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Original Article

Does the relative muscle activation of the vastus medialis, rectus femoris, and vastus lateralis, during the various activities, change in relation to the quadriceps angle?

Nakyung Lee, MS, DPT[1)]

[1)] *Department of Physical Therapy, College of Medical Science, Konyang University: Medical Science B/D, Gwanjeodong-ro 158, Seo-gu, Daejeon-city 35365, Republic of Korea*

Abstract. [Purpose] The purpose of this study was to examine the correlation between the quadriceps angle and muscle-activation ratios for the vastus medialis, rectus femoris, and vastus lateralis during various activities. [Subjects and Methods] Seventeen heathy females were recruited. The quadriceps angles were measured with long-arm goniometers. The muscle activity of the vastus medialis, rectus femoris, and vastus lateralis were measured using electromyography under four different activity settings: walking, squatting, step-up, and sit-to-stand. The muscle activation ratios were calculated and their correlations with the quadriceps angles were analyzed. [Results] The activation ratio of the rectus femoris to the vastus medialis (and, although less significant, of the vastus lateralis to the vastus medialis) was positively correlated with the quadriceps angle during the step-up and sit-to-stand. A similar tendency was also seen during squatting. The activation ratio of the vastus lateralis to the rectus femoris was negatively correlated with the quadriceps angle during walking. [Conclusion] The relative muscle activity among the muscles composing the quadriceps was correlated with the quadriceps angle. During activities involving deeper knee flexion like the step-up, sit-to-stand, and squatting, the relative activity of the lateral muscles tended to increase as the quadriceps angle increased. Meanwhile, during walking the activity of the medial muscles seemed to increase with a larger quadriceps angle.

Key words: Quadriceps angle, Muscle activation ratio, Electromyography

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INTRODUCTION

Various mechanisms have been considered to cause patellofemoral pain syndrome (PFPS)[1–4]. One of them is a mechanical dysfunction caused by a larger quadriceps angle. As the quadriceps angle becomes larger, and the laterally directed force of the quadriceps muscles acting on the patella becomes greater, lateral tracking of the patella occurs[5, 6]. That is, as the patella tracks up and down with the knee joint movement, the patella laterally glides into the elevated lateral facet of the trochlear groove, which eventually inflames the patella giving rise to pain in the anterior knee[5, 6]. The structural and functional factors considered to increase the quadriceps angles include a wider pelvis, internal rotation of the hip, foot malalignment, weak hip muscles, and a weak vastus medialis (VM) compared to the vastus lateralis (VL)[2, 7]. Strengthening the VM, the musculature located more medially in the quadriceps, was suggested and widely used as a treatment of PFPS[8]. Simultaneously, strengthening the hip external rotators has also been frequently targeted more recently[7].

However, although an increased quadriceps angle is considered to increase lateral force to the patella, it does not necessarily increase the actual lateral force applied to the patella during the activities. That is because multiple factors determine

Corresponding author: Nakyung Lee (E-mail: wmcg_nkl@konyang.ac.kr)

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the eventual lateral force, such as muscle size, muscle morphology including pennate angle, motor control, other mechanical relationships, and muscle activation[3, 9–13]. Moreover, skeletal and muscular mechanisms are not totally independent, but sometimes influence each other making the mechanism more complicated. In addition, different movements or activities have different skeletal, muscular and joint dynamics, and the influences on the patellofemoral kinetics will be varied.

Alteration of the alignment on the sagittal plane, such as flexed knee posture by contracture, is associated with change in activities of the anterior or posterior muscles of the lower limbs[14]. I hypothesized that such association between skeletal alignment and activities of the muscles would exist on the frontal plane as well. That is, the variation in the alignment on the frontal plane from more valgum (with increased quadriceps angle) to more varum (with decreased quadriceps angle) would change the activities of the patellofemoral muscles including the medial VM, mid-located rectus femoris (RF), and the lateral VL. Any relative muscle activation changes of these muscles will influence the balance between medially-directed force and laterally-directed force to the patella, and may lead to different patellofemoral kinetics. This study aimed to investigate whether the increase of the quadriceps angle was correlated with the relative muscle activation of the individual muscles that compose the quadriceps during various activities involving the lower extremities. The study focused on understanding greater details on the mechanisms involved in patellofemoral kinetics and the causes of the patellofemoral pain (PFP).

SUBJECTS AND METHODS

Seventeen healthy female adults participated in this study. In accordance with the ethical principles of the Declaration of Helsinki, all participants were explained about the study including the purpose and signed the informed consent. The exclusion criteria were any fractures or surgeries in the lower limbs in the prior 12 months and any neurological medical history. The general characteristics of the subjects are shown in Table 1.

