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The Relationship Between Quadriceps Muscle Activation and Q Angle on Dynamic Balance in Women

Kadınlarda Kuadriseps Kas Aktivasyonu ile Dinamik Dengede Q Açısı Arasındaki İlişki

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Öz

Giriş: Alt ekstremite biyomekaniği, Q açısı, kuadriseps kas aktivasyonu ve denge arasındaki ilişkiyi etkiler.
Amaç: Kadınlarda dinamik dengede Q açısı ile kuadriseps kas aktivasyonu arasındaki ilişkiyi incelemek amaçlanmıştır.
Gereç ve Yöntem: Çalışmaya 40 kadın dahil edilmiştir. Tek ayak üstünde dinamik denge sırasında kuadriseps kas aktivasyonu kaydedilmiştir. Q açısı bir mezura ile; kas aktivasyonu yüzeyel Elektromiyografi ile; statik denge Flamingo Denge Testi ile; dinamik denge TechnoBody PK 200WL bilgisayarlı denge cihazıyla ve fonksiyonellik Kısa Form Kas-iskelet Değerlendirmesi ile ölçülmüştür.
Bulgular: Ayakta ve sırtüstü pozisyonda Q açısı ve vastus medialis kas aktivasyonu arasında istatistiksel olarak anlamlı, pozitif korelasyon saptandı (sırasıyla; r=0.35, p=0,02; r=0.40, p=0.01). Ayakta/sırtüstü pozisyonda Q açısı ile çevre uzunluğu arasında istatistiksel olarak anlamlı pozitif korelasyon bulunmuştur (sırasıyla; r=0.33, p=0.04; r=0.32, p=0.04). Alan boşluk yüzdesi ve ayakta Q açısı (r=0.89, p=0.02), sırtüstü pozisyon Q açısı değerleri (r=0.63, p=0.03) pozitif korelasyon göstermiştir.
Sonuç: Vastus medialis daha kuvvetlenirse Q açısı daha normalleşir, böylece kuadriseps kası güçlendirme egzersizleri Q açısının normalleşmesine yardımcı olur. Ayrıca Q açısı normalleştirildiğinde tek ayak üstünde durma dengesi artacaktır.

Anahtar Kelimeler: Q açısı, Kuadriseps kas aktivasyonu, Elektromiyografi, Denge

Abstract

Introduction: Lower extremity biomechanics affects the relationship between Q angle, quadriceps muscle activation and balance.
Objective: The aim was to examine the relationship between Q angle and quadriceps muscle activation on dynamic balance position in women.
Materials and Methods: Forty women were included in the study. The muscle activation of the quadriceps during dynamic balance in a single-leg stance was recorded. A tape measure was used to measure Q angle, surface electromyography was used to assess muscle activation, the Flamingo Balance Test was used to assess static balance, the TechnoBody PK 200WL computerized balance device was used to assess dynamic balance, and the Short Form Musculoskeletal Assessment was used to assess functionality.

Results: There was a statistically significant positive correlation between the Q angle standing and supine position and vastus medialis muscle activation respectively, (r=0.35, p=0,02; r=0.40, p=0.01). There was a statistically significant positive correlation between the perimeter length and Q angle in standing/supine position respectively, (r=0.33, p=0.04; r=0.32, p=0.04). Area gap percentage and Q angle standing (r=0.89, p=0.02), supine position Q angle values (r=0.63, p=0.03) were positively correlated.
Conclusion: If vastus medialis is more strengthened, the Q angle would be more normalized, so quadriceps muscle strengthening exercises are helpful for the normalization of the Q angle. Also, when the Q angle is normalized, a single-leg balance would be improved.

Keywords: Q angle, Quadriceps muscle activation, Electromyography, Balance

1. Introduction

Q angle is the angle between the quadriceps muscle extensor mechanism and the patellar tendon [1]. Clinically, drawing two imaginary lines from the anterior superior iliac spine to the center of the patella and from the tibial tuberosity through the middle of the patella creates the Q angle in the frontal plane [1]. Normal values of Q angle are reported to range from 10° to 14° for males, and 14.5° to 17° for females [2]. Women consistently have higher Q angles than males, and patellofemoral issues afflict them more frequently because of the increased pelvic width, shorter femur length, femoral neck anteversion and quadriceps muscle weakness [3].

