Original Article

A Study on the Differences of Quadriceps Femoris Activities by Knee Alignment during Isometric Contraction

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Abstract. [Purpose] This study attempted to identify how genu varum or valgum affects the electromyographic activities of the vastus medialis, vastus lateralis, and rectus femoris during knee isometric contraction. [Subjects] Fifty-two healthy young adults were enrolled in this study. They were enrolled and classified into three groups by knee alignment conditions: the genu varum, genu valgum, and control groups. [Methods] The electromyographic activity ratio of the vastus medialis to the vastus lateralis and rectus femoris were calculated using the percentage of maximum voluntary contraction. The participants contracted their quadriceps during isometric contraction at 30 and 60° of knee flexion. [Results] The genu varum group had more activity in the vastus medialis than in the vastus lateralis and rectus femoris, whereas the genu valgum group had more activity in the vastus lateralis and rectus femoris than in the vastus medialis. There was a significant difference in the muscle activity ratio between the vastus medialis and vastus lateralis by angle of knee flexion degree only in the genu valgum. There were no significant differences in any of the three groups in terms of the muscle activity ratio of the vastus medialis to the rectus femoris by angle of knee flexion. [Conclusion] The quadriceps femoris was used for different strategies according to knee alignment during isometric contraction at 30 and 60°. This study suggests that rehabilitation training programs used to strengthen the quadriceps should consider the knee alignment conditions of the target subjects.
Key words: Electromyography, Quadriceps muscle, Isometric contraction

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INTRODUCTION

The quadriceps femoris affects the bones it attaches to and the joints it passes; it also affects the alignment of the lower extremities. For instance, genu recurvatum is caused by quadriceps weakness or stiffness[1)]; it is evidence of the imbalances between the vastus medialis and lateralis by femoral torsion[2)]. Genu varum and valgum are poor alignments in the frontal plane. The quadriceps is concerned with movements in the sagittal plane, such as knee flexion and extension[1)]; moreover, the vastus medialis and lateralis, which cause medial and lateral pulling force, respectively[3)], may affect genu varum and valgum.

Genu varum and valgum have a large affect on the alignment of the lower extremities. Genu varum induces femoral retroversion, tibial medial torsion, decreased Q-angle, patellar medial dislocation, toe-in, and subtalar supination, and so on. In contrast, genu valgum induces femoral anteversion, tibial lateral torsion, increased Q-angle, patellar lateral dislocation, toe-out, subtalar pronation, and so on[4–7)]. Many previous studies[2, 7, 8)] have examined the quadriceps in relation to femoral torsion, Q-angle, and patellar movement. However, there have been few studies demonstrating the direct relation between the quadriceps and genu varum or valgum. Therefore, an EMG analysis of the quadriceps by knee alignment is needed.

Sogabe et al.[9)] measured quadriceps cross sections using MRI by knee alignment. The results showed that the genu varum group had a larger vastus medialis than vastus lateralis, whereas the genu valgum group had a larger vastus lateralis than vastus medialis. Tsakoniti and Stoupis[8)] studied quadriceps cross sections by Q-angle and reported that people with a smaller Q-angle had a larger vastus lateralis than people with a larger Q-angle. These studies demonstrated significant correlation between knee alignment and quadriceps cross sections. The size of the cross section is related to the muscle length; moreover, it can be easily inferred that both genu varum and genu valgum are related to an imbalance in muscle power between the vastus me-

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dialis and lateralis. These muscles pull on the patella, and an imbalance between these muscles causes the patella to move in an abnormal direction; this could cause secondary musculoskeletal problems.

Patellofemoral pain syndrome is a disease in which the patellar medial pulling force is weakened due to a weak vastus medialis and the patella is dislocated laterally, so it causes knee pain[6, 10]. Patients with this syndrome are treated with selective strength training programs for the vastus medialis in order to decrease pain and treat the disease[11–13], and a lot of research has been performed to identify ways to improve the vastus medialis selectively[14–16]. Thus, the muscle imbalance between the vastus medialis and lateralis could cause pain, and training programs to relieve the muscle imbalance are needed if there are imbalances between these two muscles according to knee alignment. There are some studies that have reported an imbalance between the vastus medialis and lateralis; however, there have been no studies demonstrating quadriceps activities using EMG by knee alignment. Therefore, analysis of quadriceps activities by knee alignment is needed.

