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Original Article

A study on muscle activity and ratio of the knee extensor depending on the types of squat exercise

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Abstract. [Purpose] For preventing the patellofemoral pain syndrome, this study aims to suggest a proper squat method, which presents selective muscle activity of Vastus Medialis Oblique and muscle activity ratios of Vastus Medialis Oblique/Vastus Lateralis by applying squat that is a representative weight bearing exercise method in various ways depending on the surface conditions and knee bending angles. [Subjects and Methods] An isometric squat that was accompanied by hip adduction, depending on the surface condition and the knee joint flexion angle, was performed by 24 healthy students. The muscle activity and the ratio of muscle activity were measured. [Results] In a comparison of muscle activity depending on the knee joint flexion angle on a weight-bearing surface, the vastus medialis oblique showed a significant difference at 15° and 60°. Meanwhile, in a comparison of the muscle activity ratio between the vastus medialis oblique and the vastus lateralis depending on the knee joint flexion angle on a weight-bearing surface, significant differences were observed at 15° and 60°. [Conclusion] An efficient squat exercise posture for preventing the patellofemoral pain syndrome is to increase the knee joint bending angle on a stable surface. But it would be efficient for patients with difficulties in bending the knee joint to keep a knee joint bending angle of 15 degrees or less on an unstable surface. It is considered that in future, diverse studies on selective Vastus Medialis Oblique strengthening exercise methods would be needed after applying them to patients with the patellofemoral pain syndrome.
Key words: Squat exercise, Vastus medialis oblique, Vastus lateralis

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INTRODUCTION

Patellofemoral pain syndrome (PFPS) is one of the representative types of pain that usually develop in adolescents or young adults who engage in sports[1)]. The reported causes of patellofemoral pain include increased Q-angle (quadriceps muscle), excessive lateral torsion of the shinbone, and lateral tracking of the patella caused by postural changes due to an imbalance in the quadriceps muscle[2)]. Such pain can progress into a chronic disease such as arthritis, which is difficult to cure completely and requires good management[3)]. Weakening of the vastus medialis oblique (VMO) muscle attached to the upper interior corner of the patella does not contribute to dynamic medial stabilization and causes lateral deviation of the patella[4)]. Patients with PFPS were found to have a lower muscle activity ratio between the VMO and the vastus lateralis (VL) than healthy subjects[5)]. Therefore, correction of the balance between the VMO and VL should be a goal in rehabilitation programs for patients with patellofemoral pain, in order to determine the appropriate exercise for preventing PFPS[6)]. Open kinetic chain

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Table 1. Characteristics of the study subjects

Character	Mean ± SD	Range
Age (years)	26.04 ± 2.19	22–29
Height (cm)	175.33 ± 3.93	168–183
Weight (kg)	72.8 ± 6.29	63–85

exercises were reported to be difficult to apply in patients with PFPS because they cause hypertonus of the cranial cruciate ligament and nonfunctional muscle recruitment patterns[7]. Conversely, closed kinetic chain exercises produce less shearing force owing to the increase in the pressure on the patellofemoral joint and the co-contraction between the quadriceps and hamstring muscles, and may provide functional muscle recruitment patterns caused by multijoint movements[8]. The squat is one of the most common exercises used in muscle strengthening and training programs, and the representative closed kinetic chain exercise that is usually performed as a rehabilitation strategy[9]. Antagonistic muscles may have a considerable influence on the stability of weakened joints, as they act efferently on each other[10]. Performing an exercise in an incorrect position or with an inappropriate weight could cause injury rather than produce benefits. Many studies on the effects of various squat postures on the treatment of PFPS have been conducted. During a squat exercise, a higher concentration of muscle activation was observed in the VMO when the legs were spread at shoulder width than when the legs were spread much wider[11]. Earl et al.[2] reported that the mixed effects of exercises that involve an assortment of isometric hip joints could be obtained during static movement rather than during dynamic movement in order to reinforce the VMO selectively. Jang et al.[12] reported that during a squat exercise that involves an assortment of isometric hip joints, the muscle activity of the VMO could be increased selectively. Squat exercises on an unstable surface have been reported to stimulate the neuromuscular delivery system; co-contract the agonist and synergist muscles; improve muscle strength, balance ability, and stability; and maximize the effects of exercise[13]. Squat exercises have also been reported to improve the core muscles that maintain balance and trigger the effects of reinforcing the joint function and muscle activation of the lower limb muscles[14]. However, no consensus has been reached among such reports concerning the muscle activities of the VMO and VL, depending on surface condition and the knee joint flexion angle.

Therefore, this study compared the muscle activity ratio between the VMO and the VL depending on the surface condition and the knee joint flexion angle during exercise, especially during isometric squat exercises with a ball, and has proposed appropriate exercises for increasing the activity of the VMO.