Anatomical alignment of the lower extremity has been reported as a risk factor, especially for lower extremity injuries such as knee injuries [3]. Abnormal changes in the Q angle cause impairments in neuromuscular control or distortion of the knee joint motion plane and joint overload. Therefore, the abnormal changes observed in the Q angle can lead to injuries in individuals as a result of the abnormal force applied by the quadriceps muscle to the knee joint. Accordingly, the Q angle has been associated with the dynamic balance of vastus medialis and vastus lateralis muscles. Besides, quadriceps muscle activation is considered an important aspect of balance. The delays in the muscle activation initiation times in the vastus medialis relative to the vastus lateralis and the differences in the balance between each other may result from disorders in the lower extremity alignment due to the Q angle [4]. It is known that females have larger Q angles than men. Women who have excessive Q angles may be more likely to experience higher Q angle changes after performing isometric quadriceps contractions. A significant decrease in the Q angle may point to the presence of an imbalance in the strength of the quadriceps muscles, even if a minor decrease in the Q angle with quadriceps isometric activation would be expected. Especially, it is thought that the vastus medialis actively counterbalances the valgus pressures acting on the patellofemoral joint. Weakness of the vastus medialis may decrease the Q angle and muscle activation of the quadriceps due to the patella displacing laterally [5].

The Q angle provides an overview of the biomechanics of the lower extremities. Knee kinematics are impacted by changes to Q angle in both static and dynamic postural situations [6]. According to the studies, postural sway problems and quadriceps muscle weakness damage the balance of the lower extremity [7,8]. Nguyen et al. reported that biomechanical problems of the knee joint and muscle weakness lead to difficulty in controlling balance in activities in daily living [9]. Especially, it is known that lower extremity biomechanics affects the relationship between Q angle and the balance in the posterior direction [10].

There are not many studies of knee joint biomechanics concerning balance ability, quadriceps muscle activation and functionality in women. The purpose of this study was to examine the relationship between Q angle and quadriceps muscle activation on dynamic balance in women.

2. Materials And Methods

2.1. Study Design

This research has been approved by the Institutional Review of Board the authors' affiliated institutions and was conducted in accordance with the principles of the Declaration of Helsinki. The study was approved by XXX University Institutional Non-Invasive Ethics Committee (Decision number:XXX/date:10.06.2020). Eligible participants received written information and provided informed consent before participation. The protocol of the study was registered at ClinicalTrials.gov (XXX).

2.2. Participants

The sample size was determined using the G*power sample size calculator. The required sample size was 45 with an 85% power (α=0,05), considering the minimal clinically important difference of 8 points in the Balance Evaluation Systems Test [11]. We aimed to enroll at least 40 participants considering the drop-outs.

The participants who were women 19-25 years of age, not having musculoskeletal or neurological problems, not having any communication problems were included in the study. The exclusion criteria include having undergone surgery within the previous year, using medication for lower limb issues, and experiencing persistent pain or discomfort in the lower extremities. Fifty participants were screened, forty women between the ages of 19–25 were included in the study.

2.3. Procedures

Forty healthy young women of age 19-25 years were selected for the study. The purpose of the study, procedure, potential benefits and possible risk was explained to all participants before the study and written consent has obtained. The Q angle measured in the supine and standing positions, as well as the electromyographic (EMG) amplitude on dynamic balance position, were examined. The vastus medialis and vastus lateralis muscle activation during dynamic balance position was measured using the EMG signals, which were then recorded. All participants' functional status, static and dynamic balance, and Q angle were assessed.

2.3.1. Leg dominance evaluation

Leg dominance was determined by the ball-kicking test.