This study classified subjects by knee alignment into genu varum, genu valgum, and control groups, and determined how genu varum or valgum affects the quadriceps during isometric contraction of the knee. Moreover, it demonstrated whether knee alignment conditions influence muscle imbalance. It also tried to suggest theoretical evidence for treatment and prevention of secondary musculoskeletal problems, which could occur as a result of muscle imbalance.

SUBJECTS AND METHODS

This study enrolled 52 healthy young adults with no history of orthopedic or neurologic symptoms and no knee pain. They were classified into three groups by knee alignment; the genu varum, genu valgum, and control groups. The genu varum group was composed of people whose intercondylar distances of the knee joint were over 4 cm in the standing position, whereas the genu valgum group was composed of people whose intermalleolar distances of the ankle joint were over 4 cm in the standing position. Other individuals not fitting into the either of these groups were classified as the control group[9]. There were significant differences in Q-angle among the three groups (Table 1). The subjects understood the experimental purpose and methods and agreed voluntarily to participate. Prior to participation, all participants were required to read and sign an informed consent form in accordance with the ethical standards of the Declaration of Helsinki. The protocol for this study was approved by the local ethics committee of the Catholic University of Daegu.

An 8-channel wireless surface EMG system (WEMG-8, LAXTHA, Daejeon, South Korea) was used to measure the electromyographic activities of the vastus medialis, vastus lateralis, and rectus femoris during isometric contraction. Surface EMG electrodes (Ag/AgCl 2223, 3M, Seoul, South Korea) were attached to points at 50° relative to the femoral longitudinal axis and over 5 cm from the superomedial patella for the vastus medialis, which is the diagonal direction of the lateral 15° of 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[17].

Table 1. Anthropometric data (M±SD)

	Control	Genu varum	Genu valgum
N	20	20	12
Age (y)	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	7.3 ± 1.5	18.6 ± 1.3
Distance†			
IC (cm)**	0.42 ± 1.54	5.06 ± 0.75	-
IM (cm)**	-	-	6.13 ± 1.03

M±SD: Mean±standard deviation
**$p<0.01$
†Distance: intercondylar distance (IC) of the knee in the genu varum group; intermalleolar distance (IM) of the ankle in the genu valgum group

The sample rate for the EMG signal was set at 1,024 Hz, and it was filtered using a 13 to 430 Hz band-pass filter and a 60 Hz notch filter. The collected EMG signals were calculated as the root-mean-square and then quantified.

Muscle activities were determined using the ratio of muscle activity at each motion by maximum voluntary isometric contraction during isometric contraction. Then, each muscle activity was measured during isometric contraction at 30 and 60° of knee flexion. Data were collected for 5 seconds, and data for 3 seconds, except for the first and last 1 second, were analyzed[18]. Muscle activities were measured three times at each angle of knee flexion during isometric contraction; then, the mean value was used and analyzed.

The electrographic activity ratio of the vastus medialis to the vastus lateralis was calculated as the standardized amplitude of the vastus medialis divided by the standardized amplitude of the vastus lateralis. Likewise, the electrographic activity ratio of the vastus medialis to the rectus femoris was calculated as the standardized amplitude of the vastus medialis divided by the standardized amplitude of the rectus femoris[18].

The Kruskal-Wallis test was used to analyze quadriceps activities according to the knee alignment conditions. Tukey and Duncan post hoc tests were converted as rank cases; hence, a one-way ANOVA was used. Statistical analyses were performed using PASW version 18.0 for Windows, and p-values less than 0.05 were considered to indicate significant differences.

RESULTS

There were significant differences in the activity ratio of the vastus medialis to the vastus lateralis both at 30 and 60° of knee flexion among the three groups during isometric contraction. If the electromyographic activity ratio of the vastus medialis to the vastus lateralis is 1, the muscle activities of the two muscles are the same. If the ratio is over

Table 2. Electromyographic activity ratio of the vastus medialis to the vastus lateralis by knee joint angle during isometric contraction (M±SD)

VM/VL	Control	Genu varum	Genu valgum*
30°**	0.95 ± 0.08	1.31 ± 0.25	0.66 ± 0.05
60°**	0.89 ± 0.11	1.15 ± 0.12	0.54 ± 0.12

