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Alteration of Quadriceps Muscle Activity During Functional Step Tasks After Extended Sitting Session

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Ethical Approval: The study protocol was conducted according to the declaration of Helsinki and was approved by the Mahidol University Central Institutional Review Board (COA 2017/030.0202).

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ALTERATION OF QUADRICEPS MUSCLE ACTIVITY DURING FUNCTIONAL STEP TASKS AFTER EXTENDED SITTING SESSION

INTRODUCTION

The quadriceps muscle plays an important role in the working of the lower limb in daily activities, such as walking, stair climbing, and running. The quadriceps muscles group comprises the vastus lateralis (VL), vastus medialis (VM), vastus intermedius, and rectus femoris (RF) muscles and mainly controls knee flexion or extension and patellar movements [1]. Functional impairment of the quadriceps muscle is a potential contributing factor to knee pain [2]. Patellofemoral pain syndrome (PFPS) is a common source of knee pain among young adult women [3] which presents as VM muscle weakness and delayed muscle activity onset. VM and VL muscles directly attach to the patella, where VM muscle is thought to be the patella's primary active medial stabilizer, however, it is frequently overpowered by lateral forces such as the VL muscle [4,5]. Therefore, an imbalance between VM and VL may cause mal-patellar tracking [6]. Stefanik et al. found PFPS was only present with lateral patellofemoral joint damage, and this structural damage was associated with recurrent pain in PFPS [7].

Individuals with PFPS commonly report knee pain during activities involving knee flexion or extensions, such as prolonged sitting, squatting, and stair climbing [8]. This may be due to high degrees of hip and knee flexion during prolonged sitting, which causes compressive loading at the patellofemoral joint [8,9]. One muscle activation strategy to reduce patellofemoral compression is to increase VL muscle activity [10]. Compared with healthy individuals, individuals with PFPS may demonstrate reduced compressive force

of the patellofemoral joint during stair ambulation [11]. During stair ascent and descent, people with PFPS had lower knee extension moments, quadriceps forces, and patellofemoral joint reaction force than healthy controls [12,13]. Moreover, Wilson et al showed gluteus muscle activity increased in female with PFPS during stair ambulation [14].

Prolonged sitting with high knee flexion is a common activity of daily living and is performed in various postures and knee flexion positions, which may affect patellofemoral joint compression and quadriceps muscle length [15]. Cross-legged sitting is the most common sitting position on the ground [16]. Immediate reductions in quadriceps muscle force and EMG activity are commonly observed after static stretching [17], which greatly affects patellar movement [18] and dynamic stability during stair ambulation [19], during which patellofemoral joint forces reach 3.3 times the force of an individual's body weight [20]. Prolonged sitting with high knee flexion may therefore contribute to the development of PFPS. Sitting with high knee flexion and deep squats can facilitate knee pain and, therefore, should be avoided in an individual's daily routine. Exploring the activation of quadriceps muscles following prolonged sitting with high knee flexion is interesting, as it may help to explain the mechanism of changes in the VM and VL muscles after sitting, as a result of which, PFPS may develop.

Several studies have evaluated the onset time, muscle activity duration, and quadriceps contraction ratio to determine dynamic stability during stair ambulation [10,19,21]. However, only few studies have elucidated the mechanism underlying the effect of prolonged sitting on the quadriceps muscle in a healthy population. Therefore, the present study aimed to investigate quadriceps activity during performing challenge task which was step-up and -down tests after prolonged periods of sitting in various

positions: cross-legged sitting, side-sitting, and sitting on a chair without back support. The findings of the present study could be implied in similar activities, such as stair ambulation and squatting which require high knee flexion with weight bearing. This would guide clinicians on how the quadriceps muscle changes after prolonged sitting and can help develop preventive strategies for knee pain. Therefore, improving one's understanding regarding the effect of prolonged sitting in different positions on the EMG activity of the quadriceps muscle during stair ambulation is important.