2.3.2. Q angle evaluation

With the use of a conventional universal goniometer, the Q angle was calculated. It was measured by drawing two lines: one from the center of the tibial tubercle to the center of the patella and the other from the anterior superior iliac spine to the patella. The Q angle is the angle formed by the intersection of these lines. The Q angle was measured while the subject was seated and standing. Whether patients were standing with their feet a comfortable width apart, knees straight, and feet in a natural position without shoes, participants were positioned in the supine position with the quadriceps completely relaxed (Figure 1 and Figure 2). The same researcher took each measurement three times for the right leg. The recorded average value was accepted as the Q angle [12].

Figure 1. Q angle in supine position

Figure 2. Q angle in standing position

2.3.3. EMG measurement

A device called EMG biofeedback monitors neuromuscular contractions and sends participants feedback signals [13]. Electrode location and placement techniques will be undertaken by Basics of Surface EMG applied to Physical Rehabilitation and Biomechanics recommendations [13]. The skin was cleaned with ethanol and the surface electrode interface was made from medical-grade adhesive. Accordingly, the reference electrode was positioned at the opposing extremity, while the active electrode was positioned at the motor point. The vastus medialis and lateralis motor points were positioned 5–6 cm and 10 cm, respectively, above the superomedial and lateral corners of the patella. Quadriceps muscle activation data was recorded in dynamic balance in a single-leg stance evaluated with the PK 200WL device.

2.3.4. Static Balance Evaluation

Static balance was examined with Flamingo Balance Test (FBT) in open and closed eyes conditions. The participants stood on the 50 cm long, 5 cm tall, and 3 cm wide beam. The free leg was flexed at the knee and the foot was held close to the buttocks while standing on the dominant leg. The participant then attempted to maintain this position for a full minute while the instructor started the stopwatch. Every time the participants wobbled, the stopwatch was stopped. It was restarted until they once again lost their balance. After the allotted time had passed, the participants' subsequent tries were added up, and this score was recorded [14].

2.3.5. Dynamic Balance Evaluation

For dynamic balance testing, a TechnoBody PK200WL computerized balance device was used. During the TechnoBody PK200WL balance system, vastus medialis and vastus lateralis muscle activity levels were recorded at 1000-Hz sample data-regulating Surface EMG device (Chattanooga Intelect Advanced Color Stim+ EMG) and analyzed using the Biometrics Datalog (UK) system. The participants' dominant side bare feet were positioned uniformly on the balance platform. The subject is required to move in a reference circle on a computer screen, which continuously provides visual input to help the participant distinguish between what is happening at the motor level and what they were feeling on a kinaesthetic level. Using the easy mode, dynamic balance on the right or left foot was assessed independently for 30 seconds. Test outcomes comprised 5 variables; Perimeter length; the total number of degrees that occurred throughout the test period; Area gap percentage; percentage of the drawn area that is outside the reference circle; Medium speed; the average number of degrees traversed in a second; Medium equilibrium center-AP; the average of the values obtained on a backward-forward axis; Medium equilibrium center-ML; the average of the values obtained on a backward-forward axis (Figure 3) [15].

Figure 3. Dynamic balance measurement in PK 200WL device

2.3.6. Functionality Assessment

Participants' functional state was assessed with the help of the Short Musculoskeletal Function Assessment Questionnaire (SMFA). A wide variety of musculoskeletal injuries and diseases are examined by the SMFA, which is intended to assess patients' functional state. The SMFA has two parts (one part is the Dysfunction Index; the second part is the Bothersome Index), forty-six items, and a self-reported health status questionnaire, which can be completed in about ten minutes [16].