M±SD: Mean±standard deviation
VM/VL: activity of vastus medialis/activity of vastus lateralis
*p<0.05; **p<0.01

Table 3. Electromyographic activity ratio of the vastus medialis to the rectus femoris by knee joint angle during isometric contraction (M±SD)

VM/RF	Control	Genu varum	Genu valgum
30°**	0.92 ± 0.08	1.17 ± 0.13	0.58 ± 0.15
60°**	0.84 ± 0.09	1.08 ± 0.06	0.53 ± 0.05

M±SD: Mean±standard deviation
VM/RF: activity of vastus medialis/activity of rectus femoris
**p<0.01

1, the muscle activity of the vastus medialis is larger than that of the vastus lateralis; if the ratio is less than 1, the muscle activity of the vastus lateralis is larger than that of the vastus medialis. According to the results of this study, the ratio was over 1 in the genu varum group, and moreover, the activity of the vastus medialis was larger than that of the vastus lateralis. In the genu valgum group, the ratio was less than 1, and the activity of the vastus lateralis was larger than that of the vastus medialis (Table 2).

There was a significant difference in the muscle activity ratio between the two muscles by angle of knee flexion only in the genu valgum group (Table 2).

There were significant differences in the activity ratio of the vastus medialis to the rectus femoris both at 30 and 60° of knee flexion among the three groups during isometric contraction. The ratio was over 1 in the genu varum group, and the vastus medialis showed higher activity than the rectus femoris. The ratio was less than 1 in the genu valgum group, and the rectus femoris showed higher activity than the vastus medialis (Table 3).

There were no significant differences in any of the three groups in terms of the muscle activity ratio between the two muscles according to the angle of knee flexion (Table 3).

DISCUSSION

The results of the present study showed that the electromyographic activity ratio of the vastus medialis to the vastus lateralis during isometric contraction at 30° of knee flexion were 1 in the control group, 1.3 in the genu varum group, and 0.7 in the genu valgum group. At 60° knee flexion, the ratio were 0.9 in the control group, 1.2 in the genu varum group, and 0.5 in the genu valgum group. These values were calculated as the electomyographic activity of the vastus medialis divided by that of the vastus lateralis. Thus, if the value was over 1, the muscle activity of the vastus medialis was larger than that of the vastus lateralis. If the value was less 1, the muscle activity of the vastus lateralis was larger than that of the vastus medialis. Therefore, the vastus medialis activity was larger than that of the vastus lateralis in the genu varum group, while the vastus lateralis activity was larger than that of the vastus medialis in the genu valgum group. Sogabe et al.[9)] reported that the cross-sectional ratio of the vastus medialis to the vastus lateralis was approximately 1.2 in their genu varum group and 0.9 in their genu valgum group. There are higher correlations between muscle strength and muscle thickness[19)]; thus, the results in this study were similar to the results in the study of Sogabe et al[9)]. In addition, Souza and Gross[20)] studied the muscle activity ratio of the vastus medialis oblique to the vastus lateralis in people with patellofemoral pain syndrome. According to their results, the muscle activity ratio of the vastus medialis oblique to the vastus lateralis in people with patellofemoral pain syndrome was lower than that in the normal group. Patellofemoral pain syndrome could cause genu valgum[21)], and therefore, this agrees with the results in this study, which showed that the activity of the vastus lateralis was higher than that of the vastus medialis in the genu valgum group. Therefore, this study suggested that the genu varum group had a stronger vastus medialis, whereas the genu valgum group had a stronger vastus lateralis. Genu valgum cannot be considered the same symptom with patellofemoral pain syndrome. However, studies about the genu varum or the genu valgum related quadriceps were rare. Because genu valgum increases the risk factors related to patellofemoral pain syndrome[6, 10)], studies concerning patellofemoral pain syndrome need to be considered.