MATERIALS AND METHODS

Participants

Thirty healthy females voluntarily participated in the present study and were randomly allocated into three groups: cross-legged sitting (n=10), side-sitting (n=10), and sitting on a chair (n=10) (Figure 1). Side and cross-legged sitting are common postures on the floor in daily living, while a high knee flexion posture is sustained. Sitting on a chair without back support is a common activity that causes knee flexion of approximately 90°, which was used for the control group in this study. The participants were aged 18-24 years old, had no knee pain, and had no histories of severe injury or surgery in their lower extremities. All participants were right leg dominant, which was determined by asking them which leg they would use to kick a ball for a long distance?' [22]. Participants were excluded if they had flat feet, leg length discrepancies >2 cm [23], and Q-angles >20° [24]. The researcher explained the study protocol to all study participants, after which they signed a consent form. The study protocol was conducted according to the

declaration of Helsinki and was approved by the XXX University Central Institutional Review Board (COA 2017/XXX.XXXX).

Quadriceps muscle activity was assessed during step-up and step-down tasks, which included the RF, VM, and VL of the dominant side. Surface EMG was conducted using Trigno Avanti Delsys wireless sensors (Delsys Inc., USA) with a 2,000 Hz sampling rate. Before EMG sensors were placed, the skin was shaved and cleaned with alcohol to reduce skin impedance. Electrode placement was determined based on the European Recommendation for Surface Electromyography guidelines [25].

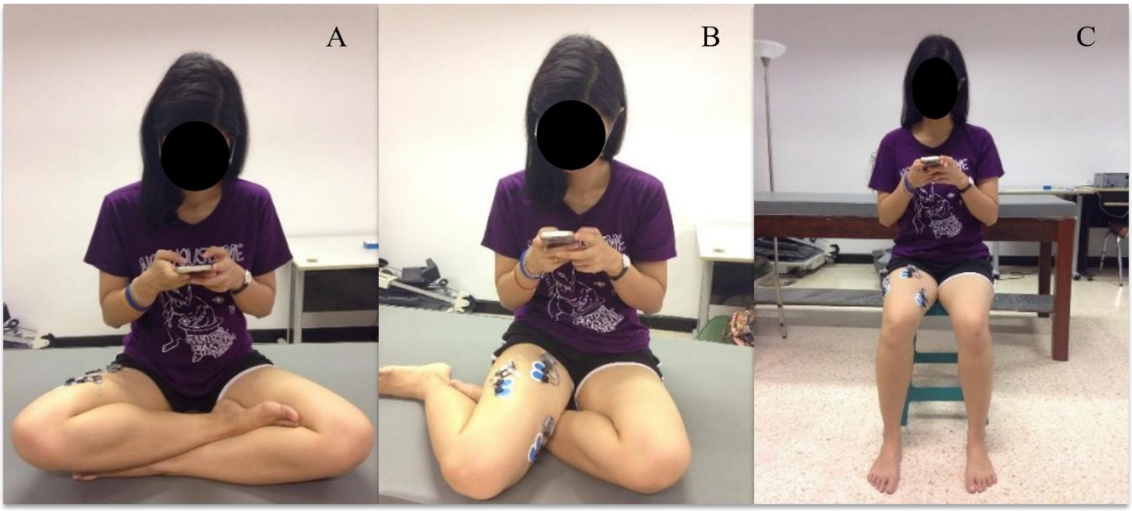

Figure 1. Prolonged sitting position. A, cross-legged sitting; B, side-sitting; C, sitting on a chair

Procedures

Participants were asked to perform three tests, which comprised stepping up and down randomly from a 20 cm-high box with the dominant leg. This height was selected based on the standard height of a stair step. Resting between step trials and step sessions

was allowed for 30 and 60 s, respectively, to prevent muscle fatigue. EMG data were recorded from three trials as baseline data.

Participants were asked to sit and maintain lower limb postures according to the assigned posture for 15 min without any hand support. In conditions of side-sitting and cross-legged sitting, all participants were asked to sit with the right-leg on top (Figure 1). Playing cell phone was allowed during 15 min test to avoid hand support. After 15 min of sitting, participants were examined immediately to collect EMG data during the step-up and -down tasks after prolonged sitting.

Maximum voluntary isometric contraction (MVIC) was assessed and used to normalize EMG data for comparing between the sitting groups. Participants were asked to perform maximum quadriceps isometric contraction tests at 60° knee flexion [26] using a Biodex machine (Biodex Inc., USA). The average EMG in the present study was presented in terms of MVIC (%MVIC) [27,28].