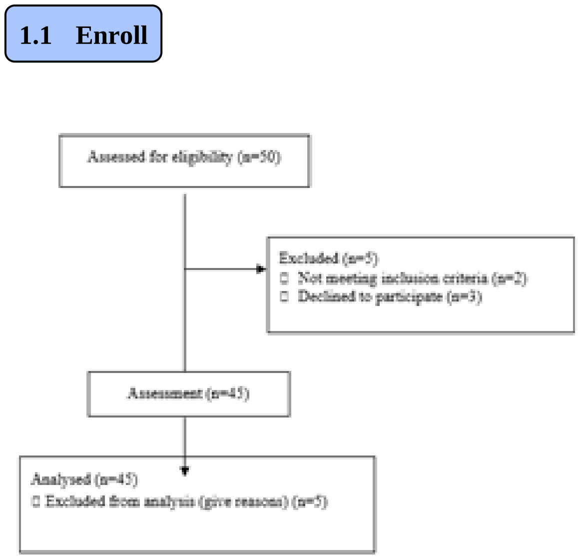
2.4. Statistical Analyses

Statistical Package for Social Sciences version 22.0 was used for the analyses (SPSS Inc, Chicago, USA). According to the situation, descriptive statistics were expressed as means and standard deviations, or as a number and proportions. Specifically, r =0.5-1.0 was strong; 0.30-0.49 was intermediate; and 0.1-0.29 was weak. The Pearson correlation coefficient (r) was utilized to examine the association between Q angle and the sum of all outcome variables (static balance, dynamic balance, and SFMA). The significance level was established at $p<0.05$.

3. Results and Discussion

Fifty women who met the inclusion criteria were included in the study. After the exclusions and drop-outs, forty women completed assessments and were analyzed in this study. The allocation of the participants was shown in Figure 4.

Figure 4. Consort flow diagram



Participants' demographic information were presented in Table 1. Vastus medialis muscle activation and Q angle values were positively correlated in standing and supine positions respectively, (r=0.35, p=0,02; r=0.40, p=0.01). There was a statistically significant positive correlation between the perimeter length and Q angle in standing/supine position respectively, (r=0.33, p=0.04; r=0.32, p=0.04). These correlations were moderate. Also, area gap percentage and Q angle standing (r=0.89, p=0.02), supine position values (r=0.63, p=0.03) were positively strongly correlated. No significant relationship was observed between Q angle results in both positions and vastus lateralis, FBT, or SFMA (p>0.05). The correlations between parameters were shown in Table 2.

Table 1. Demographic information of the participants

Variables	Mean (SD) (n=40)	Min - Max
Age (year)	21.77 (1.59)	19-25
Height (cm)	58.77 (8.57)	40-83
Weight (kg)	1.68 (0.05)	1.57-1.82
Q angle-standing position (°)	13.55 (1,69)	10-17
Q angle-supine position (°)	14.85 (1,65)	12-18
Leg dominance (R/L)	35/5	

SD: Standard deviation, R: Right, L: Left

Table 2. Pearson's correlation coefficients between Q angle and dynamic balance on single leg stance, VM/VL muscle activation, FBT and SFMA

Variables	Q angle (standing position)		Q angle (supine position)	
	p	r	p	r
VM- (EMG)	0.02*	0.35	0.01*	0.40
VL- (EMG)	0.95	-0.05	0.63	0.07
P.L. (º)	0.04*	0.33	0.04*	0.32
A.G.P (%)	0.02*	0.89	0.03*	0.63
M.S. (º/sec)	0.78	0.05	0.76	0.05
M.E.C. (AP) (º)	0.93	0.13	0.60	-0.08
M.E.C. (ML) (º)	0.77	-0.47	0.86	-0.02
FBT- open eyes	0.85	0.03	0.72	0.05
FBT- open closed	0.89	0.21	0.75	0.05
SFMA/ function index	0.06	0.30	0.64	0.07
SFMA- bothersome index	0.34	0.15	0.39	0.08

*p<0.05, VM: Vastus medialis, VL: Vastus lateralis, PL: Perimeter length, AGP: Area Gap Percentage (estimation), MS: Medium Speed. MEC(AP): Medium Equilibrium Center (Anteroposterior), MEC(ML): Medium Equilibrium Center (Medialolateral), FBT: Flamingo balance test, SFMA: Short Functional Musculoskeletal Assessment,*Correlation is significant at the p<0.05 level. (2-tailed).

3.1. Discussion

In the present study, we examined the association between quadriceps muscle activation and Q angle on dynamic balance position in women. It was found that the Q angle in standing and supine positions have a positive relationship with perimeter length and area gap percentage in dynamic balance in single-leg stance and vastus medialis muscle activation in women.