The electromyographic activity ratios of the vastus medialis to the vastus lateralis during isometric contraction were smaller at 60° of knee flexion than at 30° in all three groups. This suggests that a larger knee flexion angle would result in higher vastus lateralis activity; however, there was a significant difference only in the genu valgum group. As a result, it was found that the genu valgum group had higher activity in the vastus lateralis than the vastus medialis as well as a larger knee flexion angle. This study suggests that it is more efficient for people with genu valgum to be trained through isometric contraction at 30° of knee flexion and for people with genu varum to be trained through isometric contraction at 60° of knee flexion. Ninos et al.[22)] reported that the muscle activity of the vastus medialis increases in accordance with increases in the knee flexion angle. Mariani and Caruso[23)] reported that people with patellar subluxation showed higher activity of the vastus lateralis than the vastus medialis at the end range on knee extension compared with their normal group. In the present experiment, healthy adults without patellar subluxation or knee pain were enrolled; thus, investigation of muscle imbalance by knee flexion angle is needed in people with orthopedic problems, such as patellar subluxation caused by knee malalignment. Smillie[24)] reported that the vastus medialis selectively fires in the last 10° of knee extension and that it produces the last 10° of knee extension. Duffell et al.[25)] reported that the ratio of the muscle activity of the vastus medialis to that of the vastus lateralis increased at the end of knee extension at a speed of 30°/sec for knee

extension. Although there were differences in the types of muscle contraction or knee joint angles among these studies, they indicate that the muscle activity of the vastus medialis increased as the knee flexion angle decreased; thus, the results were similar to those of the present study.

There were significant differences in the electromyographic activity ratio of the vastus medialis to the rectus femoris during isometric contraction both at 30 and 60°. Further, the activity of the vastus medialis was higher in the genu varum group, whereas the activity of the vastus lateralis was higher in the genu valgum group. These were similar to that of the vastus lateralis.

There were no significant differences in the activity ratio of the vastus medialis to the rectus femoris by knee flexion angle in the three groups. These results agree with those of the studies of Signorile et al.[26] and Han[27], who found that there were no significant differences in quadriceps activity and knee flexion angle during isometric contraction.

The limitations of this study included the number of subjects in the genu valgum group compared with the genu varum and control groups, and the difference in general characteristics, such as the mean height and weight, between the genu valgum group and the other two groups, as the ratio of male was larger than that of females in the other two groups. However, the electromyographic activity ratio in this study was compared between the vastus medialis and vastus lateralis individually, not between individuals, so there might be no difference depending on gender. Well-controlled subjects should be used in future studies.

The results showed that the genu varum group had higher activity of the vastus medialis, whereas the genu valgum group had higher activity of the vastus lateralis. More specifically, the genu varum group had a weak vastus lateralis, whereas the genu valgum group had a weak vastus medialis. Also, the vastus medialis in the genu valgum group showed higher activity at 60° of knee flexion. Therefore, rehabilitation training programs conducted to strengthen the quadriceps should consider the knee alignment conditions of the target subjects.

In the future, studies will be needed to verify whether selective quadriceps strength training programs that consider the knee alignment conditions of the target subjects can prevent or treat pain or deformities caused by knee malalignment.

