RESEARCH ARTICLE

The effect of gender on vastus medialis oblique/vastus lateralis activation ratio during weight and non-weight bearing activities in recreationally subjects

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Abstract

Objective: To investigate the effect of gender on the activation ratio of vastus medialis oblique to vastus lateralis during straight leg raising and stepdown activities.

Method: The cross-sectional study was conducted at the College of Medical Rehabilitation Sciences, Taibah University, Medina, Kingdom of Saudi Arabia, from September 2021 to March 2022, and comprised recreationally active subjects without knee pathology who were distributed in 2 gender-based groups. All the participants were subjected to straight leg raising and stepdown activities thrice and the average value of each activity was noted. The vastus medialis oblique and vastus lateralis electromyographic activity of the dominant limb was recorded using surface electromyography during the activities. The normalised value of the activation ratio of vastus medialis oblique to vastus lateralis levels was calculated. Data was analysed using SPSS 25.

Results: Of the 60 subjects, there were 30(50%) males with mean age 30.00±5.91 years, mean height 167±5.63cm, mean body weight 66.76±6.14kg, and mean body mass index 23.97±3.02kg/m^2. There were 30(50%) females with mean age 29.03±5.34 years, mean height 186±6.20cm, mean body weight 68.5±5.6 kg and mean body mass index 23.76±3.22 kg/m^2. There was no significant difference in the normalized electromyography activities of the vastus medialis oblique and vastus lateralis muscles between males and females (p>0.05). Also, no significant difference was found in the activation ratio between the genders (p>0.05).

Conclusion: There were no gender-based differences in the activation ratio of vastus medialis oblique to vastus lateralis during weight-bearing and non-weight-bearing activities.

Keywords: Quadriceps muscle, Patellofemoral pain, Sex factors, Weight, Electromyography.

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Introduction

The patella, which is considered a sesamoid bone, is connected to the quadriceps muscle and acts to increase the mechanical efficiency of the knee during extension, and in turn decreases capsular tension, friction and load on the knee joint cartilage.[1] Patellofemoral pain syndrome (PFPS) is twice as prevalent in females as males, and is caused by the delayed activation of the vastus medialis oblique (VMO) relative to the vastus lateralis (VL), which has been proposed as a risk factor for PFPS.[2]

A study reported that in runners of both genders with PFP syndrome, there was a significant decrease in the VM and rectus femoris (RF) muscle activation compared to the control group, indicating a relationship between knee pain related to PFPS and the imbalance of bioelectric activity of VM and RF muscles.[3] Recently, Pavone et al.[4] reported that the incidence of clinical symptoms connected to PFPS was not correlated with the amount of athletic activity in young female athletes.

Neuromuscular imbalance of the VMO in relation to the VL muscle was supposed to be a key contributing factor in PFPS[5,6], which creates malt racking of the patella through the femoral trochlea.[7] Patella malt racking was considered to increase load on the joint cartilage, accelerating cartilage degeneration.[8] Specific exercises were recommended to restore the VMO/VL activation ratio, such as the partial lung exercise[9], and sling-based closed kinetic knee extension exercise.[10]

Moreover, malalignment of patellofemoral joint can disturb the balance of the nearby structures, including muscles, tendons and joints.[5] Subsequently, increasing the dynamic balance between knee musculature and the overall strength of lower extremity musculature can help in the prevention of knee disorders and injuries.

In both the step-up and stepdown stages of the stair-stepping exercise, the electromyographic (EMG) commencement of VL in PFPS subjects happened before that of VMO.[11] In comparison to healthy participants, a review research revealed a trend towards a delayed onset of VMO relative to VL[12], which was linked to a considerable

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loss in the knee extension strength.[13] However, the EMG timing of sit to stand, stand to sit, squat, step-up and stepdown activities did not differ between healthy and PFPS subjects until the peak.[14]

Bouillon et al.[15] reported that muscle activation among rectus abdominus (RA), external oblique (EO), erector spinae (ES), RF, tensor fascia latae (TFL), gluteus medius (GM), gluteus maximus (GMx) and biceps femoris (BF) muscles was similar in females and males during the sidestep and stepdown tasks in healthy participants. However, females demonstrated decreased VMO/VL activation ratio compared to males.[16] During drop-landing, the mean ratio of the VMO/VL muscle was 1.07 for males and 0.78 for females.[17] A recent review study showed that there were no significant differences between muscle activity and muscle contraction timing in both genders of all lower limb muscles except VL.[18] Gender differences in VMO and VL activity is theoretically regarded as a contributing factor to the higher prevalence of PFPS in females.[17,18]