Data acquisition

All EMG data analyses were performed using Delsys EMGworks® software (Delsys Inc., USA). Raw EMG signals from VM, VL, and RF muscles were filtered at 20-450 Hz using a second-order band-pass Butterworth filter, after which full-wave rectification was performed [29].

During the step-up and step-down tasks, an average of 100 ms of EMG amplitude of each muscle was selected from 50 ms before and after the peak value time event (Figure 2). The average EMG during step-up and step-down tasks was reported as %MVIC. Muscle activity of the VM, VL, and RF muscles was compared before and after prolonged sitting and within the sitting groups and compared among the three types of postures.

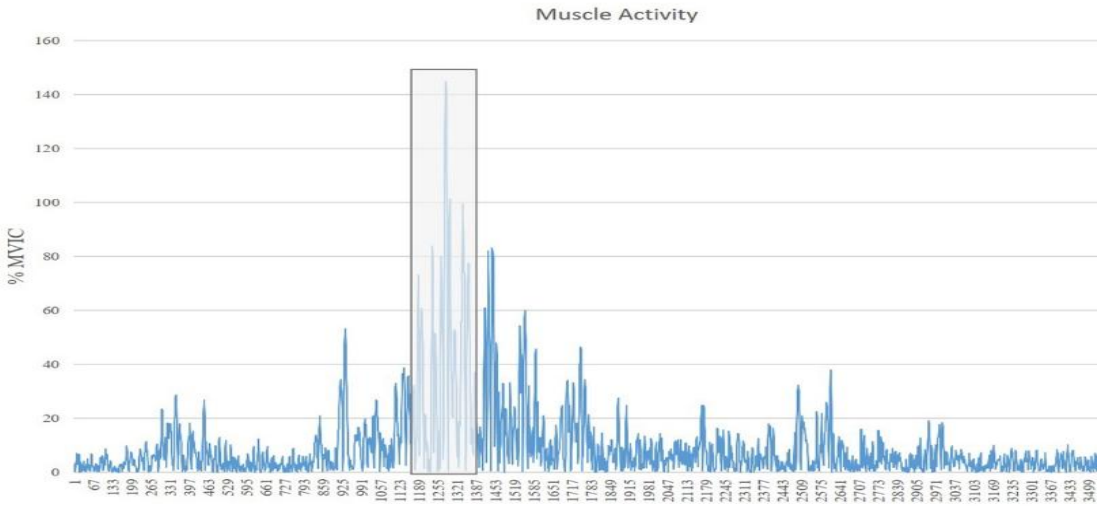

Figure 1. An example of EMG selection before 50 ms and after 50 ms to peak EMG amplitude during step-up task

Statistical analysis

Participant characteristics (age, height, weight, and Q angle) are reported in Table.1. EMG data with non-normal distribution were assessed using the Shapiro–Wilk test and Kruskal-Wallis analysis of variance was used to analyze differences in muscle activity among the prolonged sitting group. If statistically significant values were observed, the least significant difference method was used with the significance level set at $p<0.05$. Furthermore, the Wilcoxon signed-rank test was used to compare muscle activity before and after prolonged sitting within each group. All analyses were performed using SPSS for Windows, version 23 (New York, NY, USA).

RESULTS

Thirty participants were female and right leg dominant, and their age, weight, height, and Q angle are presented in Table 1. The participants' characteristics did not differ significantly between the sitting groups. The postures used during prolonged sitting significantly affected the %MVIC of the VL (p=0.02) and VM (p=0.02), but not the RF (p=0.32) during the step-up task. In contrast, postures used during prolonged sitting did not significantly affect VL (p=0.45), RF (p=0.10), or VM activity (p=0.93) during the step-down task (Table 2). Furthermore, the cross-legged sitting position significantly affected VM (p=0.01) activity during the step-down task. However, other prolonged sitting positions did not significantly affect the activity of all the quadriceps muscles (Table 2).

