle as general characteristics (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.

An eight-channel wireless surface electromyograph (WEMG-8, LAXTHA, Daejeon, Korea) was used to measure the onset timing of the vastus medialis and lateralis during isokinetic concentric contraction. The surface electrodes (Ag/AgCl 2223, 3M, Seoul, Korea) were attached to point at 50° relative to the femoral longitudinal axis and over 5 cm from the superiomedial patella for the vastus medialis, which was the diagonal direction of the lateral 15° of the midline at 3 to 5 cm above the patella for the vastus lateralis. The ground electrode was attached to a point on the skin above the tibial tuberosity at 6 to 12 cm from the inferior patella[15]. The EMG signal sampling rate was 1,024 Hz, and it was filtered using a 13–430 Hz bandpass filter and a 60 Hz notch filter. The EMG signals were converted to root mean square values. Muscle onset timing was the time in the first 25 ms of contraction when the signal exceeded a value three standard deviations above the mean EMG baseline signal measured in the 200 ms before the isometric contraction. The value obtained by subtracting the vastus lateralis onset time from the vastus medialis onset time was the difference in the onset timing between the vastus medialis and lateralis[16]. A Biodex System IV (Biodex Medical Systems, Inc., Shirley, NY, USA) was used to provide isokinetic resistance for the quadriceps at angular velocities of 30, 60 and 90°/sec. The subjects sat on the Biodex, with their thighs, chest, and ankles fixed with straps. Subsequently, they performed knee extensions by pushing a lever arm placed over the ankle. Onset timing was measured three times at each angular velocity during concentric contraction, and the mean values were used in the analysis.

The Kruskal-Wallis test was used to determine the significance of differences in onset timing between the vastus medialis and lateralis of the various knee alignments. Tukey's and Duncan's post-hoc tests were converted as rank cases; hence, one-way analysis of variance was used. Statistical analyses were performed using PASW ver. 18.0 for Windows. P values < 0.05 were considered significant.

RESULTS

Significant differences in onset timing were observed between the vastus medialis and lateralis at 30, 60, and 90°/sec of angular velocity during concentric contractions among the knee alignments ($p < 0.05$). Negative onset timing values indicate that the onset time for the vastus lateralis was delayed compared to that of the vastus medialis, whereas positive values indicate a delayed vastus medialis onset compared to that of the vastus lateralis. For the genu varum group, our results show the onset timing was negative; thus, firing of the vastus lateralis was delayed compared to that of the vastus medialis. Onset timing was positive in the genu valgum group; thus, firing of the vastus medialis was delayed compared to that of the vastus lateralis.

Table 2. Onset timing (ms) between the vastus medialis and lateralis at different angular velocities of concentric contraction (M ± SD)

	Control	Genu varum	Genu valgum
30°/sec**	4.02 ± 3.04	−4.15 ± 5.23	34.27 ± 48.01
60°/sec**	2.73 ± 2.91	−2.62 ± 3.30	10.74 ± 7.49
90°/sec**	3.36 ± 3.00	−2.61 ± 3.52	33.40 ± 28.82

M ± SD: mean ± standard deviation.
*$p < 0.05$, **$p < 0.01$

No differences in onset timing were observed between the vastus medialis and lateralis among the angular velocities used for during concentric contractions in any of the three groups (Table 2).