Nevertheless, there is no agreement in literature about the presence of clear difference in VMO and VL amplitude and latency between genders and about the reasons of gender differences, if present. It was found that gender does not affect the VMO/VL activation ratio throughout execution of different forms of exercise, including closed and open-chain exercises, and the relative EMG activity should not be considered a predisposing factor to the claimed higher prevalence of PFPS in females.[19] Bowyer et al.[20] detected no difference in EMG intensity of VMO/VL activation ratio between one male and one female, and excluded the difference in quadriceps intensity ratio as a contributing factor in the incidence of PFPS in healthy subjects. Similar studies found that gender did not affect the activity of VM muscle during dynamic contraction.[21,22]

In contrast, it has been reported that the females have lower activation in the VMO muscle and higher activation in the VL muscle than the males. The VMO motor units of females fire faster than males.[23] Similar studies examined gender differences in the activity of major knee joint muscles without comparing VMO and VL activation, and detected some gender differences.[24,25] According to a recent study[26], females produce muscle force in the VL muscle using distinct neuromuscular recruitment strategies different from males, which are characterised by smaller motor units discharging more quickly.

The disparity in the VMO/VL activation ratio may explain the gender variation in the occurrence of PFPS during weight-bearing and non-weight-bearing activities. Moreover, understanding the differences in the knee joint muscle activation between males and females may help health practitioners identify athletes who may be at the risk of injury.[27]

The current study was planned to investigate the effect of gender on VMO/VL activation ratio during straight leg raising (SLR) and stepdown activities. It was hypothesised that there would be no significant differences between the genders during weight-bearing and non-weight-bearing activities.

Subjects and Methods

The cross-sectional study was conducted at the College of Medical Rehabilitation Sciences, Taibah University, Medina, Kingdom of Saudi Arabia from September 2021 to March 2022. After approval from the institutional ethics review committee, the sample size was calculated using G*Power 3.1.9.4.[28] A pilot study was done on 5 males and 5 females to estimate the effect size. The sample was determined with effect size 0.75, alpha 0.05 and power 0.80. Flyers were dispersed throughout the campus and the neighbourhood to recruit subjects. The sample comprised recreationally active subjects without knee pathology. Persons were considered recreationally active if they engaged in recreational activities 3-5 times per week for at least 30 minutes each session.[15] Those with musculoskeletal, cardiovascular, vestibular, visual, or balance issues as well as a history of back injuries, back discomfort, or back deformities requiring medical attention were excluded. After taking written informed consent from the subjects, they were divided into 2 equal gender-based groups.

Surface EMG was measured from VMO and VL using a portable EMG machine (DELSYS Myomonitor). For electrode placement on the dominant leg, each subject was requested to relax in half-lying position. First, skin cleaning was done with alcohol followed by the application of conducting gel. For VMO, recording electrode was placed 4cm above and 3cm medial to the supero-medial edge of the patella and directed 55° to the femur.[11] For VL, the electrode was positioned 10cm above and 7cm lateral to the upper edge of the patella with 15° orientation angle to the femur with the reference electrode fixed on the contralateral tibial tuberosity[11,29] (Figure 1). All measurements were taken at the same time of the day (13:00-16:00 hrs) to avoid the diurnal variations in muscle force and flexibility.[30]

For SLR, after assuming the starting position, each participant was asked to practise SLR with keeping the knee straight and with neutral rotation of the hip. The leg was raised to the level that the heel of the exercised leg approached a guiding card with a length of 17.5cm, then holding the contraction for 3 seconds. Three trials were completed with a 30-se rest between the trials[20] (Figure 2).