Table 1. Characteristics of participants in three groups classified according to sitting styles (mean (SD))

Characteristics	Cross-legged sitting (n=10)	Side-sitting (n=10)	Sitting on chair (n=10)	p-value
Age (years)	21.3 (1.8)	22.8 (1.4)	21.5 (2.0)	0.31
Weight (kg)	52.1 (4.3)	51.3 (5.1)	54.2 (4.0)	0.31
Height (m)	1.5 (0.04)	1.6 (0.05)	1.5 (0.04)	0.7
Q-Angle (degree)	18.2 (2.16)	18.2 (1.49)	17.6 (1.40)	0.43

SD: standard deviation

Table 2. Comparison of muscle activity (%MVIC) during step tests pre- and post-prolonged sitting sessions in various postures

Task	Muscle	Cross-legged sitting				P-value	Side-sitting				P-value	Sitting on a chair				P-value
		pre-sitting		post-sitting			pre-sitting		post-sitting			pre-sitting		post-sitting		
		Mean (SD)	Median	Mean (SD)	Median		Mean (SD)	Median	Mean (SD)	Median		Mean (SD)	Median	Mean (SD)	Median	
Step-up	VL	111.3 (44.8)	102.5	121.7 (46.9)	117.0	0.16	113.7 (47.7)	101.9	121.0 (49.4)	129.1	0.89	67.7 (11.3)	65.5	69.4 (12.4)	68.8	0.67
	RF	67.9 (33.0)	59.0	80.6 (45.3)	64.1	0.16	74,6 (30.2)	79.3	87.1 (35.8)	97.0	0.06	56.3 (19.8)	51.7	56.0 (26.5)	49.2	0.78

	VM	115.8 (66.0)	102.2	128.1 (71.4)	115.8	0.32	119.3 (49.1)	124.5	146.0 (90.2)	115.1	0.48	94.0 (42.9)	79.9	91.0 (33.6)	78.2	0.78
Step-down	VL	78.8 (27.8)	77.6	82.5 (23.3)	86.0	0.48	70.6 (26.2)	69.5	68.3 (21.6)	76.8	0.89	42.0 (11.4)	39.2	37.3 (10.7)	38.1	0.89
	RF	63.0 (22.51)	60.8	58.2 (17.3)	59.6	0.40	47.6 (22.4)	39.7	48.7 (22.3)	41.4	0.40	30.9 (9.2)	28.9	28.3 (8.4)	27.0	0.67
	VM	75.4 (23.4)	80.5	88.1 (28.1)	89.7	0.01*	89.3 (41.3)	76.0	79.5 (35.8)	79.8	0.26	49.5 (22.7)	46.7	44.6 (17.0)	43.1	0.40

* Significant difference: $p<0.05$
SD, standard deviation; VL, vastus lateralis; RF, rectus femoris; VM, vastus medialis

Table 3. Comparison of muscle activity changes (%MVIC) during step tests after extended sitting sessions among three groups

Task	Muscle	Cross-legged sitting		Side-sitting		Sitting on a chair		P-value
		mean (SD)	median	mean (SD)	median	mean (SD)	median	
Step-up	VL	9.2 (22.3)[a]	14.8	-5.8 (24.5)	-3.4	1.3 (7.6)	0.4	0.02*
	RF	11.3 (21.7)	9.4	0.8 (16.7)	1.0	-0,3 (10.3)	1.6	0.32
	VM	10.9 (26.0)[a]	12.2	-7.8 (19.3)	-8.5	-2.4 (11.6)	0.7	0.02*
Step-down	VL	3.3 (18.2)	7.5	1.3 (16.2)	0.5	-3.6 (15.5)	0.7	0.45
	RF	-4.2 (14.3)	-1.7	-0.3 (11.2)	2.1	-2.0 (8.9)	-0.9	0.10
	VM	11.2 (13.3)	7.3	-2.3 (11.5)	-2.6	-3.8 (24.8)	3.1	0.93

* Significant difference: $p<0.05$
[a] Significant difference compared with the 'sitting on chair' group
SD, standard deviation; VL, vastus lateralis; RF, rectus femoris; VM, vastus medialis

Cross-legged sitting tended to increase muscle activity of all the quadriceps muscles during the step-up task, whereas VL and VM activity decreased slightly after participants sat in the side-sitting posture, and sitting on the chair did not affect the muscle activity of the quadriceps (Figure 3). However, VL, RF, and VM muscle activity did not differ significantly during the step-up task after prolonged sitting in various positions (Table 3).

