Original Article

J. Phys. Ther. Sci.
26: 989–992, 2014

Effect of Weight-bearing Therapeutic Exercise on the Q-angle and Muscle Activity Onset Times of Elite Athletes with Patellofemoral Pain Syndrome: A Randomized Controlled Trial

Jehoon Lee, PT, PhD[1)], Hwangjae Lee, PT, MSc[1)], Wanhee Lee, PT, PhD[1)*]

[1)] Department of Physical Therapy, Sahmyook University: 26-21 Gongneung 2-dong, Nowon-gu, Seoul 139-742, Republic of Korea

Abstract. [Purpose] The purpose of this study was to determine the effect of a weight-bearing therapeutic exercise program for elite athletes diagnosed as having patellofemoral pain syndrome (PFPS). [Subjects] The subjects were 34 elite athletes from the Seoul T Center. They were randomly allocated to three groups: an elastic band exercise group (EBG), a sling exercise group (SEG), or a control group (CG). [Methods] Therapeutic exercises were performed 3 times a week for 8 weeks. The visual analogue scale (VAS) hamstring length, and static and dynamic Q angles were used to test the exercise effect of the exercises, as well as the onset time of electromyographic activity of vastus medialis oblique (VMO) and vastus lateralis (VL). [Results] Decrease of the dynamic Q-angle in EBG was significant and significantly greater than that in CG. The decrease in VAS in SEG was significant and significantly greater than that in CG. There were significant differences in the VL and VMO activity onset times in SEG between pre- and post-test, and their differences between pre- and post-test were also significantly different. [Conclusion] Weight-bearing therapeutic exercise is hoped that clinicians will use this information for better implementation of effective exercise methods for elite athletes with PFPS.

Key words: Electromyographic onset time, Patellofemoral pain syndrome, Q-angle

(This article was submitted Nov. 25, 2013, and was accepted Jan. 8, 2014)

INTRODUCTION

Patellofemoral joint pain syndrome (PFPS) is one of the most common pathologic conditions of the knee in sports medicine[1)]. It is well documented that female athletes are more likely than male athletes to suffer with PFPS[2)]. PFPS can be caused by a variety of factors, including quadriceps weakness, increased Q-angle, loss of lower extremity function, hypermobile patella, ligamentous laxity, and lateral retinaculum tightness[3–5)]. Onset of symptoms is usually insidious and may occur bilaterally. Specific activities, such as prolonged sitting, stair descent and squatting often aggravate the pain[6)]. Also, one of the most commonly accepted etiologies of PFPS is abnormal tracking of the patella within the femoral trochlea[7)]. A cause of this abnormal tracking may be delayed muscle activity onset time of the vastus medialis oblique (VMO) relative to the vastus lateralis (VL)[8)].

In the past, the patellofemoral joint has been regarded as the main problem of PFPS. However, a recent study demonstrated that poor hip adduction and internal rotation control during weight-bearing activities were related to PFPS in athletes due to weakness of the hip abductor and external rotator muscles[9)]. Other studies have reported significant improvements in hip abduction and lateral rotation strength. These reports suggest that improving pain and hip lateral rotator and abductor muscle strength improves the function of patients with patellofemoral pain[9, 10)].

Many therapeutic exercises emphasize the importance of the VMO muscle because of its medial pull on the patella[1, 11, 12)]. A previous study investigated the effect of a rehabilitation program on the activity timing of the VMO relative to the VL using a McConnell-based rehabilitation program[13)]. Also, Boling et al. demonstrated effects of a weight-bearing rehabilitation program on pain, electromyographic activity, and function in subjects with PFPS[14)].