With respect to stepdown exercise, after standing over a 19cm step with feet apart and toes just behind the edge of the step, each subject was requested to step down from the step for three trials (21) (Figure 3). The test is known to aggravate PFPS symptoms.[31,32]

Maximal voluntary isometric contraction (MVIC) of the quadriceps was measured to help normalise EMG data.[33,34] Rectification and smoothening of raw EMG data was done using AcqKnowledge 3.7 analysis software with 6Hz low-pass filter. EMG values of VMO and VL were averaged for each activity and the mean of the three trials was calculated. After determining the average EMG for MVIC recordings, the average EMG was determined in a similar fashion, and normalisation was obtained for SLR and stepdown activities as a percentage of MVIC.[33,35] Utilising MVIC for normalisation has shown good reliability and permits representation of muscle activity as an expression of activity in an understandable ratio.[33] The VMO/VL activation ratio during SLR and stepdown activities was determined by dividing the normalised value of VMO by that of VL.

Data was analysed using SPSS 25. For comparing demographic characteristics, independent t-test was used. Data normality was checked using Shapiro-Wilk test, while homogeneity between the groups was checked using Levene's test. Independent t-test was used to compare the normalised EMG values of VMO and VL as well as VMO/VL ratio of the two groups. P<0.05 was considered statistically significant with 95% confidence interval (CI).

Results

Of the 60 subjects, there were 30(50%) males with mean age 30.00±5.91 years, mean height 167±5.63cm, mean body weight 66.76±6.14kg, and mean body mass index (BMI) 23.97±3.02kg/m^2. There were 30(50%) females with mean age 29.03±5.34 years, mean height 186±6.20cm, mean body weight 68.5±5.6kg and mean BMI 23.76±3.22kg/m^2. There was no significant differences between the two groups in terms of age (p=0.540), weight (p=0.291), height (p=0.360) and BMI (p=0.801).

Figure-1: Electrode placement.

Figure-2: Straight leg raise (SLR) exercise.

Figure-3: Stepdown activity.

Table : Mean normalised values of VMO and VL muscles and the VMO/VL activation ratio.

		Male group (Mean ±SD)	Female group (Mean ±SD)	MD (95% CI)	t-value	*p-value*
Step down	VMO (%)	20.12 ± 2.71	19.00 ± 2.74	1.12 (-0.39:2.64)	1.48	0.144
	VL (%)	25.39 ± 3.26	24.7 ± 3.18	0.69 (-1.1:2.48)	0.77	0.443
	VMO/VL ratio	0.79 ± 0.05	0.77 ± 0.08	0.02 (-0.01:0.05)	1.08	0.283
Straight leg raise	VMO (%)	22.31 ± 2.65	21.18 ± 2.68	1.13 (-0.36:2.61)	1.51	0.131
	VL (%)	25.76 ± 2.26	25.03 ± 2.96	0.73 (-0.74:2.19)	0.99	0.321
	VMO/VL ratio	0.86 ± 0.05	0.85 ± 0.09	0.01(-0.02:0.05)	0.71	0.470

VMO: Vastus medialis oblique, VL: Vastus lateralis, SD: Standard deviation, MD: Mean difference, CI: Confidence interval.

There was no significant difference in the normalized EMG activities of VMO and VL muscles between males and females (p>0.05). Also, no significant difference was found in the activation ratio between the genders (Table).

Discussion

The current study was conducted to determine if there is any gender effect on the VMO/VL activation ratio in recreational subjects during weight-bearing and non-weight-bearing activities. The results, in line with the null hypothesis, showed no differences in the VMO/VL activation ratio between males and females during SLR and stepdown. The finding was also consistent with earlier reports[15]. Spairani et al.[36] reported that both open and closed kinetic chain exercise similarly activate the VMO, vastus medialis longus (VML) and VL muscles. SLR and stepdown activities aggravate the PFPS symptoms, specially the closed-chain activities, and they were commonly prescribed to strengthen the quadriceps muscle[32,37] and to evaluate the efficacy of PFPS treatment.[38,39]

Thongduang et al.[37] indicated that a closed-chain squat with hip co-contraction can produce a greater activity in the VMO muscle, which led to a significant VMO/VL ratio as well, while open-chain SLR better activates the RF muscle activity. A review study[40] showed that the quadriceps muscle complex displayed the highest EMG activity throughout closed-chain exercise, which was shown to rise as the knee flexion angle increased.

