THE DIFFERENCE OF ELECTROMYOGRAPHIC ACTIVITIES OF VASTUS MUSCLE IN OPEN AND CLOSED KINETIC CHAIN EXERCISES BETWEEN SUBJECTS WITH AND WITHOUT PATELLOFEMORAL PAIN SYNDROME

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In this study, ten normal subjects and ten patients with patellofemoral pain syndrome (PFPS) were enrolled for knee isokinetic exercise test and closed kinetic chain exercise by squatting-standing respectively. Surface electromyography was applied to vastus medialis obliquus (VMO) and vastus lateralis (VL) muscles during exercise. According to the integrated electromyography, VMO/VL ratio was calculated by dividing normalized EMG of VMO by those of VL. The statistic results revealed that the VMO/VL ratio of patients with PFPS was significantly lower than those of normal subjects during knee isokinetic exercise (p=0.047). However, there is no statistic difference in VMO/VL ratio between the subjects with and without PFPS during closed kinetic chain exercise (p=0.623).

KEY WORDS: patellofemoral pain syndrome, integrated electromyography, isokinetic exercise, closed kinetic chain exercise, knee pain

INTRODUCTION: The most common pathology of the patellofemoral pain syndrome (PFPS) arises from extensor mechanism malalignment, which can be caused by several factors including anatomical abnormalities of the patellofemoral configuration, malalignment of the extremity relating to knee mechanics, and deficiency or imbalance of the supporting muscles (Insall, 1979; Kramer, 1986; Sczepanski, Gross, Duncan, Chandler, 1991). Many investigators have indicated the critical balance between the vastus medialis obliquus (VMO) and the vastus lateralis (VL) (Maquet, 1979; Mariani, Caruso, 1979; Leveau, Rogers, 1980; Souza, Gross, 1991). Lieb and Perry demonstrated that the only selective function of VMO is medial stabilizer responsible for counterbalancing the lateral directed force on the patella by the larger vastus lateralis (Lieb, & Perry, 1968). Hence VMO insufficiency will generate more exposure of lateral facet of the patella due to excessive lateral pull by the VL, leading to abnormal lateral pressure and, ultimately, patellofemoral pain and dysfunction.
Nonoperative management has been advocated by many authors to relieve symptom and restore function in patients with PFPS. These conservative treatments include electrical stimulation, biofeedback, knee bracing, patellar taping, orthotic fabrication, physical modalities, anti-inflammatory medications, and therapeutic exercise (Currier, Lehman, Lightfoot, 1979; Bentley, & Down, 1984; Lysholm, Nordin, Ekstrand, & Gillquist, 1984; Hughouse, Walsh & Puddu, 1984; McConnell, 1986; Bechman, Craig, & Lehman, 1989; Shelton, & Thigpen, 1991; Eng, & Pierrynowski, 1993; Larsen, Andreasen, Urfer, Mickelson, & Newhouse, 1995). Based on the consensus that VMO is the crucial factor of medial patellar stabilization, therapeutic exercise with emphasis on the VMO muscle strengthening has been recommended as the key component of the rehabilitation programs (Bechman et al. 1989; Shelton, & Thigpen, 1991; Knight, Martin, & Londeree, 1979; King, Ahles, Martin, & White, 1984).
The purpose of this study was to assess the difference of vastus muscle performance in open kinetic chain exercise of isokinetics and closed kinetic chain exercise of squatting by measuring dynamic electromyography, further determine which exercise will be more effective as a strengthening program for PFPS.

METHOD: Twenty subjects participated in this study. The control group included ten healthy individuals (five males and five females) with no complaints of knee pain or other lower limb musculoskeletal disorders. Their ages ranged from 21 to 32 years with the average of 25.7 years. The experimental group consisted of ten subjects (four males and six females) with PFPS. Ages ranged from 19 to 48 years and the mean age was 28.2 years. The subjects of PFPS group were examined by a same physiatrist. They all have bilateral anterior knee pain for a minimum of six weeks. The pain was elicited during at least two of the following activities: squatting, stair climbing, kneeling, and prolonged sitting. Patients with concomitant ligamentous injury were excluded, as were patients had previous knee surgery, those with direct trauma leading to patella dislocation, and those with any other neuromuscular disorder affecting the lower limbs. Radiographic examination of Merchant view then was performed to confirm patellofemoral malalignment.