Weight-bearing exercises are more functional than non-weight-bearing exercises because they need multi-joint movement, facilitate functional movement of muscle recruitment, and stimulate proprioceptors[15)]. In addition, evidence has been provided that during weight-bearing activities, altered patellofemoral tracking may be the result of the femur rotating medially beneath the patella, rather than the patella moving laterally on the femur[16)]. Because of these advantages, weight-bearing exercises are recommended for the rehabilitation of PFPS[14)]. However, the actual study of weight-bearing exercises performed by elite

*Corresponding author. Wanhee Lee (E-mail: whlee@syu.ac.kr)

©2014 The Society of Physical Therapy Science. Published by IPEC Inc.
This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (by-nc-nd) License <http://creativecommons.org/licenses/by-nc-nd/3.0/>.

athletes with PFPS is insufficient. Therefore, the purpose of this study was to investigate the effects of a weight-bearing rehabilitation program for elite athletes with PFPS through changes in the visual analogue scale, static and dynamic Q-angles, and the electromyographic onset timing of the VMO and VL muscles. We hypothesized that after 8 weeks, the weight-bearing rehabilitation program groups would demonstrate greater improvement in static and dynamic Q-angles, and electromyographic onset timing of the VMO and VL muscles than the control group.

SUBJECTS AND METHODS

The subjects were 34 (21 men, 13 women) track and field hockey elite athletes from Seoul T center. The criteria used for the diagnosis of PFPS were based on those used in other PFPS studies: diagnosis of PFPS by a medical doctor[17]; and at least two of the following activities exacerbated their symptoms: prolonged sitting, ascending or descending stairs, squatting, and kneeling. Exclusion criteria were unregulated neurological impairment, knee surgery in the past 2 years, or acquired structural or functional lower limb failures, such as systemic arthritis ligamentous knee injury. This study used a randomized pre- and post-test, three group design. Subjects randomly allocated to a sling exercise group (n=11, SEG), elastic band exercise group (n=13, EBG), or control group (n=10, CG). All 34 elite athletes completed the intervention. The randomization was generated by a computer using a basic random number generator. Prior to subjects' participation, all the procedures were explained to them and each subject provided his/her written informed consent to participation. This study was approved by the Sahmyook University Institutional Review Board.

In the training course, the therapeutic exercises of SEG and EBG were performed 3 times a week (30 min) for 8 weeks. Each therapeutic exercise program included a warm-up (stationary bike, 10 min), exercise program (SEG or EBG with weight-bearing, 20 min), and cool-down (hamstring self-stretching, 5 min). Therapeutic exercise programs were performed one-on-one with a physical therapist. The details of both therapeutic exercise programs are described in Table 1. In contrast, the control group did not perform a therapeutic exercise program.

Prior to the intervention, a physical characteristics analyzer (Inbody 520, Biospace, Korea) was used to measure the body weight and body mass index (BMI). A 10 cm visual analogue scale (10 cm − VAS) was used pre- and post-test to assess pain and discomfort during stair-climbing, descending stairs, squatting, and long sitting. The static Q-angle of the standing position and dynamic Q-angle of coming down the stairs were also measured. All participants had their anterior superior iliac spines (ASIS), tibial tubercles and midpoint of their patella marked bilaterally by the same examiner[16]. Static and dynamic Q-angles for the standing position were measured on digital images of the subjects captured by a digital video camera (SONY, DCR-SR300, Japan). The camera was positioned on a tripod 2 m away from the subjects, with the camera height set to each individual's patella height. The angles were calculated using Dartfish software (Prosuit 4.2, Switzerland). The muscle activity onset time of the VMO and VL muscles while subjects descended stairs was measured by surface EMG (Pocket EMG, BTS, Italy). The electrode (Norotrode, 20TM Bipolar, USA) for the VMO was placed approximately 4 cm superior to and 3 cm medial to the superomedial border of the patella and oriented 55° to the long axis of the femur[14]. The electrode for VL was placed approximately 10 cm superior and 7 cm lateral to the superior border of the patella and oriented 15° to the long axis of the femur[14].

SPSS ver. 12.0 statistical software was used for all analyses. Descriptive statistics were used to describe patient characteristics after confirming the data was normally distributed. Comparisons of all groups' general characteristics were performed using the independent t-test or the χ^2 test. Pre- and post-data were analyzed using the paired t-test the within to test differences groups and one-way ANOVA to test differences among the groups. Scheffe's post hoc test was used to test the significance of differences between the groups. A significance level of 0.05 was used for all measurements.