The Q angle is a crucial mechanism that affects how the musculoskeletal system balances and plays a part in how women get injured. Since women's pelvises are generally known to be wider than men's, it makes sense to suppose that their anterior superior iliac spines are similarly more lateralized. Women would experience patellar instability more frequently than males if a woman's anterior superior iliac spine were more lateralized since this would cause the quadriceps' pull to be more lateral. So, women are more prone to injury and balance problems than men due to the Q angle [17].

Lower extremity malalignments may develop from impairment of the extensor mechanism brought on by changes in the Q angle, which may lead to hypermobile knee joints and patellar instability. A strong spike in the force vector occurred in the lateral anterior aspect of the patella when the knee

extensor mechanism, together with the Q angle, increased as a consequence of the applied pulling force of the patellar tendon. The Q angle effect is what is indicated by this. The vastus medialis exerts additional force to adjust the Q angle, which normalizes this impact [18]. More lateral tracking of the patella results from a high Q angle, and to correct this, the vastus medialis must exert more effort [19]. Accordingly, this study showed that there was a statistically significant positive correlation between Q angle and vastus medialis activation evaluated with EMG on dynamic balance conditions.

Surface EMG analysis is a useful device for examining the muscle activation results during evaluation and treatment processes [13]. One study reported that there was a statistically significant decrease in muscle activation of the vastus medialis obliques based on surface EMG readings in patients with patellofemoral pain [20]. Another study showed that the Q angle measurements and vastus medialis activation correlation were statistically significant in normal adults [21]. Also, one study reported that there was a correlation between the Q angle and the knee joint strength, on the contrary, there was no correlation with quadriceps muscle activity level [22]. Another study noted that an abnormal increase in the Q angle led to genu valgum and could cause patellofemoral pain syndrome due to excessive pressure. So, normalization of quadriceps muscle activation and Q angle is very important for preventing lower extremity musculoskeletal problems [23]. For this reason, it is aimed to examine the relationship of Q angle and quadriceps muscle activation on balance conditions in healthy young individuals.

Numerous studies have revealed that, when compared to men, females may have more quadriceps activation during activity [24,25]. The increased risk of knee injuries seen in females has been linked to increased anterior tibia shear stresses and increased quadriceps activation [25]. It showed that EMG recordings have been documented that females tend to dominate vastus lateralis activation during sports activities in contrast to male athletes who tend to demonstrate vastus medialis dominance [25]. So, increased activity of the vastus lateralis would be expected to increase the risk of a knee injury. Also, according to research by Lathinghouse and Trimble [5], women may be more likely than males to have higher lateral patella displacement during vigorous activities that keep the quadriceps muscle under stress. In this study, the relationship between vastus medialis and Q angle in women was proved.

It is assumed that people with an increment of Q angle have weak quadriceps muscles and are more susceptible to patellofemoral joint problems because the Q angle exhibits an inverse relationship with quadriceps strength, where the smaller the angle, the greater the force produced by the quadriceps [4]. Instead of concentrating exclusively on muscle strengthening, recent research has looked at how to improve the vastus medialis control, strengthen muscles in a functional way, and rectify patella biomechanics [26]. Also, they showed that the increase in Q angle (>15°) causes excessive vastus lateralis force, and accordingly, improper lateral displacement of the patella causes lateral patellar displacement in dynamic activities involving quadriceps muscle activity. Also, Je-Ho Kim [27] showed a significant difference in Q angle and quadriceps muscle activation during the squat exercise. They reported quadriceps strengthening is helpful for the improvement of Q angle and quadriceps muscle activation in patellofemoral pain syndrome [27]. Another study showed that when the Q angle is lower than 10°, the quadriceps muscle exhibits a more effective traction force. Also, they stated that when the Q angle is low, loss of balance can be observed [28]. In this study, there was no statistical correlation between Q angle and static balance. The reason for this is thought to be that the dominant side Q angle is within normal limits in this study.