The VMO muscle acts to pull the patella medially (as its fibre align obliquely from 40° to nearly horizontally) to balance the lateral pulling of the VL for the maintenance of proper patellar alignment. This shows the role of VMO as the main patellar stabilizer during knee extension.[23] To early recruit the VMO, the SLR exercise is regarded as an ideal position compared to the position of 90° knee flexion. This is due to the fact that in fully extended position, the patella moves medially with the activation of VMO, while progressive flexion of the knee is accompanied by less medial shift of the patella and lowered activation of VMO.[23,41,42]

The current findings are in line with several studies[19,20,22,43] which found no gender differences in the VMO/VL activation ratio. However, contrary findings have also been reported[16,17] by studies that investigated the VMO/VL activation ratio during weight-bearing activity in both genders, and during isometric contraction of quadricep.[2] Kim et al.[17] reported a higher ratio of VMO/VL activation ratio in males than females.

The EMG normalisation data in a study[16] was done to levels elicited with a 20-kg weight in seated knee extension. This protocol differed from the one commonly used in such circumstances in which a maximal contraction is used for the purpose.[5,32,44,45] The present study adopted the maximal contraction protocol. Furthermore, a recent review[18] concluded that all lower limb muscles except VL showed no significant difference between muscle activity and muscle contraction timing in both genders before and after foot contact.

Gender differences in EMG activities and VMO/VL activation ratio were found during vertical stepdown. EMG data was normalised to the % maximal voluntary contraction (%MVC) of knee extension executed at a combined position of 80° knee flexion and 90° hip flexion in seated position. It was concluded by a study that the likelihood of developing PFPS was higher in females than males during vertical drop-landing.[17] The contradictory findings may have been due to limited sample size and due to differences in exercises and activities used; vertical drop-landing versus SLR and stepdown. The vertical stepdown may have excessively overloaded the quadriceps muscle. Also, the pattern of activity differed between males and females as the females did not flex their knees sufficiently during vertical landing.[17] Additionally, during single-leg drop-landings, females had a decrease in the semitendinosus/VL pre-activation ratio, which was projected to result in an increase in knee anterior reaction force.[46]

To determine the ideal exercises for the management of PFPS, the VMO/VL activation ratio was measured during hip adduction and terminal knee extension exercises in an open-chain design. There were no gender differences observed during hip adduction training, while EMG activity of the VL was higher than VMO activity in males during the terminal knee extension training.[47] Moreover, Coqueiro et al.[32] found that the VL muscle was significantly greater than that of the VMO muscle during double-leg semi-squat exercise trials without hip adduction exercises only for females with PFPS. However, no differences were found between healthy females and others with PFPS during double-leg semi-squat exercise trials with maximum hip adduction isometric contraction exercises. In line with the present findings, no gender differences were found in the EMG intensity ratio of VMO/VL activation in healthy subjects during SLR and stepdown activities.[20] But the earlier findings should be considered with caution due to their limited sample size having one female and one male.

The average of VMO/VL activation ratio during stepdown activity was lower in participants with PFPS compared to healthy subjects.[43,48,49] These findings may indicate that PFPS may be related to lowered activity of VMO muscle[3], and the authors also observed that the activity of VMO and

VL in healthy females was doubled to enable them to execute the stepdown activity compared to the males. The current study did not find gender differences in VMO/VL activation ratio in healthy subjects, but such differences may be present in subjects with PFPS. Also, there were many differences in the methodology of various studies, like normalisation protocol, placement of electrodes and type of recording electrodes. These variations may lead to contradictory results.

The current results reflected no gender differences in VMO/VL activation ratio during stepdown and SLR. In contrast, Kim et al.[17] observed differences in the of VMO/VL activation ratio, which may be explained by adoption of other activities that overloaded the quadriceps. Also, other variables may be relevant to the higher prevalence of PFPS in females than males, such as a wider Q angle in females that affects the distance between attachments of VL muscle, smaller knee bending angle during vertical landing in females' fat mass, or strength per body weight.[17,50-52]

According to a recent study, the VMO/VL activation ratio was not significantly different between healthy individuals and those with PFPS. Additionally, performing the proprioception neuromuscular facilitation (PNF) patterns under load dramatically increased the activity of the VMO and VL muscles. Furthermore, it was found that the VMO/VL activation ratio values in PNF patterns were substantially higher in the PFPS group. Therefore, the PNF patterns can be said to engage the VMO muscle more than the SLR.[53] These findings could explain the inability of SLR to elicit high activation of the VMO and VL muscles. Moreover, a study conducted on female with and without PFPS showed that backward walking increases VMO muscle activation and maintains the VMO/VL ratio in PFPS subjects[54], which should be considered during further weight-bearing testing of VMO/VL activation ratio.