DISCUSSION

Differences in onset timing between the vastus medialis and lateralis during isokinetic concentric contractions were measured. Significant differences in onset timing were observed among the three groups at 30, 60 and 90°/sec of angular velocity among the three groups. Onset timing between the vastus medialis and lateralis was calculated by subtracting the onset time of the vastus lateralis from that of the vastus medialis. When the value was negative, firing of the vastus lateralis was delayed compared to that of vastus medialis; when the value was positive, firing of the vastus medialis was delayed; and when the value was 0, the two muscles contracted simultaneously. The value was negative in the genu varum group in the present study; thus, the vastus lateralis firing was delayed compared to that of the vastus medialis. In contrast, the value was positive in the genu valgum group, so the vastus medialis firing was delayed compared to that of the vastus lateralis. These results were observed at all angular velocities; thus, angular velocity did not affect quadriceps activity. In particular, differences in onset timing in the genu valgum group were five to ten times that of the control group. Thus, delayed firing of the vastus medialis in the genu valgum group was longer than that in the vastus lateralis of the genu varum group. More specifically, the firing delay in the vastus medialis of the genu valgum group was more serious than the delay in the vastus lateralis on the genu varum group. This result is in agreement with Park[14)], who analyzed differences in onset timing between the vastus medialis and lateralis during isometric contractions. However, our result was different from that of Karst and Willett[17)], who compared onset timing between the vastus medialis obliquus and vastus lateralis in subjects with patellofemoral pain syndrome and those without pain during active nonweight-bearing knee extension; they found no significant differences between the groups.

The quadriceps pulls the patella both upward and laterally[1)], and the pulling direction is referred to as the Q-angle or quadriceps angle[18)]. The balance of physiological characteristics between the vastus medialis and lateralis induces the patella to slide normally; however, delayed firing or a weak vastus medialis causes excess lateral sliding of the patella, thereby inducing genu valgum and lateral patellar subluxation. Therefore, the quadriceps cannot stabilize and protect the patella sufficiently, ultimately causing patellofemoral pain syndrome[2–5)].

There is much controversy over whether or not patellofemoral pain syndrome is caused by delayed firing of the vastus medialis. Many studies have claimed that delayed firing of the vastus medialis is a cause of patellofemoral pain syndrome[15, 19)], whereas others claim that patellofemoral pain syndrome does not delay firing of the vastus medialis[17, 20)]. Our subjects were not patients with patellofemoral pain syndrome; however, knee alignment or Q-angle affects the quadriceps as follows. First, the subjects in the genu valgum group had an increased Q-angle in this study, and an increased Q-angle is a cause of patellofemoral pain syndrome[4)]; therefore, patellofemoral pain syndrome affects genu valgum[3)].

The vastus medialis is the quadriceps muscle most often seen to weaken, and various interventions to selectively strengthen the vastus medialis have been studied to prevent and treat pain or injury induced by weakness of the vastus medialis[21–23)]. Thus, a selective training program for the vastus medialis is needed for people with genu valgum; however, such a program may cause more severe problems. Accordingly, it is necessary to consider knee alignment and quadriceps firing prior to applying a rehabilitation program to strengthen the vastus medialis. In other words, a rehabilitation program to balance the vastus medialis and lateralis may be needed for subjects with knee pain or injury.

No significant differences in onset timing were observed between the vastus medialis and lateralis among different angular velocities. It was difficult to compare our results with those of prior studies because only a few studies have reported differences in onset timing between the vastus medialis and lateralis during concentric contraction. Na et al.[24)] reported that vastus lateralis activity tended to be higher at an angular velocity of 60°/sec during isokinetic concentric contractions, and that vastus medialis activity tended to be higher at 120°/sec; however, they did not find significant differences. Han and Lee[25)] found that the thicknesses of the vastus medialis and rectus femoris increased regardless of angular velocity. Muscle thickness is related to muscle strength[26)]; thus, it may be related to muscle EMG characteristics, such as muscle activity or onset time.

One of the limitations of this study was that the subjects were healthy young adults with no knee pain; thus, future studies should enroll patients with knee pain or knee joint instability. Moreover, some general characteristics, such as mean height and weight in the genu valgum group, were different from those in the other group due to a higher proportion of males. However, the onset times of the vastus medialis and lateralis were compared individually, and not between subjects; which may have eliminated potential gender differences. Future studies should control subjects well. In addition, experiments using various angular velocities are necessary. Moreover, if changes in muscle activities are measured during activities of daily living, such as gait, the results would help the prevention or treatment of injuries during daily activities.

In conclusion, genu varum and valgum, which are caused by lower limb malalignment of the musculoskeletal system, affect quadriceps firing. No differences were detected between the genu valgum and varum groups at different angular velocities. Selective rehabilitation training of the quadriceps femoris should be considered to prevent pain or knee malalignment deformities.

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