ASSOCIATION BETWEEN LOWER EXTREMITY KINEMATICS AND HORIZONTAL JUMP PERFORMANCE IN HEALTHY YOUNG ADULTS

Tufan Ulcay[1], Nurseli Ekici Özdemir[1], Özkan Görgülü[2], Muhammed Fırat Aladağ[1], Emre Uğuz[1], Ruken Öncü[1], Mehmet Kutlu[1], Esra Bayramoğlu Demirdöğen[3], Burcu Kamaşak Arpaçay[1], and Kenan Aycan[1]

[1]*Kırşehir Ahi Evran University, Faculty of Medicine, Department of Anatomy, Kırşehir, Türkiye*
[2]*Kırşehir Ahi Evran University, Faculty of Medicine, Department of Biostatistics and Medical Information, Kırşehir, Türkiye*
[3]*Kırşehir Ahi Evran University, Department of Pilot University Coordinatorship of Health Rectorship, Kırşehir, Türkiye*

Original scientific paper
DOI 10.26582/k.57.1.10

Abstract:

This study investigates the correlation between lower extremity anthropometric parameters and the quadriceps angle in relation to horizontal jump performance in healthy young adults. Ninety-six healthy young adults (52 females and 44 males, aged 18-30 years), participating in no regular sports activity, were included. Measurements of lower extremity length, thigh length, leg length, foot length, hip circumference, and waist circumference were taken in centimeters using a non-elastic tape measure in an upright position. The quadriceps angle was measured with a goniometer, and horizontal jump performance was assessed via the standing broad jump test. Data were analyzed using SPSS version 29.00. A significant negative correlation was found between the quadriceps angle (both legs) and hip circumference, waist circumference, foot length, and horizontal jump distance. The quadriceps angle of the right leg also negatively correlated with lower extremity, thigh, and leg lengths. Horizontal jump distance positively correlated with lower extremity, thigh, leg, and foot lengths. Longer lower extremity, thigh, leg, and foot lengths enhance horizontal jump performance, while an increased quadriceps angle reduces it. These results highlight the quadriceps angle as a critical factor in horizontal jump performance, warranting further research.

Keywords: *anthropometry, quadriceps angle, standing broad jump test*

Introductıon

Anthropometric measurements encompass a wide array of parameters, including circumferential dimensions, linear lengths, diameters, and assessments of adipose tissue, with circumference measurements being the most commonly utilized among these. The quantitative data obtained from these anthropometric evaluations can be effectively correlated with individual's motor capabilities and overall performance outcomes. For example, the relationship between children's somatic growth, developmental trajectory, and kinetic output is significantly influenced by their anthropometric characteristics (Pekel, Balcı, Bağcı, Pepe, & Güzel, 2004; Yıldırım & Özdemir, 2010a,b).

The quadriceps (Q) angle, a crucial biomechanical parameter, is defined as the acute angle formed between two axes: one extending from the anterior superior iliac spine to the midpoint of the patella, and the other from the midpoint of the patella to the tibial tuberosity (Figure 1) (Raveendranath, Nachiket, Sujatha, Priya, & Rema, 1995). Although there is variation in the literature regarding normative Q angle values, Schulthies, Francis, Fisher, and Van de Graaff (1995) synthesized existing data to conclude that typical values range from 10.00º-14.00º in males and 14.50º-17.00º in females. The Q angle is an important measurement used to assess knee joint function, detect lower limb misalignment, and evaluate the health of the patellofemoral joint. It also helps estimate the risk of lower limb injuries (Raveendranath, et al., 1995; Schulthies, et al., 1995). Orsi et al. (2016) found that when the knee is bent at a 25° angle, a combination of knee valgus and internal rotation of the thigh bone significantly increases the stress on the anterior cruciate ligament. Similarly, Homyk et al. (2012) studied the effects of thigh bone rotation and valgus forces under the same knee angle and found that valgus forces pose a greater risk for anterior cruciate ligament injury than rotation alone. The Q angle has also received attention for its role in jump performance (Taş, Ok, Akdeniz, & Bingül, 2024). Daneshmandi, Saki, Shahheidari, and Khoori (2011) showed that people with a smaller Q angle could produce more force, which might help them perform better in jumping. Chester et al. (2008) added that a larger Q angle was linked to slower muscle responses in the quadriceps, the main muscle group used during jumps. Daugherty, Weiss, Paquette, Powell, and Allison (2021) also found that a smaller Q angle was connected to better jump performance, suggesting that proper alignment affects athletic ability. In line with this, Caia et al. (2016) found a strong connection between Q angle and jumping ability, emphasizing its importance in jump efficiency and performance.