The current study has some significant limitations, including the lack of data related to muscle strength, such as torque, and power, and the absence of functional tests. The fact that the participants did not exert their true maximum effort during the muscle testing utilised to determine the MVIC is another potential limitation. Even though both men and women were enrolled, the participants were generally young, healthy and active in their leisure time. Evaluation of other age categories was not done. Cross-talk with the use of surface EMG electrodes with nearby muscles is also a constraint as each of the muscles evaluated,[29,55] standardised electrode implantation was adopted. According to some reports, placing surface EMG electrodes using a regular procedure enhances the quality of the recordings at each muscle site.[29] Future research should investigate possible VMO/VL activation ratio gender differences in subjects with PFPS because important factors like Q angle and knee-bending, and tibiofemoral angles, which may be more associated with higher incidence of PFPS[56], with consideration of body position during measurement of the Q angle, where the standing position aggravates the symptoms of the PFPS more than the supine position.[57] Future studies should evaluate the effect of gender on the VMO/VL activation ratio during backward walking, as it develops more activations of the quadriceps muscles.[58] Finally, the leg length of the participants was not considered during normalisation of the obtained EMG data.[15]

Conclusion

Gender differences in the VMO/VL activation ratio during weight-bearing and non-weight-bearing activities were not found.

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References

1. Neumann DA. Kinesiology of the musculoskeletal system: foundations for physical rehabilitation, 2nd ed. St. Louis, Missouri: Mosby. Inc, 2010; pp 522–26.
2. Peng YL, Johnson AE, Griffin L. Sex differences in neuromuscular control of quadriceps. Eur J Appl Physiol 2020;120:2193-202. doi: 10.1007/s00421-020-04443-0.
3. Gawda P, Ginszt M, Zawadka M, Skublewska-Paszkowska M, Smołka J, Łukasik E, et al. Bioelectrical Activity of Vastus Medialis and Rectus Femoris Muscles in Recreational Runners with Anterior Knee Pain. J Hum Kinet 2019;66:81-8. doi: 10.2478/hukin-2018-0065.
4. Pavone V, Vescio A, Panvini FMC, Lucenti L, Caldaci A, Sapienza M, et al. Patellofemoral Pain Syndrome in Young Female Athletes: A Case-Control Study. Adv Orthop 2022;2022:e1907975. doi: 10.1155/2022/1907975.
5. Tang SF, Chen CK, Hsu R, Chou SW, Hong WH, Lew HL, 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;82:1441-5. doi: 10.1053/apmr.2001.26252.
6. Chen S, Chang WD, Wu JY, Fong YC. Electromyographic analysis of hip and knee muscles during specific exercise movements in females with patellofemoral pain syndrome: An observational study. Medicine (Baltimore) 2018;97:e11424. doi: 10.1097/MD.