Procedures. Every subject of these two groups was tested under two different exercise modes. Isokinetics, as an open kinetic chain exercise, was performed using a KIN-COM isokinetic dynamometer (Chattecx Corporation). Testing procedure began with a 5 minutes warm-up on a stationary bicycle followed by stretching quadriceps, hamstrings, iliotibial band, and calf musculature. Positioning on the KIN-COM dynamometer was according to manufacturer□s protocol with the back supported and the hip flexed approximately to 80 degrees. Trunk and thigh straps were fastened for stabilization. Quadriceps concentric and eccentric contractions were performed and recorded between 0° and 90° of knee flexion at the angular velocity of 120°/sec. Both legs were tested while the order of testing was determined randomly. 5 minutes cool-down and ice packing 10 minutes ensued after the tests were completed.

Closed kinetic chain exercise tested by squatting was performed under VICON 370 motion analysis system with six cameras containing infrared light-emitting diodes. Reflective markers placed on the sacrum, bilateral anterior superior iliac spin, greater trochanter, anterior thigh , medial and lateral malleoli, anterior tibia, dorsum of foot, fifth metatarsal head, and posterior heel were used to determine the motion of the lower extremity on saggital plane. Squatting/standing repeated twice with the trunk kept in erectile position. Squatting was quadriceps eccentric contraction and standing was quadriceps concentric contraction.

Myosystem 2000 (Noraxon Inc, Arizona, USA) was utilized to acquire EMG signals on bilateral lower limbs. The raw EMG electrical signals were band-pass filtered (20-200Hz) and sampled at 1000Hz. The signals were rectified and low-pass filtered (with a cutoff frequency of 6 Hz). This system uses bipolar gold-plated surface electrodes to collect raw EMG signals. Before electrode application, the skin was prepared by shaving and cleansing with isopropyl alcohol. Two surface electrodes then were attached to the muscle belly of VMO and VL respectively as described by Basmajian and Blumenstein (Basmajian, & Blumenstein, 1980). EMG signal was normalized to allow for comparison of EMG intensity between subjects and muscles by dividing maximal EMG value of individual muscles. Mean EMG of VMO and VL were then calculated with every 15 degrees interval from 0 to 90 degrees of knee flexion.

Statistic analysis. Software SYSTAT and repeated measured ANOVA was used to analyze the normalized VMO/VL ratio between normal subjects and patients with PFPS in different exercise mode. The significance level was set at $p<0.05$.

RESULTS: No statistically significance difference of VMO/VL ratio between right and left leg was noted in both isokinetics and squatting. Thus mean VMO/VL ratio was calculated by averaging VMO/VL ratio of bilateral legs. In the open kinetic chain exercise using KIN-COM isokinetic dynamometer, the VMO/VL ratio was lower in patients with PFPS ($p=0.047$). The quadriceps eccentric contraction produced higher VMO/VL ratio in both normal subjects and patients with PFPS ($p=0.015$). A significant difference was noted in the VMO/VL ratio of different knee flexion angle with a tendency of increased VMO/VL ratio in proportion to the angle of knee flexion ($p=0.001$), In another word, the VMO/VL ratio was higher when the knee more flexed (Table 1).

In the closed kinetic chain exercise performed by squatting/standing, there is a tendency of larger VMO/VL ratio in patients with PFPS though there is no significant statistical difference ($p=0.623$). Also the quadriceps eccentric contraction or concentric contraction made no difference in VMO/VL ratio (p=0.593). However, A significant difference was still found in the VMO/VL ratio of different knee flexion angle (p=0.00), but the peak VMO/VL ratio was noted in 60 degrees of knee flexion (Table 2).

DISCUSSION: Various authors have indicated that imbalance between the vastus medialis obliquus and vastus lateralis is the major cause of patella maltracking leading to patellofemoral pain syndrome (Maquet, 1979; Mariani & Caruso, 1978; Leveau, et al. 1980; Souza, et al. 1991). Souza and Gross have shown that VMO/VL ratio was significantly greater in normal subjects than in those with PFPS in their study of VMO:VL integrated electromyographic (IEMG) ratios under isotonic and isometric quadriceps femoris muscle contraction (Souza, et al. 1991). In our study using isokinetic knee exercise by KIN-COM dynamometer, we have the same result of greater VMO/VL ratio in normal subjects. According to our results, we believed that isokinetics provide good differentiation between subjects with and without PFPS by measuring the VMO/VL ratio of IEMG.

