Vastus Medialis Obliquus and Vastus Lateralis Activity in Open and Closed Kinetic Chain Exercises in Patients With Patellofemoral Pain Syndrome: An Electromyographic Study

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Objective: To evaluate the electromyographic activities of vastus medialis obliquus (VMO) and vastus lateralis (VL) muscles in open and closed kinetic chain exercises in subjects with patellofemoral pain syndrome (PFPS).

Design: Case-controlled study.

Setting: Rehabilitation science center in a tertiary medical center.

Participants: Ten patients with bilateral knee pain diagnosed with PFPS and 10 healthy volunteers.

Interventions: Subjects performed open kinetic chain exercise on an isokinetic dynamometer and closed kinetic chain exercise by squat-to-stand and stand-to-squat tasks. Surface electromyography was done for the VMO and VL muscles.

Main Outcome Measures: VMO/VL ratios were calculated after normalization of muscle activities.

Results: The VMO/VL ratios of PFPS subjects were significantly lower than were those of unimpaired subjects during knee isokinetic closed kinetic chain exercises (p = .047). However, there was no statistical difference in VMO/VL ratio between subjects with and without PFPS during closed kinetic chain exercises (p = .623). Maximum VMO/VL ratio was obtained at 60° knee flexion in closed kinetic chain exercise.

Conclusion: In closed kinetic chain exercises, more selective VMO activation can be obtained at 60° knee flexion. Maximal VMO/VL ratio was observed at this knee flexion angle, and muscle contraction intensity was also greatest.

Key Words: Electromyography; Exercise; Femur; Knee; Pain; Patella; Rehabilitation.

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PATELLOFEMORAL PAIN SYNDROME (PFPS) is a common problem that affects both the athletic and nonathletic populations.1 It is among the most common knee problems in physically active young adults.2 PFPS is defined as retropatellar or peripatellar pain, or both, that results from physical and biochemical changes in the patellofemoral joint.3 The basic origin and exact pathogenesis of PFPS are unknown, but many predisposing factors have been proposed, including acute trauma, knee ligament injury and surgery, instability, overuse, immobilization, overweight, genetic predisposition, malignment or dysfunction of the knee extensor mechanism, congenital anomalies of the patella, prolonged synovitis, recurrent hemorrhage into a joint, joint infection, and repetitive intraarticular injections of corticosteroids. In many cases, however, there are no obvious reasons for the symptoms, and there is no clear association between the severity of the symptoms and the radiologic and arthroscopic findings.2

The biomechanics of the patellofemoral joint are controlled by its static and dynamic components. The primary dynamic components are the 4 parts of the quadriceps femoris complex, with accessory input from the iliotibial band, the adductor magnus and longus, the pes anserine group, and the biceps femoris. Some theories for the origin of nontraumatic gradual onset of PFPS are: (1) neuromuscular imbalances of the vastus medialis obliquus (VMO) and the vastus lateralis (VL) muscles; (2) tightness of the lateral knee retinaculum, hamstrings, iliotibial band, and gastrocnemius; and (3) overpronation of the subtalar joint. Excessive lateral tracking of the patella in the trochlear groove of the femur is believed to be caused by the previously mentioned factors. Lateral excessive tracking of the patella is evident in many people with PFPS.1,3,4

The Q angle deserves special mention because a large Q angle is often implicated as a predisposing factor in patients with PFPS. It is defined as the angle between the quadriceps force vector and the patella-tibial tubercle axis.

However, there is no consensus about its importance, and it has not been shown to vary significantly between symptomatic and asymptomatic subjects.3

As stated earlier, PFPS has multifactorial causes. Many rehabilitation strategies have been implemented for patients with PFPS. In general, the goals of patellofemoral rehabilitation are to maximize quadriceps strength while minimizing the patellofemoral joint reaction forces and stress.5-10 Strengthening of the quadriceps mechanism is typically performed in the last 30° of knee extension, but the selectivity of this method for strengthening only the VMO is debatable. Recent works by Steinkamp et al9 indicates that the best method to strengthen the quadriceps group while incurring the least patellofemoral joint reaction force and stress is with a short arc (≤45° flexion to extension), closed kinetic chain exercise.9 Selective VMO strengthening may possibly be enhanced by hip adduction exercises, which may also give the VMO a stable origin from which to contract. Hanten and Schulthies11 showed that during
hip adduction, the electrical activity of the VMO is significantly greater than that of the VL. Therefore, hip adductor contraction, in conjunction with quadriceps sets and straight leg raises, is recommended to facilitate VMO strengthening.