0000000000011424.
7. O'Sullivan SP, Popelas CA. Activation of vastus medialis obliquus among individuals with patellofemoral pain syndrome. J Strength Cond Res 2005;19:302-4. doi: 10.1519/1533-4287(2005)19[302:AOVMOA]2.0.CO;2.
8. Powers CM, Landel R, Perry J. Timing and intensity of vastus muscle activity during functional activities in subjects with and without patellofemoral pain. Phys Ther 1996;76:946-55. doi: 10.1093/ptj/76.9.946.
9. Nam KS. Comparison of the VMO/VL EMG activity ratio according to resistance condition in partial lunge exercise. J Kor Phys Ther 2020;32:273–6. Doi: 10.18857/jkpt.2020.32.5.273.
10. Chang WD, Huang WS, Lai PT. Muscle Activation of Vastus Medialis Oblique and Vastus Lateralis in Sling-Based Exercises in Patients with Patellofemoral Pain Syndrome: A Cross-Over Study. Evid Based Complement Alternat Med 2015;2015:e740315. doi: 10.1155/2015/740315.
11. Cowan SM, Bennell KL, Hodges PW, Crossley KM, McConnell J. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Arch Phys Med Rehabil 2001;82:183-9. doi: 10.1053/apmr.2001.19022.
12. Chester R, Smith TO, Sweeting D, Dixon J, Wood S, Song F, et al. The relative timing of VMO and VL in the aetiology of anterior knee pain: a systematic review and meta-analysis. BMC Musculoskelet Disord 2008;9:64. doi: 10.1186/1471-2474-9-64.
13. Vora M, Curry E, Chipman A, Matzkin E, Li X. Patellofemoral pain syndrome in female athletes: A review of diagnoses, etiology and treatment options. Orthop Rev (Pavia) 2018;9:e7281. doi: 10.4081/or.2017.7281.
14. Cavazzuti L, Merlo A, Orlandi F, Campanini I. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Gait Posture 2010;32:290-5. doi: 10.1016/j.gaitpost.2010.06.025.
15. Bouillon LE, Wilhelm J, Eisel P, Wiesner J, Rachow M, Hatteberg L, et al. Electromyographic assessment of muscle activity between genders during unilateral weight-bearing tasks using adjusted distances. Int J Sports Phys Ther 2012;7:595-605.
16. Myer GD, Ford KR, Hewett TE. The effects of gender on quadriceps muscle activation strategies during a maneuver that mimics a high ACL injury risk position. J Electromyogr Kinesiol 2005;15:181-9. doi: 10.1016/j.jelekin.2004.08.006.
17. Kim MH, Yoo WG, Yi CH. Gender differences in the activity and ratio of vastus medialis oblique and vastus lateralis muscles during drop landing. J Phys Ther Sci 2009;21:325–9. DOI:10.1589/jpts.21.325.
18. Seyedahmadi M, Minoonejad H, Ardakani MK, Heidari Z, Bayattork M, Akbari H, et al. What are gender differences in lower limb muscle activity during jump-landing tasks? A systematic review and meta-analysis. BMC Sports Sci Med Rehabil 2022;14:77. doi: 10.1186/s13102-022-00469-3.
19. Herrington L, Blacker M, Enjuanes N, Smith P, Worthington D. The effect of limb position, exercise mode and contraction type on overall activity of VMO and VL. Phys Ther Sport 2006;7:87–92. DOI:10.1016/J.PTSP.2006.01.003.
20. Bowyer D, Armstrong M, Dixon J, Smith TO. The vastus medialis oblique: vastus lateralis electromyographic intensity ratio does not differ by gender in young participants without knee pathology. Physiotherapy 2008;94:168–73. Doi: 10.1016/j.physio.2007.08.007.
21. Carneiro JG, Gonçalves EM, Camata TV, Altimari JM, Machado MV, Batista AR, et al. Influence of gender on the EMG signal of the quadriceps femoris muscles and performance in high-intensity short-term exercise. Electromyogr Clin Neurophysiol 2010;50:326-32.