The current body of literature underscores the significance of Q angle in jump performance given its association with superior force generation, faster neuromuscular activation, and overall biomechanical advantage. The Q angle thus emerges as a key factor in the complex interplay of variables that govern jumping efficacy.

Jumping represents a fundamental form of human movement that is intricately modulated by a multitude of biomechanical and physiological factors, including body anthropometry, muscular strength, explosive power, flexibility, and motor coordination. These interrelated components collectively enable an individual to generate sufficient force to overcome gravity and propel the body upwards. Proficiency in diverse types of jumping is not only critical for athletic success across numerous disciplines but also plays an essential role in specific aspects of daily motor tasks (Ugarkovic, Matavulj, Kukolj, & Jaric, 2002). Jumping is recognized as a key biomechanical determinant in the etiology of sports-related injuries (Milić, et al., 2025). Beyond their role in injury mechanisms, biomechanical variables have also been shown to significantly influence the phases of gait in activities of daily living. Although the biomechanics of fundamental motor tasks such as jumping, walking, running, rising from a seated position, and stair climbing have been well documented as discrete functional activities, methodological inconsistencies, variability in measurement techniques, and heterogeneity in study populations make data synthesis challenging (Khajooei, Quarmby, Kaplick, Mayer, & Engel, 2022; Reznick, et al., 2021).

Horizontal jumping specifically refers to the forward propulsion of the body from a vertical to a horizontal plane, executed either bilaterally or unilaterally (Yıldırım & Özdemir, 2010a). As a multifactorial motor skill, performance in horizontal jumping is contingent upon an array of biomechanical and physiological parameters that together determine the maximal jump distance. Existing literature predominantly emphasizes elite athletic populations and investigates determinants such as plyometric training, neuromuscular coordination, sport-specific skill acquisition (e.g., soccer), the role of a double-arm swing, lower limb kinematics, functional training regimens, muscular strength of the lower extremities, anthropometric factors, and flexibility (Ulusu, Keser, & Gündüz, 2018; Usgu, Yakut, & Kudaş, 2020; Vazini Taher, Pavlović, Ahanjan, Skrypchenko, & Joksimović, 2021; Zileli, & Söyler, 2021). Nevertheless, there exists a notable gap in the literature regarding the potential correlation between the Q angle and horizontal jump performance.

The objective of the present study is to identify the correlation between lower extremity anthropometric measurements and the Q angle in relation to horizontal jump performance among healthy young adults. Furthermore, this study aims to enrich the existing body of knowledge by providing data-driven insights and contributing empirical evidence to the current literature through the findings of our research.

Methods

A total of 96 volunteer participants, 52 females and 44 males, aged between 18 and 30 years and not professionally involved in athletic activities, were selected for this study. The exclusion criteria encompassed individuals younger than 18 years of age, those who had sustained any lower extremity trauma within the preceding six months, and individuals diagnosed with neurological, cardiovascular, vestibular, or rheumatic disorders. Additionally, participants with lower limb amputations or prostheses, those utilizing walking aids or other assistive devices, and individuals with a history of lower extremity fractures were excluded. Prior to enrollment, the study protocol was thoroughly explained to all participants, and informed consent was duly obtained in accordance with the established ethical standards.

The study proposal was approved by the local ethics committee (Decision No: 2022-23/203, Date: 20/12/2022), and conducted in accordance with the principles of the Declaration of Helsinki. This study was conducted between January and April 2023.

Anthropometric measurements

Anthropometric assessments were meticulously conducted by a single examiner to ensure measurement consistency across all voluntary participants. Each measurement was performed twice, and the mean of the two readings was subsequently

Figure 1. The reference points of the measurement of Q angle.

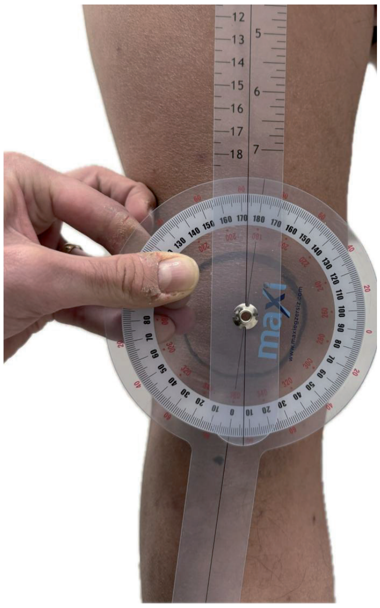

Figure 2. The measurement of Q angle.

recorded for analysis to enhance data accuracy. The anthropometric parameters evaluated included lower extremity length, thigh length, leg length, foot length, hip circumference, and waist circumference. Specifically, lower extremity length was measured as the distance from the anterior superior iliac spine to the medial malleolus with the participant in a standing posture. Thigh length was determined from the midpoint of the inguinal ligament to the proximal patella while the participant was seated with legs freely suspended over the edge of a chair. Leg length was quantified as the distance between the tibial plateau and the medial malleolus with the participant seated in a cross-legged position. Foot length was measured from the heel to the tip of the longest toe in a standing posture. Hip circumference was assessed at the broadest point of the gluteal region, and waist circumference was measured at the level of the umbilicus, both with the participant standing and the measurements taken parallel to the ground (Otman, Demirel, & Sade, 2014).