This study assessed the VMO and VL concentric and eccentric contraction performances in isokinetic open kinetic chain and closed kinetic chain exercises. The open kinetic chain exercise was performed with a KIN-COM isokinetic dynamometer. The closed kinetic chain exercise was performed with squat-to-stand and stand-to-squat exercises. The raw electromyographic data for VMO and VL muscles were rectified and quantified. VMO/VL ratios were calculated after normalization of muscle activities.

METHODS

Subjects
Ten subjects (5 women, 5 men; age range, 21–32yr; mean, 25.7yr) with asymptomatic knees and 10 subjects (6 women, 4 men; age range, 19–48yr; mean, 28.2yr) with bilateral PFPS were included in the study. Asymptomatic subjects were defined as individuals with pain-free knees who had never had significant knee or lower extremity pathology or surgery.

The symptomatic subjects had no history of direct trauma to the patellofemoral joint, but had bilateral anterior knee pain for a minimum of 6 weeks. The pain was elicited by squatting, stair climbing, kneeling, and prolonged sitting. Patients with concomitant ligamentous injury were excluded. Examinations of the knees with merchant’s views confirmed patellofemoral malalignment. The symptomatic group was diagnosed and examined by the same physiatrist (SFTT).

Procedures
Subjects performed all tasks under instructions from an engineer at the Rehabilitation Science & Engineering Service Center of Chang Gung Memorial Hospital, Taiwan. Informed consent was obtained from all subjects before they entered the study.

To prepare the area for attachment of surface electromyographic electrodes, the anterior thigh and medial tibial crest were cleaned with isopropyl alcohol. Surface electrodes were centered on the muscle bellies of the VMO and distal VL, as described by Basmajian and Blumenstein. A MyoSystem 200 was used to acquire electromyographic signals from 9 channels, of which 8 signals were from the surface electrodes placed on the lower limbs. The last channel was used as an event marker. The raw electromyographic signals were band-pass filtered (15–500Hz) and sampled at 1000Hz. The signals were rectified and low-pass filtered (cutoff frequency, 6Hz). This system used bipolar gold-plated surface electrodes to collect electromyographic signals.

Both legs of subjects in the symptomatic group were tested. Because there is no evidence of a relation between unilateral patellofemoral dysfunction and leg dominance, we tested randomly chosen legs of the asymptomatic subjects. Every subject in both groups was tested under 2 exercise modes, the open kinetic chain and the closed kinetic chain.

In the isokinetic open kinetic chain exercise, a KIN-COM isokinetic dynamometer was used. The testing procedure began with a 5-minute warm-up on a stationary bicycle, followed by stretching of the quadriceps, hamstrings, iliotibial band, and calf musculatures. Subjects’ positioning on the dynamometer was according to the manufacturer’s protocol, with the the back supported and the hip flexed to approximately 80°. Trunk and thigh straps were fastened for stabilization. Quadriceps concentric and eccentric contractions were recorded at between 0° and 90° of knee flexion. All the tests were done at the angular velocity of 120°/s. Both legs of symptomatic subjects were tested, with the order of testing chosen randomly. After testing there was a 5-minute cool-down period, after which ice was applied for 10 minutes to the examined knees.

In the closed kinetic chain exercise, stand-to-squat, and squat-to-stand tasks were repeated twice in our gait laboratory with a Vicon 370 motion analysis system with 6 cameras containing infrared light-emitting diodes. Reflective markers were placed on the sacrum, bilateral anterosuperior iliac spines, greater trochanters, anterior thighs, medial and lateral malleoli, anterior tibia, dorsum of the foot, fifth metatarsal heads, and posterior heels. Motion analysis of the lower extremity was then determined for the sagittal plane. The trunk was kept upright and, to obtain better balance control, the subjects were asked to hold the 2 arms of a walker (fig 1). Quadriceps eccentric contraction intensity was recorded during squatting, whereas quadriceps concentric contraction intensity was recorded during squatting-to-standing tasks. The contraction intensities were recorded by surface polyelectromyography. Subjects performed all the tasks at a speed comfortable to them.
In the normalization process of muscle activity, subjects were positioned at the dynamometer. Maximum voluntary isometric contraction of the quadriceps was performed from 90° knee flexion to complete full knee extension at 15° intervals, and the electromyographic activities of the VMO and VL were recorded. Each maximum contraction was done for 5 seconds. In the PFPS group, we found that when knee flexion angle increased, knee pain became more obvious, and there was less quadriceps isometric contraction intensity. The quadriceps isometric contraction activities were similar in both groups during complete knee extension. Therefore, the maximum quadriceps isometric contraction data obtained during complete knee extension was used as the reference value.