The Q angle is a clinical frontal plane measurement used to approximate the quadriceps muscle force acting on the patella as a result. Abnormal postural control components change the deterioration of biomechanics of the lower extremity [11]. One study showed that a high Q angle is related to increased body sway in elderly women [6]. In contrast, Samaei et al. showed that varus knee problems could increase postural sway in the mediolateral direction in both static and dynamic situations and also the falling risk in a young group [29]. Hassan et al. [30] demonstrated a connection between bilateral postural sway and maximal voluntary quadriceps activation in individuals with osteoarthritis. Additionally, one study found no correlation between dynamic balance, jumping ability, and Q angle in soccer [5]. In this study, there was a relationship between Q angle measured in supine and standing positions of the dominant side and some scores of dynamic balance. And there was no statistically significant correlation between Q angle and static balance.

4. Conclusion

As a result of this study, there was a relationship between Q angle measured in supine and standing positions and perimeter length and area gap percentage in dynamic balance in single leg stance scores in women. Besides, there was an association between the Q angle and vastus medialis activation measure with EMG. Therefore, If quadriceps muscle, specifically vastus medialis is more strengthened, the Q angle is more normalized, so quadriceps muscle strengthening exercises are helpful for the normalization of the Q angle. In this way, when the Q angle is normalized, dynamic balance in single-leg stance will reveal in the result of this study.

References

1. Umunnah, J.O, Ogbueche, C.M, Uchenwoke, C.I, Okemuo, A.J, Association of tibiofemoral angle, quadriceps angle and body mass index in a selected adolescent population, *African Health Sciences*, 2020, 20(2), 891-896.
2. Austin, W.M, Women in Sports, Q Angle and ACL Injuries, *Dynamic Chiropractic*, 2003, 21(21).
3. Nyugen, A.D, Boling, M.C, Levine, B, Shultz, S.J, Relationships between lower extremity alignment and the quadriceps angle, *Clinical Journal Sport Medicine*, 2009, 19(3), 201-206.
4. Sanchez, H.M, De Morais, S.E.G, Baraúna, M.A, Canto, R.S.T, Evaluation of Q angle in differents static postures, *Acta Ortopedica Brasilia*, 2014, 22(6), 325-329.
5. Lathinghouse, L.H, Trimble, M.H, Effects of isometric quadriceps activation on the Q-angle in women before and after quadriceps exercise,

Journal of Orthopaedic & Sports Physical Therapy, 2000, 30(4), 211-216.