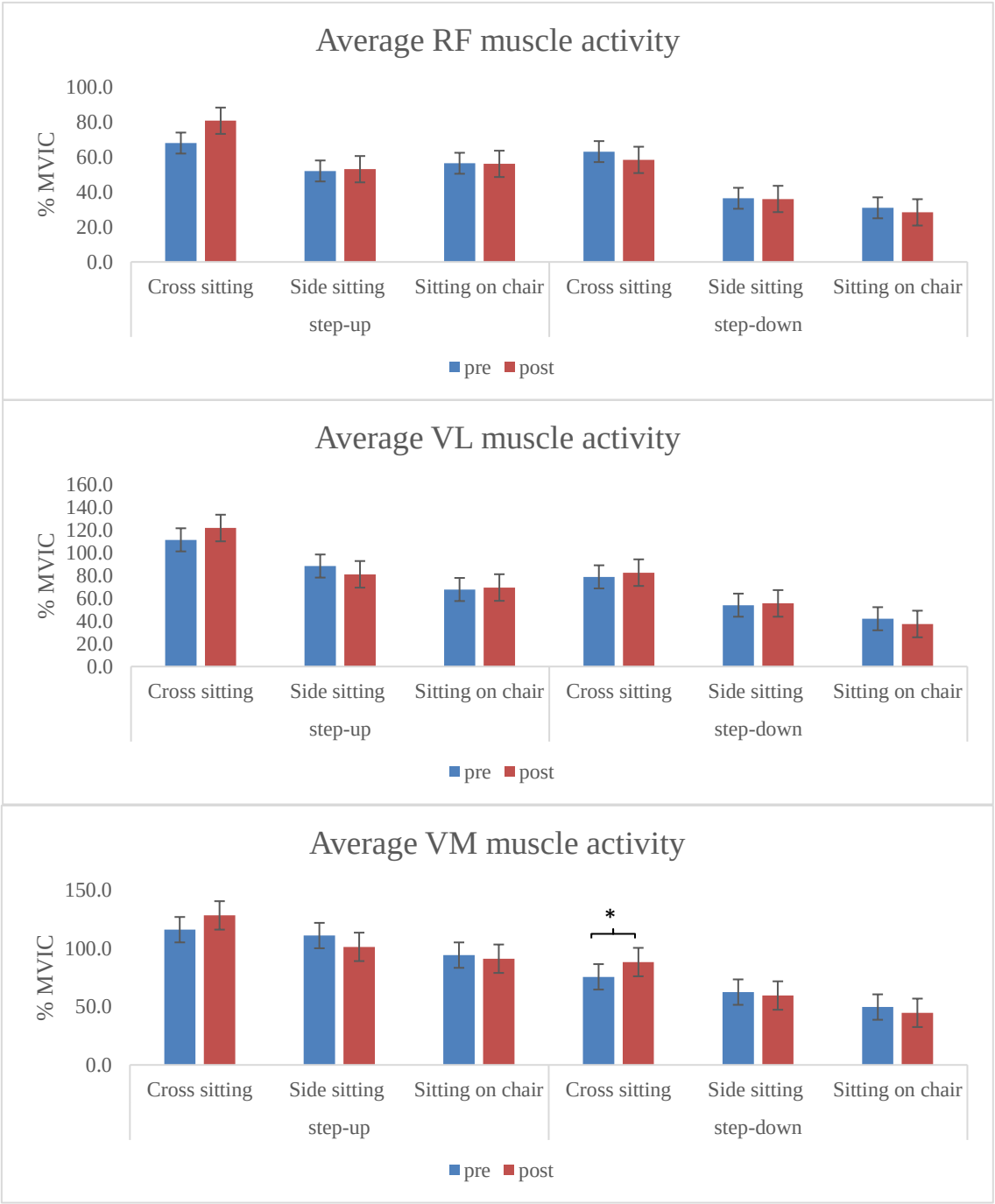

Figure 3. Comparison of muscle activity pre and post prolonged sitting during step-up and stepd-down tasks

DISCUSSION

Prolonged sitting is a common activity of daily life and is performed in various postures with different knee flexion positions that could affect quadriceps muscle function [15]. Cross-legged sitting is the most common sitting position on the ground, especially in Asian countries [16,30]. Therefore, this study evaluated the activity of the quadriceps muscle using EMG after a prolonged period of sitting in various positions (cross-legged sitting, side-sitting, and sitting on a chair without back support). The study findings showed that the EMG activity of the VM muscles increased significantly (p=0.01) during the step-down test after prolonged sitting in the cross-legged sitting group (Table 2). Differences in sitting positions between the groups significantly influenced (p=0.02) the VL and VM activity during the step-up test. A significant difference was noted in the pairwise comparison between the 'cross-legged sitting' and 'sitting on a chair' groups (Table 3).