Normalized VMO and VL electromyographic data obtained in both exercise modes were presented as the VMO/VL ratio. A ratio greater than 1 meant that the VMO was exerting a larger muscular contractile intensity than was the VL. In both exercise modes, electromyographic data were obtained at 15° intervals (15°, 30°, 45°, 60°, 75°, 90°). During knee flexion from 0° to 90°, 6 electromyographic data points could be obtained for quadriceps eccentric contractions. The same data acquisition applied for quadriceps concentric contractions. Six electromyographic data points could be obtained during knee extension from −90° to 0°.

Statistical Analysis
In the symptomatic group, the mean VMO/VL ratio for each subject was calculated by averaging the VMO/VL ratio of both legs. SYSTAT software and repeat-measures analysis of variance were used to analyze the VMO/VL ratios between asymptomatic and symptomatic subjects in both exercise modes. Statistical significance was set at \( p < 0.05 \).

RESULTS
In the open kinetic chain exercise with the dynamometer, we observed a VMO/VL ratio greater than 1 during eccentric contractions at 75° (1.083 ± 0.582) and 90° (1.105 ± .695) of knee flexion in the PFPS symptomatic group. In the asymptomatic group, VMO/VL ratio was greater than 1 during eccentric contractions at 60° (1.030 ± .380), 75° (1.138 ± .551), and 90° (1.259 ± .916) of knee flexion (table 1, fig 2). When the entire symptomatic group, which includes concentric and eccentric contractions in all angles, was compared with the asymptomatic group, we found that VMO/VL ratios were smaller in the PFPS symptomatic group (\( p = .047 \)). When the concentric contractions in both groups were compared with eccentric contractions, the contractile intensity was smaller for concentric contraction forces (\( p = .015 \)).

In the closed kinetic chain exercise during stand-to-squat and squat-to-stand tasks, VMO/VL ratios greater than 1 were observed during concentric contractions at 60° (1.052 ± .430) and 90° (1.025 ± .204) of knee flexion for the PFPS symptomatic group. Eccentric contraction with VMO/VL ratio greater than 1 was noted during 60° (1.153 ± .299) and 75° (1.054 ± .298) of knee flexion for the same group. In the asymptomatic group, VMO/VL ratio greater than 1 was observed only for eccentric contraction during 60° of knee flexion (1.080 ± .233) (table 2, fig 3). As in the open kinetic chain exercise, we compared VMO/VL ratios in both groups; however, no statistical significance was found, nor was there statistical significance when concentric and eccentric contractions from both groups were compared.

DISCUSSION
PFPS is frequently encountered in physically active young adults and in sports injury clinics. The causes for this syndrome remain enigmatic.\(^{13}\) Witvrouw et al\(^{14}\) proposed that a shortened quadriceps muscle, an altered VMO muscle reflex response time, a decreased explosive strength, and a hypermobile patella had a significant correlation with the incidence of patellofemoral pain and are risk factors for PFPS. Predisposing factors such as repetitive loading of the patellofemoral joint, trauma, congenital anomalies, and malalignment of the patella are also believed to cause PFPS.\(^{1,2}\)

### Table 1: VMO/VL Ratio of Quadriceps Muscle Contraction in KIM- COM Open Chain Isokinetic Exercises

<table>
<thead>
<tr>
<th>Knee Flexion (deg)</th>
<th>PFPS Symptomatic Subjects</th>
<th>Normal Asymptomatic Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concentric Contraction(^*)</td>
<td>Eccentric Contraction(\dagger)</td>
</tr>
<tr>
<td>15°</td>
<td>.803 ± .149</td>
<td>.862 ± .177</td>
</tr>
<tr>
<td>30°</td>
<td>.832 ± .160</td>
<td>.875 ± .173</td>
</tr>
<tr>
<td>45°</td>
<td>.877 ± .145</td>
<td>.897 ± .188</td>
</tr>
<tr>
<td>60°</td>
<td>.822 ± .142</td>
<td>.916 ± .234</td>
</tr>
<tr>
<td>75°</td>
<td>.851 ± .203</td>
<td>1.083 ± .582</td>
</tr>
<tr>
<td>90°</td>
<td>.831 ± .255</td>
<td>1.105 ± .695</td>
</tr>
</tbody>
</table>

\( * p = .047 \) when comparing the entire symptomatic group, which includes concentric and eccentric contractions in all angles (\( * \) and \( \dagger \)), with the asymptomatic group (\( \dagger \) and \( \dollar \)).