22. Gallina A, Gazzoni M. Selective activation of muscle sub-portions within the vastus medialis: effect of gender, knee angle and force level. Ital J Physiother 2013;3:20–9.
23. Peng YL, Tenan MS, Griffin L. Hip position and sex differences in motor unit firing patterns of the vastus medialis and vastus medialis oblique in healthy individuals. J Appl Physiol (1985) 2018;124:1438-46. doi: 10.1152/japplphysiol.00702.2017.
24. White KK, Lee SS, Cutuk A, Hargens AR, Pedowitz RA. EMG power spectra of intercollegiate athletes and anterior cruciate ligament injury risk in females. Med Sci Sports Exerc 2003;35:371-6. doi: 10.1249/01.MSS.0000053703.65057.31.
25. Zeller BL, McCrory JL, Kibler WB, Uhl TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. Am J Sports Med 2003;31:449-56. doi: 10.1177/03635465030310032101.
26. Guo Y, Jones EJ, Inns TB, Ely IA, Stashuk DW, Wilkinson DJ, et al. Neuromuscular recruitment strategies of the vastus lateralis according to sex. Acta Physiol (Oxf) 2022;235:e13803. doi: 10.1111/apha.13803.
27. Moltó IN, Albiach JP, Amer-Cuenca JJ, Segura-Ortí E, Gabriel W, Martínez-Gramage J, et al. Wearable Sensors Detect Differences between the Sexes in Lower Limb Electromyographic Activity and Pelvis 3D Kinematics during Running. Sensors (Basel) 2020;20:6478. doi: 10.3390/s20226478.
28. Kang H. Sample size determination and power analysis using the G*Power software. J Educ Eval Health Prof 2021;18:e17. doi: 10.3352/jeehp.2021.18.17.
29. Criswell E. Introduction. In: Criswell E, eds. Cram's Introduction to Surface Electromyography, 2nd ed. Sadbury, Massachusetts: Jones and Bartlett Publishers LLC, 2011; pp 5–9.
30. Abdel-Aziem AA, Draz AH, Mosaad DM. The long-term effects of static stretching at different times of day on hamstring peak torque and flexibility in trained individuals. Physiother Q 2018;2018:13–20. Doi: 10.5114/pq.2018.734044.
31. Witvrouw E, Lysens R, Bellemans J, Cambier D, Cools A, Danneels L, et al. Which factors predict outcome in the treatment program of anterior knee pain? Scand J Med Sci Sports. 2002;12:40-6. doi: 10.1034/j.1600-0838.2002.120108.x.
32. Coqueiro KR, Bevilaqua-Grossi D, Bérzin F, Soares AB, Candolo C, Monteiro-Pedro V, et al. Analysis on the activation of the VMO and VLL muscles during semisquat exercises with and without hip adduction in individuals with patellofemoral pain syndrome. J Electromyogr Kinesiol 2005;15:596-603. doi: 10.1016/j.jelekin.2005.03.001.
33. Soderberg GL, Knutson LM. A guide for use and interpretation of kinesiologic electromyographic data. Phys Ther 2000;80:485-98. Doi: 10.1093/PTJ/80.5.485.
34. Hertel J, Earl JE, Tsang KK, Miller SJ. Combining isometric knee extension exercises with hip adduction or abduction does not increase quadriceps EMG activity. Br J Sports Med 2004;38:210-3. doi: 10.1136/bjsm.2002.003277.
35. Karst GM, Jewett PD. Electromyographic analysis of exercises proposed for differential activation of medial and lateral quadriceps femoris muscle components. Phys Ther 1993;73:286-95. doi: 10.1093/ptj/73.5.286.
36. Spairani L, Barbero M, Cescon C, Combi F, Gemelli T, Giovanetti G, et al. An electromyographic study of the vastii muscles during open and closed kinetic chain submaximal isometric exercises. Int J Sports Phys Ther 2012;7:617-26.
37. Thongduang P, Chatchawan U, Puntumetakul R, Yamauchi J, Peungsuwan P. Quadriceps Electromyographic Activity in Closed and Open Kinetic-Chain Exercises with Hip-Adductor Co-Contraction in Sedentary Women. Int J Environ Res Public Health 2022;19:12929.