RESULTS

General characteristics of subjects are presented in Table 2. No significant differences in general characteristics were observed between EBG, SEG and CG (age, 23.15 years vs. 22.55 years vs. 22.60 years; height, 170.10 cm vs. 168.17 cm vs. 168.30 cm; body mass index, 22.18 kg/m^2 vs. 22.39 kg/m^2 vs. 21.90 kg/m^2).

Differences in pre- and post-test values within groups and between groups are summarized in Table 3. Specifically, EBG showed a significant decrease in the dynamic Q-angle and the difference was significantly greater than that of CG. Also, SEG showed a significant decrease in VAS ($p < 0.01$) and the difference was significantly greater than that of CG. In addition, the muscle activity onset time of VL in SEG was significantly different between pre- and post-test and the differences in muscle activity onset times between VMO and VL in EBG were significantly different between pre- and post-test ($p < 0.001$).

DISCUSSION

The study results demonstrate that participants with PFPS had decreased pain and dynamic Q-angle, and altered VL and VMO onset timing differences after the weight-bearing therapeutic exercise program which lasted for 8 weeks.

The results of this study indicate that the elite athletes with PFPS had decreased pain in EBG and SEG. Specifically, SEG showed a significant decrease in VAS compared to CG. A previous study demonstrated that a weight-bearing rehabilitation program effectively decreased pain and increased the function of subjects with PFPS[14]. Another study showed that when osteoarthritic patients with tolerable pain perform a weight-bearing training, it might be better to begin with non-weight-bearing exercise, and progressively shift to partial weight-bearing, followed by full weight-bearing exercise[18].

Table 1. Weight-bearing therapeutic exercise program

Exercise type	Exercise program		Time (Sets/Duration)
	EBG	SEG	
Warm-up	Stationary bike		10 min
Weight-bearing therapeutic exercise	Knee extension WB (affected side) + EB	"Bridge" with Knee extension Prone position on sling	20 min (3–10 seconds repeat 4 times / 3–5 times)
	Hip flexion WB (affected side) + EB	"Bridge" with Hip flexion Prone position on sling	
	Hip extension WB (affected side) + EB	"Bridge" Supine position on sling	
	Hip abduction WB (affected side) + EB	"Bridge" Side-lying position on sling (below affected side)	
	Hip adduction WB (affected side) + EB	"Bridge" Side-lying position on sling (above affected side)	
Cool-down	Hamstring self-stretching		5 min

EBG, elastic band group; SEG, sling exercise group; CG, control group; EB, elastic band

Table 2. General characteristics of the participants

Parameters	EBG (n=13)	SEG (n=11)	CG (n=10)
Gender Male/Female (%)	7/6 (53.8/46.2)	8/3 (72.7/27.3)	6/4 (60.0/40.0)
Affected side Right/Left (%)	7/6 (53.8/46.2)	6/5 (54.5/45.5)	4/6 (40.0/60.0)
Height, (cm)	170.1 (7.8)	168.2 (7.8)	168.3 (9.1)
Age, years	23.2 (3.8)	22.6 (3.7)	22.6 (2.8)
BMI, (kg/m^2)	22.2 (2.2)	22.4 (2.0)	21.9 (2.1)

Values are n (%) or mean (SD)
EBG, elastic band group; SEG, sling exercise group; CG, control group; BMI, body mass index

Table 3. Comparison of VAS, Q-angle and muscle activity onset times of VL and VMO within groups and between groups

Parameters	Values					
	EBG (n=13)		SEG (n=11)		CG (n=10)	
	pre	post	pre	post	pre	post
VAS (cm)	3.9 (1.5)	2.3 (1.3)*	4.4 (1.4)	3.8 (1.2)** †	3.8 (1.2)	3.8 (1.8)
Static Q-angle (°)	14.9 (7.3)	12.8 (5.3)	16.1 (4.0)	12.0 (4.7)	17.0 (4.0)	17.5 (4.8)
Dynamic Q-angle (°)	22.2 (8.2)	17.1 (8.7)**†	21.7 (7.5)	21.7 (7.5)	22.2 (5.2)	23.5 (3.2)
Onset time of VL (ms)	−455.0 (182.3)	−469.1 (189.0)	−420.0 (169.3)	−434.6 (144.3)*	−390.0 (99.8)	−381.0 (77.0)
Onset time of VMO (ms)	−546.4 (186.0)	−453.9 (202.6)	−506.6 (127.9)	−422.8 (153.8)**	−438.1 (151.3)	−438.1 (151.3)
Differences of onset time VL & VMO (ms)	−91.3 (65.8)	11.15 (86.0)***	−86.7 (132.7)	57.4 (168.5)*	−53.0 (98.7)	−57.1 (93.4)