\( \dagger p = .015 \) when comparing the concentric contractions in both groups (\( \dagger \) and \( \dollar \)), with the eccentric contractions in both groups (\( \dagger \) and \( \dollar \)).
Many rehabilitation strategies have been suggested for quadriceps strengthening, especially in training the VMO. Closed kinetic chain exercises, such as squatting, working with multiple joint proprioceptive reactions, and muscular cocontraction, are generally assumed to be more functional.\textsuperscript{10,15} The VMO/VL ratios in our study for squat-to-stand tasks showed no significant differences between asymptomatic and PFPS subjects. This may explain why similar firing patterns of the VMO and VL muscles in both groups were generated during closed kinetic chain exercises. Steinkamp et al\textsuperscript{9} found that the best method to strengthen the quadriceps group is via short arc (<45° flexion to extension), closed kinetic chain exercises. However, in our squat-to-stand closed kinetic chain exercise for the PFPS symptomatic group, knee flexion angles from 15° to 45° revealed a VMO/VL ratio smaller than 1, with the optimal ratio exceeding 1 noted at 60° knee flexion. Whether the short-arc closed kinetic chain exercise should be increased to 60° knee flexion is debatable, in view of our small sample size.

We observed an interesting phenomenon in our study. As knee flexion angle increased, there were some angles with VMO/VL ratios greater than 1. However, subjects from the PFPS group complained of knee pain when the knees were more flexed. From the electromyography standpoint, the quadriceps contraction intensity was smaller, although the VMO/VL ratio was greater than 1. Whether the knees should be flexed to the angle with most optimal VMO/VL ratio for VMO strengthening requires further investigation. We must consider possible knee pain and muscle contraction intensities. During closed kinetic chain exercise, the knee flexion angle with a VMO/VL ratio greater than 1 and with optimal quadriceps muscle contraction activity was 60°.

Souza and Gross\textsuperscript{16} have shown that the VMO/VL ratio was significantly greater in reality subjects than in patients with PFPS. The same result was noted in our study—the VMO/VL ratio was greater in the asymptomatic group (p = .047). Thus, the isokinetic dynamometer may be an ideal testing tool with which to diagnose and assess PFPS. However, this remains controversial, given that Callaghan et al\textsuperscript{17} have performed multijoint isokinetic and isometric assessments in patients with PFPS. The knee angular velocity with an isokinetic dynamometer is important in muscle performance. A reasonable and comfortable range for test velocity is between 60°/s and 180°/s. We chose 120°/s because it was close to the average knee angular velocity observed during squatting and standing tasks.

We found greater quadriceps eccentric muscle contraction during closed kinetic chain exercise than with concentric contraction. Divr et al\textsuperscript{18} showed that eccentric contractions result in significantly higher pain ratings than do concentric contractions. Our results showed that the maximal VMO eccentric contractions occurred at 75° to 90° of knee flexion. Knee pain is usually induced in PFPS subjects during this range of motion (ROM). With this increase in knee flexion and in quadriceps tension, patellofemoral joint reaction force is increased over the patellofemoral joint. A larger patellofemoral joint reaction force may yield high articular stresses and heighten the chances of subchondral degenerative changes.\textsuperscript{7} Although there is a higher VMO/VL ratio generated in eccentric isokinetic exercise during knee flexion, the clinical application of eccentric contraction in VMO training should be considered cautiously.

**CONCLUSION**

Closed kinetic chain exercise from 0° to 60° of knee flexion can induce maximal VMO firing, and the overall VMO/VL ratio is lower for PFPS patients than for asymptomatic subjects. However, our sample size was relatively small. A larger sample size is needed to verify whether closed kinetic chain exercise from 0° to 60° of knee flexion is more beneficial than short arc, closed kinetic chain exercises. Further study is also needed to observe whether knee pain will be induced during this ROM.

**References**


Suppliers
a. Chattecx Corp, 4717 Hixson Rd, PO Box 489, Hixson, TN 34343.
d. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.