Eccentric isokinetic test with muscle lengthening during contraction generates excessive force on the quadriceps and, subsequently, the patellofemoral joint. Dviri et al demonstrated that eccentric contractions resulted in significantly higher pain ratings than concentric contractions (Dvir, Halperin, Shklar, & Robinson, 1991). Therefore, in spite of higher VMO/VL ratio generated in eccentric isokinetic exercise, clinical application of eccentric contraction should be considered very cautiously.

Grelsamer stated that the forces across the patella decline as the knee flexes from 0 to 90 degrees in open kinetic chain exercise such as knee extension (Grelsamer, Colman, & Mow, 1994). Our study revealed that higher VMO/VL ratio was induced when knee more flexed. It is interesting to further investigate if isokinetic exercise with more knee flexion will be beneficial in selective VMO activation without excessive PFJRF.

Closed kinetic chain exercise such as squatting, working with multiple joint proprioceptive reaction and muscular cocontraction, is generally assumed to be a more functional exercise mode (Steinkamp, Dillingham, Markel. Hill, & Kaufman, 1993; Palmitier, An, Scott, & Chao, 1991; Woodall, & Welsh, 1990). Though the VMO/VL ratio by squatting in our study showed no significant difference between normal subjects and PFPS patients, it can be explained that similar firing patterns of vastus muscle in both groups were generated during this exercise. It created more balanced muscle firing like normal subjects, thus the patella could be kept in a more proper position. It is not a selective VMO muscle activation pattern since the VMO/VL ratio approximated to 1. However, more balanced muscle firing between VMO and VL generated through the whole muscle groups activation. As lower extremity function in daily weight-bearing activities involves multiple muscle acting in synergy, these functional activities trainings might be more effective than isokinetic joint isolation exercise.

CONCLUSION: To differentiate the difference between subjects with and without PFPS, isokinetics may be more appropriate by obtaining lower VMO/VL ratio in patients with PFPS. On the other hand, the results implying closed kinetic chain exercise is good for training because it provides more balanced VMO/VL muscle firing pattern. Therefore, the program of close kinetic chain training without causing pain should be designed.

REFERENCE:

Basmajian, J.V., & Blumenstein, R. (1980) Electrode Placement in EMG Biofeedback. Baltimore, Md: Williams & Wilkins.

Bechman, M., Craig, R., & Lehman, R.C. (1989) Rehabilitation of patellofemoral dysfunction in the athlete. *Clin Sprots Med*, **8**, 841-860.

Bentley, G., & Down, G. Current concepts of etiology and treatment of chondromalacia patella. *Clin Orthop*, **189**, 209-228.

Currier, D.P., & Lehman, J. Lightfoot P. Electrical stimulation in exercise of the quadriceps femoris muscle. *Phys Ther*, **59**, 1508-1512.

Dvir, Z., Halperin, N., & Shklar, A. (1991) Robinson D. Quadriceps function and patellofemoral pain syndrome. Part I: pain provocation during concentric and eccentric