doi: 10.3390/ijerph191912929.

38. Hott A, Brox JI, Pripp AH, Juel NG, Liavaag S. Patellofemoral pain: One year results of a randomized trial comparing hip exercise, knee exercise, or free activity. Scand J Med Sci Sports 2020;30:741-53. doi: 10.1111/sms.13613.
39. Hott A, Brox JI, Pripp AH, Juel NG, Paulsen G, Liavaag S, et al. Effectiveness of Isolated Hip Exercise, Knee Exercise, or Free Physical Activity for Patellofemoral Pain: A Randomized Controlled Trial. Am J Sports Med 2019;47:1312-22. doi: 10.1177/0363546519830644.
40. Martín-Fuentes I, Oliva-Lozano JM, Muyor JM. Evaluation of the Lower Limb Muscles' Electromyographic Activity during the Leg Press Exercise and Its Variants: A Systematic Review. Int J Environ Res Public Health 2020;17:4626. doi: 10.3390/ijerph17134626.
41. Lin F, Wang G, Koh JL, Hendrix RW, Zhang LQ. In vivo and noninvasive three-dimensional patellar tracking induced by individual heads of quadriceps. Med Sci Sports Exerc 2004;36:93-101. doi: 10.1249/01.MSS.0000106260.45656.CC.
42. Huang W, Zeng X, Man GC, Yang L, Zhang Y. Simultaneous Measurement of Patellofemoral Joint Kinematics and Contact Mechanics in Intact Knees: A Cadaveric Study. Orthop Surg 2022;14:2317-29. doi: 10.1111/os.13394.
43. Cerny K. Vastus medialis oblique/vastus lateralis muscle activity ratios for selected exercises in persons with and without patellofemoral pain syndrome. Phys Ther 1995;75:672-83. doi: 10.1093/ptj/75.8.672.
44. Cesarelli M, Bifulco P, Bracale M. Study of the control strategy of the quadriceps muscles in anterior knee pain. IEEE Trans Rehabil Eng 2000;8:330-41. doi: 10.1109/86.867875.
45. Mohr KJ, Kvitne RS, Pink MM, Fideler B, Perry J. Electromyography of the quadriceps in patellofemoral pain with patellar subluxation. Clin Orthop Relat Res 2003;415:261-71. doi: 10.1097/01.blo.0000093918.26658.6a.
46. Xu X, Hu G, Williams GKR, Ma F. Gender comparisons and associations between lower limb muscle activation strategies and resultant knee biomechanics during single leg drop landings. Biomech 2022;2:562–74. Doi: 10.3390/biomechanics2040044.
47. Balogun JA, Broderick K, Dolan-Aiello M. Comparison of the EMG activities in the vastus Medialis oblique and vastus lateralis muscles during hip adduction and terminal knee extension exercise protocols. AJPARS 2010;2:1–5. DOI: 10.4314/ajprs.v2i1.62597.
48. Mazaheri M, Motealleh A, Sobhani S, Yoosefinejad AK. Evaluating electromyographic activity of vastus medialis obliqus, vastus lateralis, and hamstrings in women with patellofemoral pain syndrome. Res Sq 2020. DOI: 10.21203/rs.2.22420/v1. [Preprint]
49. Lobo P, Junior, Barbosa IA, Neto, Borges JHDS, Tobias RF, et al. Clinical muscular evaluation in patellofemoral pain syndrome. Acta Ortop Bras 2018;26:91-93. doi: 10.1590/1413-785220182602187215.
50. Natri A, Kannus P, Järvinen M. Which factors predict the long-term outcome in chronic patellofemoral pain syndrome? A 7-yr prospective follow-up study. Med Sci Sports Exerc 1998;30:1572-7. doi: 10.1097/00005768-199811000-00003.
51. Choudhary R, Malik M, Aslam A, Khurana D, Chauhan S. Effect of various parameters on Quadriceps angle in adult Indian population. J Clin Orthop Trauma 2019;10:149-54. doi: 10.1016/j.jcot.2017.11.011.
52. Chaudhary S, Jain SK, Sharma N, Bhatnagar S. Analysis of Predictors Affecting Biomechanical Function of the Knee Joint and Its Relation to Anterior Knee Pain. Cureus 2022;14:e21305. doi: 10.7759/cureus.21305.
53. Lotfi H, Moghadam AN, Shati M. Electromyography Activity of Vastus Medialis Obliquus and Vastus Lateralis Muscles During Lower Limb Proprioceptive Neuromuscular Facilitation Patterns in Individuals with and without Patellofemoral Pain Syndrome. Phys Ther Res 2021;24:218-24. doi: 10.1298/ptr.E10094.
54. Abdelraouf OR, Abdel-Aziem AA, Ahmed AA, Nassif NS, Matar AG. Backward walking alters vastus medialis oblique/vastus lateralis muscle activity ratio in females with patellofemoral pain syndrome. Turk J Phys Med Rehabil 2019;65:169-76. doi: 10.5606/tftrd.2019.2445.
55. Rainoldi A, Melchiorri G, Caruso I. A method for positioning electrodes during surface EMG recordings in lower limb muscles. J Neurosci Methods 2004;134:37-43. doi: 10.1016/j.jneumeth.2003.10.014.
56. El Gharib MH, El Tohamy AM, Mohamed NE. Determining the relationship between the quadriceps and tibiofemoral angles among adolescents. J Taibah Univ Med Sci 2021;16:70–6. Doi: 10.1016/j.jtumed.2020.10.003.
57. Abdel-aziem AA, Abdelraouf OR, El-Gohary TM. Effect of body position on measurement of Q angle in trained individuals with and without patellofemoral pain. Int J Ther Rehabil Res 2014;3:1–5. DOI:10.5455/ijtrr.00000031.
58. Abdelraouf OR, Abdel-Aziem AA, Ahmed AA, Nassif NS, Matar AG. Backward walking effects on activation pattern of leg muscles in young females with patellofemoral pain syndrome. Int J Ther Rehabil 2019;26:1–9. doi: 10.5606/tftrd.2019.2445.