The quadriceps angles were measured using a long-arm handheld goniometer (Baseline, Fabrication, USA). The angle between the two lines, one from the anterior superior iliac spine to the center of the patella, the other from the center of the patella to the tibial tuberosity, was measured in the subject's standing position. The VM, RF, and VL muscle activities were measured using surface electromyography (EMG) (TeleMyo DTS, Noraxon Inc., USA) with data acquisition/analysis system (MyoResearch XP Master Edition 1.08.17). The EMG signals were sampled at a rate of 1,000 Hz, and were filtered in the bandwidth of 20–45 Hz. The EMG signals of the VM, RF, and VL muscles were measured during 4 movement activities: (1) walking, (2) squatting, (3) stepping-up, and (4) sit-to-stand. During walking activities, signals were recorded while the subjects walked at their normal speed. During squatting, a subject maintained the squat position for 5 seconds with the knee flexed to 45 degrees. During stepping-up, the subject stepped onto a 120 mm-high step. Before sit-to-stand, the subject sat in the front part of a chair to eliminate the need for preparatory activity for standing from the sitting position. Foot switches were used to record periods and phases of during walking and stepping-up. Data from a single stride interval from the heel contact to the next heel contact of one side of the leg was selected for analysis in walking. The single leg stance phase of the measuring leg (=the swing phase of the other leg) was chosen as the interval to be analyzed for stepping-up. In sit-to-stand, the interval between the starting point of signal rise to the starting point of signal plateau was taken. Raw EMG data were full-wave rectified and root mean squared (RMS). To normalize the EMG signals, maximum voluntary isometric contractions (MVIC) were obtained using isokinetic extremity system (HUMAC NORM., CSMI, USA) while subjects performed a 5-second maximum isometric knee contraction at 30° flexion. All RMS values obtained from the above experimental procedure were normalized to the MVIC data. All measurements were taken three times and the three results were averaged. The RF/VM, VL/VM, VL/RF muscle activation ratios for each movement were calculated based on the measured EMG values among each muscle pair.

The relationship between the quadriceps angle and the muscle activation ratio was analyzed using a Pearson's correlation coefficient with SPSS (version 18.0, SPSS Inc., Chicago, IL, USA). The level of statistical significance was set at $\alpha=0.05$.

RESULTS

In the step-up, and sit-to-stand movements, the quadriceps angle showed moderately positive correlation with RF/VM ($p=0.005$, $p=0.008$ for each) and presented, at close to the statistically significant level, moderately positive correlation with VL/VM ($p=0.062$, $p=0.058$ for each) (Table 2). In squatting, although the result was a little under the set standard of statistical significance, a similarly correlated tendency was observed ($p=0.071$ with RF/VM, $p=0.144$ with VL/VM) (Table 2).

In walking, the quadriceps angle had moderate negative correlation with VL/RF ($p=0.027$) (Table 2).

DISCUSSION

This study confirmed significant correlations between the quadriceps angle and the relative muscle activations among the quadriceps muscles. One of the prominent features of these correlations shown from the results of this study is that the correlations are activity-dependent. Different trends were shown quite clearly, depending on the activity being performed. With the step-up, sit-to-stand, or squatting activities, the results showed that the activation of the lateral RF relative to the medial VM increased as the quadriceps angle increased, and the lateral VL's activation ratio became greater than that of the

Table 1. General characteristics of the subjects (N=17)

	Mean ± SD
Age (years)	19.4 ± 1.2
Height (cm)	161.2 ± 3.9
Weight (kg)	54.1 ± 6
Body Mass Index (kg/m^2)	20.8 ± 1.9

Table 2. Correlation(r) between the quadriceps angle and the muscle activation ratio

	Quadriceps angle							
	Walking		Squatting		Step-up		Sit to stand	
	r	p	r	p	r	p	r	p
RF/VM	0.303	0.237	0.449	0.071	0.648	0.005 **	0.621	0.008 **
VL/VM	−0.188	0.469	0.369	0.144	0.461	0.062	0.468	0.058
VL/RF	−0.535	0.027 *	−0.292	0.256	−0.09	0.732	−0.235	0.363

*p<0.05, **p<0.01, VL: Vastus Lateralis; RF: Rectus Femoris; VM: Vastus Medialis.

medial VM. This indicates that in these types of activities, where greater knee flexion is required, as the quadriceps angle gets larger, a kinetical relationship becomes set to increase lateral force, and muscle activation increases in the more lateral muscles to act even more unfavorably to cause patellofemoral pain. This can partly explain why PFP is more exacerbated in activities with repetitive deep knee flexion, and the results of this study indicates that the population with larger quadriceps angles may be more sensitive to develop PFP when completing these kinds of activities. On the contrary, when the activity was walking, between the VL and RF, the ratio of the medially located RF's activation becomes greater than the lateral VL as the quadriceps angle increased. Additionally, in walking, the activation ratio of VL/VM gained more VM activation with a larger quadriceps angle, although it was far from statistical significance (Table 2). Walking does seem to induce relatively more medial muscle activation. This will compensate the unfavorable effect of the larger quadriceps angle for patellofemoral kinetics, and thus, will decrease PFP development. Controversial results and studies on whether larger quadriceps angle is more generative of PFP exist probably and partly for this reason[15–17]. Kim et al.[18] reported in their study where they investigated the correlation between the hip-knee-ankle (HKA) angle and activation the muscles composing quadriceps that, the greater the HKA angle, the more medial muscle's activation ratio increased in ambulation, which is similar to the findings of this study.

VMO strengthening training as an effective treatment for PFP is supported by this study, especially for women with larger quadriceps angles whose activities involve many squats, steps, and sit-to-stand movement, as it can promote use of the medial quadriceps opposed to the natural tendency to use the lateral quadriceps in these cases.

In this study, only females, whose quadriceps angles were generally larger than those of males and were more prone to have PFP, were recruited. It will be interesting to investigate whether these findings can be detected in males too. A future study will be needed to examine the correlation of a more expanded population including males and patients with PFP. The limitations of this study also include limited number of sample size.

To summarize, when the main activity is walking, the kinetically adverse influence of a larger quadriceps angle could be compensated by more activation of the medial musculature, but when the activities involve many squatting, step-up, and sit-to-stand movements, a larger quadriceps angle's adverse effect, which can possibly cause PFP, can be augmented due to the increase in lateral muscle's involvement in the muscle activation.

Conflict of interest

None.

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