SUBJECTS AND METHODS

This study was conducted in 24 male healthy adults without limitations or pain in the range of motion of the lower limbs and truncus. The study subjects were limited to those who had never received hospital treatment for knee joint conditions, had never undergone surgery for knee joint and muscular skeletal diseases, and had not participated in regular training exercises for health reasons in the recent 6 months (Table 1). The subjects understood the purpose of this study and voluntarily agreed to participate, as documented with the written informed consent of each subject.

This study was approved by the bioethics committee of the Sehan University Center (institutional review board approval no. 2016-1).

Before the experiment, all participants received an explanation and demonstration of the exercises that they would be performing with the guidance of the experimenter. The participants wore short pants to allow easy placement of electrodes for electromyogram measurement and for ease in performing the squat exercise. Electrodes were attached to the VMO and VL on the dominant leg. To minimize resistance before attachment to the skin, the electrode was wiped with alcohol, and the hair on the attachment site for each muscle was removed before the electrode was attached.

The posture during the squat exercise was as follows: both feet were spread by 120% at shoulder width, with arms folded lightly and the truncus maintained in a standing position. A previous study reported that for selective reinforcement of the VMO, the effects of the involvement of an assortment of isometric hip joints could be achieved with static movement rather than with dynamic movement[2]. A ball with a diameter of 20 cm was placed between the left and right patella before conducting the isometric squat exercise that involved an assortment of the hip joints.

Two conditions for squat were defined in this study, as follows: (i) knee joint flexion angles of 15°, 45°, and 60° on a fixed ground; (ii) knee joint flexion angles of 15°, 45°, and 60° on an unstable surface or aerostep. The isometric squat exercise was conducted in six postures. For measurement precision, the squat was performed three times for each angle. To exclude the effects according to order when measuring the electromyographic signals during the squat, the measurement was performed randomly. For every squat exercise, isometric contraction of the knee extensor muscle was induced for 8 s at 15°, 45°, and 60° by using a goniometer, and the muscle was returned to the original position before resting. The electromyographic values measured for 6 s, excluding the first 1 s and the last 1 s, were used in the data analysis. To minimize potential muscle fatigue due to the continuous measurement process, the subjects were allowed to rest for 3 min between each exercise condition.

Table 2. Comparison of muscular activity (%MVIC) according to surface condition and knee joint flexion angle

Muscle	Angle	Stable	Unstable
VMO	15	51.03 ± 9.21[a]	59.66 ± 11.93*
	45	103.22 ± 18.3	99.91 ± 20.08
	60	176.63 ± 36.38	150.01 ± 31.44*
VL	15	62.69 ± 10.34	65.91 ± 14.16
	45	114.1 ± 20.52	109.98 ± 21.34
	60	165.15 ± 24.7	159.96 ± 25.26

*p<0.01.
[a]Mean ± SD, Independent t-test.
VMO: vastus medialis oblique, VL: vastus lateralis

Table 3. Comparison of VMO/VL muscular activation ratio according to surface condition and knee joint flexion angle

Muscle	Angle	Stable	Unstable
VMO/VL	15	0.81 ± 0.09[a]	0.91 ± 0.13*
	45	0.91 ± 0.11	0.91 ± 0.09
	60	1.06 ± 0.12	0.93 ± 0.09**

*p<0.01, *p<0.001.
[a]Mean ± SD, Paired t-test.
VMO: vastus medialis oblique, VL: vastus lateralis

The MP 150 system (Biopac System Inc., Goleta, CA, USA) was used as the surface electromyography device. The sampling rate for signal collection was set at 200 Hz, and the frequency band pass filter was set at 1–35 Hz. The signals collected were analyzed by using the Acknowledge 4.2.2 software program (Biopac System Inc.). For the VL, the electrode was attached two-third from the lower part of the electronic trunk to the upper extreme point of the patella. For the VMO, the electrode was attached to the muscle belly that showed a strong isometric contraction in relation to the VL. As individual differences could influence the results, the values obtained from all exercises were normalized into percent maximal voluntary isometric contraction (MVIC) after calculating the root mean square. When the hip joint was set at 90° in a sitting posture, the truncus was fixed and MVIC was performed while straightening the knee, and then the measured value was converted to a percentage. The cross-sectional area was measured, and muscle activity was calculated from the muscle activation ratio.

In this study, SPSS 17.0 for Windows was used for data processing. For the comparative analysis of the knee joint flexion angle between a stable surface and an unstable surface during the squat exercise, and of the VMO/VL muscle activation ratio, an independent t-test was used. The significance level was set at α=0.05.