No significant differences were noted in participants' characteristics between the three groups (Table 1). After 15 min of prolonged sitting, muscle activation in the cross-legged sitting and side-sitting groups demonstrated an increasing trend of VM, VL, and RF activity during the step-up test compared with that noted in the 'sitting on a chair' group. Muscle control of VM, VL, and RF appears to be similar during the step-up test before and after prolonged sitting on a chair. During the step-down task, significantly higher activation of the VM muscle was noted in the 'cross-legged sitting' group (Figure 3). Different muscle functions could be attributed to differences in knee flexion and tibial rotation between the groups. A previous study demonstrated that immediate reductions in the quadriceps muscle force and EMG activity were observed after static stretching [17]. In contrast, the VM and VL in the present study exhibited an increased EMG activity.

Differences in time, hip posture, and tibial rotation may have caused variations in tissue structure lengthening between the present and previous studies [17,18]. The VL exhibits greater muscle activity than the VM during isometric knee extension with medial tibial rotation [31]. Cross-legged sitting required high knee flexion and femur- and tibial rotation. However, no significant differences were noted in VL, RF, and VM muscle activity during the step-up task. The results of the present study indicate that VM muscle activity significantly increases during the step-down task. Increased muscle activity is associated with increased joint stiffness during eccentric contraction to reduce patellofemoral pressure [32]. This suggests that some changes in quadriceps muscle activation strategies occur during the step-down task after prolonged sitting. Moreover, reduced VL muscle activity indicates reduced control over the patellofemoral joint, which is associated with medial-lateral misalignment and frontal plane deviation [33]. However, this difference was not significant in the present study. A possible explanation for the significant difference between ascending and descending step was the characteristics of quadriceps muscle contraction. Quadriceps contracts concentrically and eccentrically during step-up and step down respectively. Pincivero et al [34] demonstrated increasing quadriceps muscle EMG in concentric phase, and decrease in eccentric during dynamic leg press exercise. Moreover, the %MVIC of the concentric phase is higher than eccentric during step task [35].

1 Different sitting postures significantly affected changes in VM and VL activation during the step-up task. A significant increase in VM and VL activation was observed in the cross-legged sitting group compared with that in the ‘sitting on a chair’ group. Differing degrees of knee flexion in a prolonged sitting position can affect muscle length

tension of the quadriceps muscles [8]. Mechanical factors affecting the muscle length tension relationship may reduce the contractile capacity of the muscle to produce force and affect motor unit recruitment [17]. Increasing the number of active motor units might be another response to perform the same task effectively after prolonged sitting. Prolonged sitting with different knee flexion magnitudes and femur rotations may also affect the VM and VL muscles, as shown in the present study. Rotations of the tibia and femur knee flexion position can affect the VL and VM [21]. Knee flexion with internal rotation of the femur was observed during side-sitting, whereas higher knee flexion with external rotation of the femur was noted during cross-legged sitting.

The present study demonstrated that 15 min of sitting in the cross- and side-sitting positions affected VL and VM control during step tests. Increased VM and VL activation possibly controls the patellofemoral joint. Therefore, the VM and VL muscles may become more easily fatigued when performing many step tasks or squatting exercises after prolonged cross-legged sitting, which might contribute to the development of PFPS. Therefore, individuals with knee pain should avoid cross-legged sitting. However, implications should be interpreted carefully because of the time of prolonged sitting. Individuals with PFPS should be recruited in future studies to better understand the mechanism of the role of prolonged sitting in various postures in PFPS.

Conclusions

VM and VL activity changes in healthy young women during step tasks after prolonged cross- and side-sitting. The VMs during descending controls exhibited a significantly increased activity after extended time periods of cross-legged sitting. The change in VM and VL activity after cross-legged sitting increased significantly during

the step-up task compared with that observed after sitting on chairs for extended time periods. Increased VM and VL activation may control the patellofemoral joint. The VM and VL muscles may therefore fatigue more easily when performing many step tasks or squatting exercises after prolonged cross-legged sitting, which might contribute to the development of PFPS.

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