6. Cote, K.P, Brunet, M.E, Gansneder, B.M, Shultz, S.J, Effects of pronated and supinated foot postures on static and dynamic postural stability, *Journal of Athletic Traininig*, 2005, 40(1), 41-46.
7. Thacker, S.B, Stroup, D.F, Branche, C.M, Gilchrist, J, Goodman, R.A. Prevention of knee injuries in sports. A systematic review of the literatüre, *Journal of Sports Medicine Physical Fitness*, 2000, 43, 165-179
8. Nyland, J, Smith, S, Beickman, K, Armsey, T, Caborn, D.N, Frontal plane knee angle affects dynamic postural control strategy during unilateral stance, *Medicine Science Sports Exercice*, 2002, 34(7), 1150-1157.
9. Nguyen, U.S, Felson, D.T, Niu, J, White, D.K, Segal, N.A, Lewis, C.E, The impact of knee instability with and without buckling on balance confidence, fear of falling and physical function: the Multicenter Osteoarthritis Study, *Osteoarthritis Cartilage*, 2014, 22(4), 527-534.
10. Siqueira, C.M, Moya, L, Bueno, G, Caffaro, R.R, Fu, C, Kohn, A.F, et al, Misalignment of the knees: Does it affect human stance stability, *Journal of Bodywork and Movement Therapies*, 2011, 15(2), 235-241.
11. Faul, F, Erdfelder, E, Lang, A.G, Buchner, A, G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences, *Behavior Research Methods*, 2007, 39(2), 175-191.
12. Greene, C.C, Edwards, T.B, Wade, M.R, Carson, E.W, Reliability of the Quadriceps angle measurement, *American Journal of Knee Surgery*, 2001, 14, 97–103.
13. SENIAM, Project-sensor placement, 2018, Available at http://www. seniam.org.
14. Hazar, F, Tasmektepligil, Y, The effects of balance and flexibility on agility in prepuberte period, Spormetre, J*ournal of Physical Education and Sports Science*, 2008, 6(1), 9-12.
15. Fousekis, K, Tsepis, E, Vagenas, G, Intrınsic risk factor of noncontact ankle sprains in soccer, *Ameerican Journal of Sport Medicine*, 2012, 40(8), 1842-1850.
16. Swiontkowski, M.F, Engelberg, R, Martin, D.P, Agel, J, Short musculoskeletal function assessment questionnaire: validity, reliability, and responsiveness, *Journal of Bone Joint Surgery American*, 1999, 81, 1245–1260
17. Hryvniak, D, Magrum, E, Wilder, R, Patellofemoral Pain Syndrome: An Update, *Current Physical Medicine Rehabilitation Reports*, 2014, 2, 16–24.
18. Powers, C.M, The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective, *Journal of Orthopedic Sports Physical Therapy*, 2003, 33, 639–646.
19. Masouros, S.D, Bull, A.M.J, Amis, A.A, Biomechanics of the knee joint, *Orthopedic Trauma*, 2010, 24, 84–91.
20. Lotfi, H, Moghadam, A.M, Shati, M, Comparing Electromyographic Activity of Quadriceps Muscle During Straight Leg Raise in Individuals With and Without Patellofemoral Pain Syndrome, *Physical Therapy Journal*, 2018, 7(4), 197-204.
21. Hwangbo, P.N, The effects of squatting with visual feedback on the muscle activation of the vastus medialis oblique and the vastus lateralis in young adults with an increased quadriceps angle, *Journal of Physical Therapy Science*, 2018, 27, 1507-1510.
22. Sac, A, Tasmektepligil, M.Y, Correlation between the Q angle and the isokinetic knee strength and muscle activity, *Turkish Journal of Physical Medicine Rehabilitation*, 2018, 64(4), 308–313.
23. Pollard, C.D, Sigward, S.M, Powers, C.M, Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments, *Clinical Biomechanics*, 2010, 25, 142–146.
24. Landry, S.C, McKean, K.A, Hubley-Kozey, C.L, Stanish, W.D, Deluzio, K.J, Neuromuscular and lower limb biomechanical differences exist between male and female elite adolescent soccer players during an unanticipated side-cut maneuver, *American Journal of Sports Medicine*, 2007, 35(11), 1888–1900.
25. Han, S.W, Yoon, J.R, Effect of rehabilitation exercise and backward walking and neuromuscular electrical stimulation on the quadriceps muscle function in patients with patellofemoral pain syndrome, *Exercise Science*, 2008, 7, 463-472.
26. Al Amer, H.S, Sabbahi, M.A, Alrowayeh, H.N, Bryan, W.L, Olson, S.L, Electromyographic activity of quadriceps muscle during sit-to-stand in patients with unilateral knee osteoarthritis, *BMC Research Notes*, 2018, 11, 356.
27. Kim, J.H, Effects of EMG-Biofeedback Using Closed Kinetic Chain Exercise on Q-angle and Quadriceps Muscle Activation in Patellofemoral Pain Syndrome, *Journal of Korean Physical Therapy*, 2016, 28(2), 65-70.
28. Byl, T, Cole, A, Livingston, L.A, What determines the magnitude of the Q angle? A preliminary study of select skeletal and muscular measures, *Sport Rehabilitation*, 2019, 9(1), 26-34.
29. Samaei, A, Bakhtiary, A.H, Elham, F, Rezasoltani, A, Effects of genu varum deformity on postural stability, *International Journal of Sports Medicine*, 2012, 33(6), 469-473.
30. Hassan, B, Mockett, S, Doherty, M, Static postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee osteoarthritis and normal control subjects, *Annals of the Rheumatic Diseases*, 2019, 60(6), 612.