RESULTS

The activation of the VMO depending on knee joint flexion angle showed a significant difference at 15° and 60° (p<0.01); however, no significant difference was found at 45°. The activation of the VL depending on knee joint flexion angle showed no significant difference at all angles (Table 2). The muscle activation ratio (VMO/VL) depending on the knee joint flexion angle showed a significant difference at 15° and 60° (p<0.01 and p<0.001, respectively); however, difference was not significant at 45° (Table 3). The muscle activation ratio (VMO/VL) depending on the knee joint flexion angle showed a significant difference at 15° and 60° (p<0.01 and p<0.001, respectively), but not at 45° (Table 3).

DISCUSSION

The VMO/VL muscle activation ratio is used as an index for medial and lateral forces in the patella[15]. A VMO/VL muscle activation ratio of >1 means that the normalized activation of the VMO is greater than that of the VL. This implies that exercise that induces a much greater VMO/VL muscle activation ratio will elicit various muscle activation patterns of the VMO and VL during functional activity.

The squat, one of the weight-bearing exercises that are universally used in patients with PFPS, is one of the most commonly performed exercises in muscle strengthening and training programs, and is a closed chain exercise usually performed as a rehabilitation strategy[9]. Tang et al.[5] compared subjects from the general population and patients with PFPS, and reported that the increase in the VMO/VL ratio was greater in an open chain exercise performed at between 45° and 60° knee angles than in a closed chain exercise in patients with PFPS. Thus, the authors suggested that closed chain exercises such as the squat would be much safer and effective for these patients.

Previous studies indicated that an isometric squat exercise involving an assortment of hip joints would activate the VMO selectively. Similarly, Earl et al.[2] reported that in a comparison of the VMO/VL muscle activation ratio between a squat exercise involving an assortment of hip joints and a general squat exercise in 20 healthy adults, the VMO/VL muscle activation ratio increased significantly during the squat exercise involving an assortment of hip joints. Meanwhile, in a comparison of the VMO/VL ratios between three exercise methods in 21 healthy adults, Koh et al.[16] found the highest increase in the VMO/VL ratio during the squat exercise involving an assortment of hip joints. Tang et al.[5] investigated the activity of the quadriceps muscle at various knee bending angles, and reported that the VMO/VL ratio was highest at the 60° knee flexion angle. The finding of this study was also consistent with those of the previous studies indicating that as the angle increased on a stable or an unstable surface, the muscle activation of the VMO and the VL also increased and that the VMO/VL muscle activation ratio was 1.06 and 0.93, respectively, when the knee joint flexion angle was 60°. This was attributed to the fact that as the angle increases during a squat exercise, the moment arm of the quadriceps muscle and the muscle activity also increase, and that the selective activation of the VMO was caused by the involvement of various hip joints when the knee joint flexion angle was at its highest (at 60°).

Recent clinical practice has involved the use of balanced training on an unstable surface, with an instrument such as an aerostep or a Swiss ball. Seo and Kim[17] demonstrated that the muscle activation ratios of the rectus femoris and biceps femoris were higher on an unstable surface than on a stable surface, in their balance training on 60 stroke patients. Lim[18] conducted exercise training in two groups, namely an unstable surface group and a stable surface group, in 30 patients who had undergone anterior cruciate ligament reconstruction. Both groups showed significantly higher muscle activities of the vastus medialis and the VL; however, the muscle activity was higher in the unstable surface group. This study also compared a stable surface group with an unstable surface group, and found that both the muscle activity and the muscle activation of the VMO at 15° knee flexion were significantly higher on an unstable surface than on a stable surface, which supported the results of previous studies. This is considered to be attributable to the fact that despite a small angle, the posture used to prevent a soccer ball from falling during the isometric squat exercise involved the use of various hip joints. In other words, a somatosensory exercise on a relatively unstable surface increased the activity of the VMO because postural control was conducted proactively by the activation of muscles involved in the stability of the knee joint. On the other hand, both the muscle activity and muscle activation ratio of the VMO at the knee flexion angle of 60° appeared to be significantly higher on a stable surface than on an unstable surface, which was inconsistent with the results of previous studies. This suggests that as knee bending increased on an unstable surface, all muscles passing the body segments co-contracted to maintain the balance between the truncus and the lower limbs. To overcome the instability of the front and back, and the right and left feet, the distal part rather than the quadriceps muscle was used and posture was maintained by using the ankle and triceps muscles, which is considered to have reduced the intensive activation of the VMO. It was reported in Anderson and Bhem[19] 's research that when squat exercise was conducted on a unstable surface, VMO muscle activation declined more than when it was conducted on a stable surface, due to the ankle strategy for posture control and it corresponds to the finding of this study.

This result shows that for reinforcing VMO selectively, it is effective to apply squat exercise with an angle of 15 degrees on a unstable ground with hip adduction and on a fixed ground, squat exercise with an angle of 60 degrees is most effective. This implies that for patients with joint limits caused by pain, squat exercise with an angle of 15 degrees on a unstable ground should be applied and for general muscle strengthening, squat exercise with an angle of 60 degrees on a fixed ground is effective.