Values are mean (SD). Within group differences *p<0.05, **p<0.01, ***p<0.001. Post-hoc test: † significantly greater than CG
EBG, elastic band group; SEG, sling exercise group; CG, control group; VAS, visual analogue scale (range 0–10 cm); VL, vastus lateralis; VMO, vastus medialis oblique

The Q-angle is frequently cited as a possible predictor of knee problems and lower limb injuries. Abnormally high Q-angles (more than 15° for males and 20° for females) are regarded as an anatomical risk factor in the etiology of overuse injuries of the knee[19]. Stefanyshyn et al. reported that increased knee abduction impulses should be deemed as risk factors that play a role in the development of PFPS in track athletes. Similarly, decreased strength of the hip abductors has been associated with increased knee joint medial displacement, which may be associated with an increased Q-angle in a unilateral stance[20]. In this study, weight-bearing exercise with an elastic band significantly decreased the

Q-angle compared to CG. A previous study demonstrated that exercise with an elastic band was an effective tool for performing weight-bearing exercise closed kinetic chain (CKC) exercise[15)]. Our results suggest that weight-bearing elastic band CKC increased muscle strength, and improved muscle alignment and motor control of the knee during functional activities.

In this study, electromyography (EMG) was used to determine the change of muscle activity onset time of VL and differences of muscle activity onset time between VMO and VL due to the performance of weight-bearing exercises. The muscle activity onset times of VMO and VL in EBG and SEG were not significantly different from CG. However, the post-test muscle activity onset time of VL in SEG was significantly different from its pre-test value ($p < 0.01$), and the differences in the muscle activity onset times of VMO and VL in EBG and SEG were significantly different between pre- and post-test (EBG; $p < 0.01$, SEG; $p < 0.05$). Researchers have stated that VMO should activate earlier than, or at the same time as, the VL because a delay in VMO activation may laterally move the patella and result in PFPS[21)]. A previous study demonstrated that as little as a 5 ms delay in VMO activation may cause a lateral increase in the compressive forces on the patella-femoral joint[22)]. One study conducting a weight-bearing rehabilitation program reported that patients with PFPS had altered VL and VMO onset timing differences after a McConnell-based rehabilitation program. Bolling et al. showed that weight-bearing exercises performed by subjects with PFPS (squatting, descent or ascent phase of the stair-stepping task, elastic band exercise) resulted in significant differences in VL and VMO onset times[14)]. However, the present study had some differences from these previous studies. The results of the present study show that the VL onset time of the elite athletes was shorter than that of normal adults.

Despite demonstrating of the effectiveness of weight-bearing therapeutic exercise on the Q-angle and muscle activity of the elite athletes with PFPS, this study had some limitations. First, the statistical power was not calculated and only a small number of subjects were recruited. Second, because participants consisted of only track and field hockey athletes, the results of this study cannot be generalized to all elite athletes with PFPS. Therefore, we suggest that further studies include a variety of athletes with PFPS.