REFERENCES

1) Neumann DA: Kinesiology of the Musculoskeletal System: Foundations for rehabilitation. Elsevier Science Health Science Division, 2011.
2) Park YS: The effects of the difference of angle of the femoral anteversion on the electrical activity of the quadriceps femoris in isometric exercise. Dankook University, Dissertation of Master's Degree, 2006.
3) Heegaard J, Leyvraz PF, Van Kampen A, et al.: Influence of soft structures on patellar three-dimensional tracking. Clin Orthop Relat Res, 1994, (299): 235–243. [Medline]
4) Lee TQ, Morris G, Csintalan RP: The influence of tibial and femoral rotation on patellofemoral contact area and pressure. J Orthop Sports Phys Ther, 2003, 33: 686–693. [Medline] [CrossRef]
5) Salsich GB, Perman WH: Patellofemoral joint contact area is influenced by tibiofemoral rotation alignment in individuals who have patellofemoral pain. J Orthop Sports Phys Ther, 2007, 37: 521–528. [Medline] [CrossRef]
6) Mizuno Y, Kumagai M, Mattessich SM, et al.: Q-angle influences tibiofemoral and patellofemoral kinematics. J Orthop Res, 2001, 19: 834–840. [Medline] [CrossRef]
7) Powers CM: The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. J Orthop Sports Phys Ther, 2003, 33: 639–646. [Medline] [CrossRef]
8) Tsakoniti AE, Stoupis CA, Athanasopoulos SI: Quadriceps cross-sectional area changes in young healthy men with different magnitude of Q angle. J Appl Physiol 1985, 2008, 105: 800–804. [Medline] [CrossRef]
9) Sogabe A, Mukai N, Miyakawa S, et al.: Influence of knee alignment on quadriceps cross-sectional area. J Biomech, 2009, 42: 2313–2317. [Medline] [CrossRef]
10) Reilly DT, Martens M: Experimental analysis of the quadriceps muscle force and patello-femoral joint reaction force for various activities. Acta Orthop Scand, 1972, 43: 126–137. [Medline] [CrossRef]
11) Park SK, Kim JH: Effects of EMG-biofeedback training on total knee replacement patients' lower extremity muscle activity and balance. J Korean Soc Phys Ther, 2013, 25: 81–87.
12) Kim DY, Kim SH, Lim YE, et al.: Effect of EMG biofeedback training and taping on vastus medialis oblique for function improvement of patient with patella malalignment. J Korean Soc Phys Ther, 2008, 20: 35–44.
13) Jang JH, Kim KH, Kim TH, et al.: The effects of foot and knee position on electromyographic activity of the vastus medialis and vastus lateralis for hemiplegic patients. J Korean Soc Phys Ther, 2010, 22: 21–28.
14) Hyong IH, Kang JH: Activities of the vastus lateralis and vastus medialis oblique muscles during squats on different surfaces. J Phys Ther Sci, 2013, 25: 915–917. [Medline] [CrossRef]
15) Jang EM, Heo HJ, Kim MH, et al.: Activation of VMO and VL in squat exercises for women with different hip adduction loads. J Phys Ther Sci, 2013, 25: 257–258. [CrossRef]
16) Kim MH, Yoo WG: Effects of various foot wedge boards on vastus medialis oblique and vastus lateralis muscles during lunge exercise. J Phys Ther Sci, 2013, 25: 233–234. [CrossRef]
17) Cowan SM, Bennell KL, Hodges PW, et al.: Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Arch Phys Med Rehabil, 2001, 82: 183–189. [Medline] [CrossRef]
18) Kim HH: The effect of patellar taping on the EMG activity of the vastus medialis oblique and vastus lateralis during stair stepping. J Muscle Jt Health, 2011, 18: 249–256. [CrossRef]
19) Gollnick PD, Parsons D, Riedy M, et al.: Fiber number and size in overloaded chicken anterior latissimus dorsi muscle. J Appl Physiol, 1983, 54: 1292–1297. [Medline]
20) Souza DR, Gross MT: Comparison of vastus medialis obliquus: vastus lateralis muscle integrated electromyographic ratios between healthy subjects and patients with patellofemoral pain. Phys Ther, 1991, 71: 310–316, discussion 317–320. [Medline]
21) Yip SL, Ng GY: Biofeedback supplementation to physiotherapy exercise programme for rehabilitation of patellofemoral pain syndrome: a randomized controlled pilot study. Clin Rehabil, 2006, 20: 1050–1057. [Medline] [CrossRef]
22) Ninos JC, Irrgang JJ, Burdett R, et al.: Electromyographic analysis of the squat performed in self-selected lower extremity neutral rotation and 30 degrees of lower extremity turn-out from the self-selected neutral position. J Orthop Sports Phys Ther, 1997, 25: 307–315. [Medline] [CrossRef]
23) Mariani PP, Caruso I: An electromyographic investigation of subluxation of the patella. J Bone Joint Surg Br, 1979, 61-B: 169–171. [Medline]
24) Smillie IS: Injuries of the Knee Joint. Baltimore: Williams and Wilkins, 1962.
25) Duffell LD, Dharni H, Strutton PH, et al.: Electromyographic activity of the quadriceps components during the final degrees of knee extension. J Back Musculoskeletal Rehabil, 2011, 24: 215–223. [Medline]
26) Signorile JF, Kacsik D, Perry A, et al.: The effect of knee and foot position on the electromyographical activity of the superficial quadriceps. J Orthop Sports Phys Ther, 1995, 22: 2–9. [Medline] [CrossRef]
27) Han SW: A SEMG analysis of knee joint angle during close kinetic chain exercise and open kinetic chain exercises in quadriceps muscle. J Korean Soc Phys Ther, 2004, 16: 401–411.