This study has some limitations. We did not target a large population, and the study subjects were limited to healthy persons. Therefore, in future, there should be a lot of prospective studies on good exercise methods for selective reinforcement of VMO in patients with a PFPS or those, who underwent knee surgery.

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REFERENCES

1) Myer GD, Ford KR, Barber Foss KD, et al.: The incidence and potential pathomechanics of patellofemoral pain in female athletes. Clin Biomech (Bristol, Avon), 2010, 25: 700–707. [Medline] [CrossRef]

2) Earl JE, Schmitz RJ, Arnold BL: Activation of the VMO and VL during dynamic mini-squat exercises with and without isometric hip adduction. J Electromyogr Kinesiol, 2001, 11: 381–386. [Medline] [CrossRef]

3) Jeong YH, Kim JI: Effects of a 9-week self-help management·aquatic exercise program on pain, flexibility, balance, fatigue and self-efficacy in the patients with osteoarthritis. J Muscle Jt Health, 2010, 17: 47–57. [CrossRef]

4) McConnell J: Management of patellofemoral problems. Man Ther, 1996, 1: 60–66. [Medline] [CrossRef]

5) Tang SF, Chen CK, Hsu R, et al.: Vastus medialis obliquus and vastus lateralis activity in open and closed kinetic chain exercises in patients with patellofemoral pain syndrome: an electromyographic study. Arch Phys Med Rehabil, 2001, 82: 1441–1445. [Medline] [CrossRef]
6) Loudon JK, Wiesner D, Goist-Foley HL, et al.: Intrarater reliability of functional performance tests for subjects with patellofemoral pain syndrome. J Athl Train, 2002, 37: 256–261. [Medline]
7) Chang WD, Huang WS, Lee CL, et al.: Effects of open and closed kinetic chains of sling exercise therapy on the muscle activity of the vastus medialis oblique and vastus lateralis. J Phys Ther Sci, 2014, 26: 1363–1366. [Medline] [CrossRef]
8) Cho SH, Bae CH, Gak HB: Effects of closed kinetic chain exercises on proprioception and functional scores of the knee after anterior cruciate ligament reconstruction. J Phys Ther Sci, 2013, 25: 1239–1241. [Medline] [CrossRef]
9) Schoenfeld BJ: Squatting kinematics and kinetics and their application to exercise performance. J Strength Cond Res, 2010, 24: 3497–3506. [Medline] [CrossRef]
10) Iwasaki T, Shiba N, Matsuse H, et al.: Improvement in knee extension strength through training by means of combined electrical stimulation and voluntary muscle contraction. Tohoku J Exp Med, 2006, 209: 33–40. [Medline] [CrossRef]
11) Escamilla RF, Fleisig GS, Zheng N, et al.: Effects of technique variations on knee biomechanics during the squat and leg press. Med Sci Sports Exerc, 2001, 33: 1552–1566. [Medline] [CrossRef]
12) Jang EM, Heo HJ, Kim MH, et al.: Activation of VMO and VL in squat exercises for women with different hip adduction loads. J Phys Ther Sci, 2013, 25: 257–258. [CrossRef]
13) Verhagen E, van der Beek A, Twisk J, et al.: The effect of a proprioceptive balance board training program for the prevention of ankle sprains: a prospective controlled trial. Am J Sports Med, 2004, 32: 1385–1393. [Medline] [CrossRef]
14) Saeterbakken AH, Fimland MS: Muscle force output and electromyographic activity in squats with various unstable surfaces. J Strength Cond Res, 2013, 27: 130–136. [Medline] [CrossRef]
15) Ng GY, Zhang AQ, Li CK: Biofeedback exercise improved the EMG activity ratio of the medial and lateral vasti muscles in subjects with patellofemoral pain syndrome. J Electromyogr Kinesiol, 2008, 18: 128–133. [Medline] [CrossRef]
16) Koh EK, Lee KH, Jung DY: The effect of isometric hip adduction and abduction on the muscle activities of vastus medialis oblique and vastus lateralis during leg squat exercises. Korean journal of sport biomechanics, 2011, 21: 361–368. [CrossRef]
17) Seo HW, Kim MC: Study on the correlation between muscle activity of lower extremity and sway speed of chronic stroke patients according to unstable surface training. J Korean Soc Integr Med, 2013, 1: 75–83. [CrossRef]
18) Lim CH: Comparision of the muscle activity and balance of lower extremities in exercise using TOGU on the unstable surface and stable surface after reconstruction of the ACL. J Korean Soc Phys Med, 2012, 7: 251–258. [CrossRef]
19) Anderson K, Behm DG: Trunk muscle activity increases with unstable squat movements. Can J Appl Physiol, 2005, 30: 33–45. [Medline] [CrossRef]