isokinetic contractions. *Isokinet Exerc Sci*, **1**, 26-30.
Eng, J.J., & Pierrynowski, M.R. (1993) Evaluation of soft foot orthotics in the treatment of patellofemoral pain syndrome. *Phys Ther,* **73**, 62-70.
Grabiner, M.D., Koh, T.J., & Draganich, L.F. (1994) Neuromechanics of the patello-femoral joint. Med Sci Sports Exer, **26**(1),10-21.
Grelsamer, R.P., Colman, W.W., & Mow, V.C. (1994) Anatomy and mechanics of the patellofemoral joint. *Sports Med Arthroscopy Rev*, **2**, 178-188.
Henry, J.H., & Crosland, J.W. (1979) Conservative treatment of patellofemoral subluxation. *Am J Sports Med*, **7**, 12-14.
Hughouse, J.C., Walsh, W.M., & Puddu, G. (1984) Patellar Subluxation and Dislocation, Philadelphia: WB Saunders.
Insall, J. (1979) "Chondromalacia patella". Patellar malalignment syndrome. *Orthop Clin North Am,* **10**,117-127.
King, A.C., Ahles, T.A., Martin, J.E., & White, R. (1984) EMG biofeedback-controlled exercise in chronic arthritic knee pain. *Arch Phys Med Rehabil*, **65**, 341-343.
Knight, K.L., Martin, J.A., & Londeree, B.R. (1979) EMG comparison of quadriceps femoris activity during knee extension and straight leg raises. *Am J Phys Med*, **58**, 57-68.
Kramer, P.G. (1986) Patellar malalignment syndrome: Rationale to reduce excessive lateral pressure. *J Orthop Sports Phys Ther,* **8**, 301-309.
Larsen, B., Andreasen, E., Urfer, A., Mickelson, M.R., & Newhouse, K.E. (1995) Patellar taping: A radiographic examination of the medial glide technique. *Am J Sports Med*, **23**(4), 465-471.
Leveau, B.F., & Rogers, C. (1980) Selective training of the vastus medialis muscle using EMG biofeedback. *Phys Ther*, **60**, 1410-1415.
Lieb, F.J., & Perry, J. Quadriceps function: An anatomical and mechanical study using amputated limbs. *J Bone Joint Surg*, **50**A, 1535-1548.
Lysholm, J., Nordin, M., Ekstrand, J., & Gillquist, J. The effect of a patellar brace on performance in a knee extension strength test in patients with patellar pain. *Am J Sports Med* **12**(2), 110-112.
Maquet, P. (1979) Mechanics and osteoarthritis of the patellofemoral joint. *Clin Orthop*, **144**, 70-73.
Mariani, P.P., & Caruso, I. (1979) An electromyographic investigation of subluxation of the patella. *J Bone Joint Surg*, **61**B, 169-171.
McConnell, J. (1986) The management of chondromalacia patella: A long term solution. *Aust J Physiother*, **32**, 215-223.
Palmitier, R.A., An, K.N., Scott, S.G., & Chao, E.Y.S. (1991) Kinetic chain exercise in knee rehabilitation. *Sports Med*, **11**(6), 404-413.
Sczepanski, T.L., Gross, M.T., Duncan, P.W., & Chandler, J.M. (1991) Effect of contraction type, angular velocity, and arc of motion on VMO:VL EMG ratio. *J Orthop Sports Phys Ther* **14**, 256-262.
Shelton, G.L., & Thigpen, L.K. (1991) Rehabilitation of patellofemoral dysfunction: A review of literature. *J Orthop Sports Phys Ther*, **14**(6), 243-249.
Souza, D.R., & Gross, M.T. (1991) Comparison of MVO:VL integrated electromyographic ratios between healthy subjects and patients with patellofemoral pain. *Phys Ther*, **71**, 310-320
Steinkamp, L.A., Dillingham, M.F., Markel, M., Hill, J.A., & Kaufman, K.R. (1993) Biomechanical considerations in patellofemoral joint rehabilitation. *Am J Sports Med*, **21**(3), 438-444.
Woodall, W., & Welsh, J. (1990) A biomechanical basis for rehabilitation programs involving the patellofemoral joint. *J Orthop Sports Phys Ther*, **11**, 535-542.

Table 1 VMO/VL Ratio of Quadriceps Contraction in Kincom Isokinetic Exercise

	PFPS		Normal subjects	
	concentric	eccentric	concentric	Eccentric
15°	.803±.149	.862±.177	.945±.227	.932±.320
30°	.832±.160	.875±.173	.857±.209	.942±.387
45°	.877±.145	.897±.188	.884±.154	.994±.304
60°	.822±.142	.916±.234	.888±.223	1.030±.380
75°	.851±.203	1.083±.582	.923±..164	1.138±.551
90°	.831±.255	1.105±.695	.959±.295	1.259±.916

Table 2 VMO/VL Ratio of Quadriceps Contraction in Closed Kinetic Chain Exercise by Squatting/Standing

	PFPS		Normal subjects	
	concentric	eccentric	concentric	Eccentric
15°	.793±.307	.881±.405	.726±.197	.807±.289
30°	.889±.222	.854±.444	.830±.235	.833±.354
45°	.989±.218	.965±.359	.932±.224	.938±.388
60°	1.052±.430	1.153±.299	.980±.265	1.080±.233
75°	.995±.214	1.054±.298	.978±..200	.985±234
90°	1.025±.204	.972±.276	.984±.171	.979±319