REFERENCES

1) Cerny K: Vastus medialis oblique/vastus lateralis muscle activity ratios for selected exercises in persons with and without patellofemoral pain syndrome. Phys Ther, 1995, 75: 672–683. [Medline]
2) Taunton J E, Ryan M B, Clement D B, et al.: A retrospective case-control analysis of 2002 running injuries. Br J Sports Med, 2002, 36: 95–101. [Medline] [CrossRef]
3) Ruffin MT 5th, Kiningham RB: Anterior knee pain: the challenge of patellofemoral syndrome. Am Fam Physician, 1993, 47: 185–194. [Medline]
4) Messier SP, Davis SE, Curl WW, et al.: Etiologic factors associated with patellofemoral pain in runners. Med Sci Sports Exerc, 1991, 23: 1008–1015. [Medline] [CrossRef]
5) Witvrouw E, Lysens R, Bellemans J, et al.: Intrinsic risk factors for the development of anterior knee pain in an athletic population. A two-year prospective study. Am J Sports Med, 2000, 28: 480–489. [Medline]
6) Dixit S, DiFiori J P, Burton M, et al.: Management of patellofemoral pain syndrome. Am Fam Physician, 2007, 75: 194–202. [Medline]
7) Fulkerson JP: Diagnosis and treatment of patients with patellofemoral pain. Am J Sports Med, 2002, 30: 447–456. [Medline]
8) Cavazzuti L, Merlo A, Orlandi F, et al.: Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Gait Posture, 2010, 32: 290–295. [Medline] [CrossRef]
9) Robinson RL, Nee RJ: Analysis of hip strength in females seeking physical therapy treatment for unilateral patellofemoral pain syndrome. J Orthop Sports Phys Ther, 2007, 37: 232–238. [Medline] [CrossRef]
10) Long-Rossi F, Salsich GB: Pain and hip lateral rotator muscle strength contribute to functional status in females with patellofemoral pain. Physiother Res Int, 2010, 15: 57–64. [Medline]
11) Antich TJ, Brewster CE: Modification of quadriceps femoris muscle exercises during knee rehabilitation. Phys Ther, 1986, 66: 1246–1251. [Medline]
12) Hehne HJ: Biomechanics of the patellofemoral joint and its clinical relevance. Clin Orthop Relat Res, 1990, (258): 73–85. [Medline]
13) Cowan SM, Bennell KL, Crossley KM, et al.: Physical therapy alters recruitment of the vasti in patellofemoral pain syndrome. Med Sci Sports Exerc, 2002, 34: 1879–1885. [Medline] [CrossRef]
14) Boling MC, Bolgla LA, Mattacola CG, et al.: Outcomes of a weight-bearing rehabilitation program for patients diagnosed with patellofemoral pain syndrome. Arch Phys Med Rehabil, 2006, 87: 1428–1435. [Medline] [CrossRef]
15) Schulthies SS, Ricard MD, Alexander KJ, et al.: An electromyographic investigation of 4 elastic-tubing closed kinetic chain exercises after anterior cruciate ligament reconstruction. J Athl Train, 1998, 33: 328–335. [Medline]
16) Witvrouw E, Danneels L, Van Tiggelen D, et al.: Open versus closed kinetic chain exercises in patellofemoral pain: a 5-year prospective randomized study. Am J Sports Med, 2004, 32: 1122–1130. [Medline] [CrossRef]
17) Crossley KM, Bennell KL, Cowan SM, et al.: Analysis of outcome measures for persons with patellofemoral pain: which are reliable and valid? Arch Phys Med Rehabil, 2004, 85: 815–822. [Medline] [CrossRef]
18) Tsauo JY, Cheng PF, Yang RS: The effects of sensorimotor training on knee proprioception and function for patients with knee osteoarthritis: a preliminary report. Clin Rehabil, 2008, 22: 448–457. [Medline] [CrossRef]
19) Ilahi OA, Kohl HW 3rd: Lower extremity morphology and alignment and risk of overuse injury. Clin J Sport Med, 1998, 8: 38–42. [Medline] [CrossRef]
20) Jacobs CA, Uhl TL, Mattacola CG, et al.: Hip abductor function and lower extremity landing kinematics: sex differences. J Athl Train, 2007, 42: 76–83. [Medline]
21) Voight ML, Wieder DL: Comparative reflex response times of vastus medialis obliquus and vastus lateralis in normal subjects and subjects with extensor mechanism dysfunction. An electromyographic study. Am J Sports Med, 1991, 19: 131–137. [Medline] [CrossRef]
22) Neptune RR, Wright IC, van den Bogert AJ: The influence of orthotic devices and vastus medialis strength and timing on patellofemoral loads during running. Clin Biomech (Bristol, Avon), 2000, 15: 611–618. [Medline] [CrossRef]