Q angle measurement

The Q angle was measured using a goniometer, with the participant in a supine position to ensure accurate anatomical alignment. The center of the goniometer was placed at the midpoint of the patella, with the fixed arm directed towards the tibial tuberosity and the movable arm aligned with the anterior superior iliac spine. The acute angle formed by the intersection of these two arms was recorded as the Q angle (Figure 2) (Havaslı, Demir, Çiçek, & Yoldaş, 2017). This standardized measurement technique ensures precision in capturing the angular relationship between the femur and tibia, which is critical for evaluating lower extremity biomechanics.

Horizontal jump distance measurement

In this study, horizontal jump performance was assessed using the standing broad jump test (Figure 3). Our study will center on the standing broad jump test, a key performance assessment in

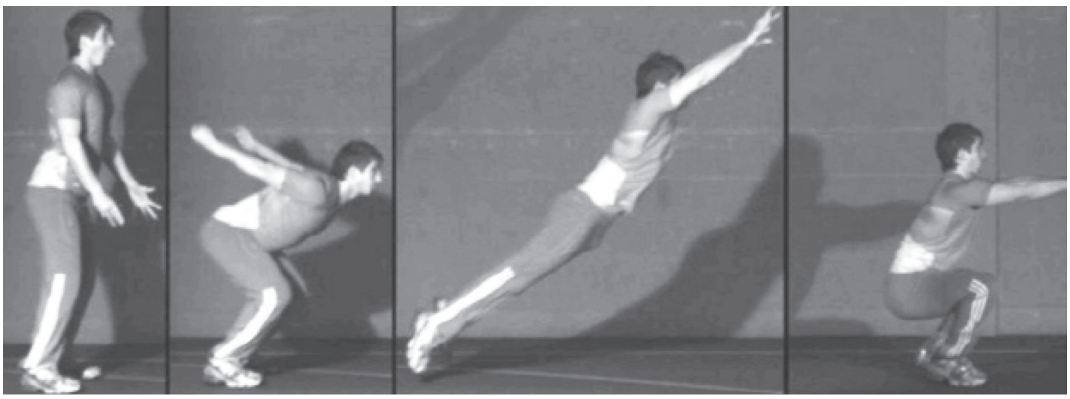

Figure 3. Standing broad jump test (Wild, Bezodis, Blagrove, & Bezodis, 2011).

which individuals propel themselves forward from a static position utilizing bilateral foot engagement to achieve maximal horizontal displacement (Ulusu, et al., 2018). For the horizontal jump test, participants positioned themselves behind a designated starting line on a level surface. Upon receiving the command to "Jump," they launched forward with both feet simultaneously, striving to achieve maximal distance. The horizontal distance from the starting line to the posterior edge of the participant's heel at landing was measured in centimeters. Each participant performed the jump test twice, with the longest distance achieved recorded for subsequent analysis (Ayan & Kavi, 2016). This testing protocol ensures reliability in the evaluation of participants' lower body explosive strength and jump performance capacity.

Statistical analyses

Data analysis was conducted using the Statistical Package for Social Sciences (SPSS) version 29.00 for Windows (IBM SPSS Statistics for Windows, Version 29.00, Armonk, NY: IBM Corp., USA). The sample size for the study was determined through *a priori* power analysis utilizing the G*Power 3.1.9.6 software (developed by Franz Faul at the University of Kiel, Germany), ensuring sufficient statistical power for the analyses undertaken.

The assumptions of normality for the dataset were evaluated using both the Kolmogorov-Smirnov and Shapiro-Wilk tests. Based on the results of these normality tests, Spearman correlation analyses were applied to identify and quantify the relationships between the variables.

The sample size for the study was established via an *a priori* power analysis. Considering an anticipated effect size of $\rho = 0.30$ and aiming for a statistical power of $1-\beta = 0.85$, the analysis determined that a minimum sample size of 96 participants is required to ensure adequate power for detecting the specified effect.

Results

The associations between the Q angle of the right leg and other parameters among all participants are presented in Table 1. A statistically significant negative correlation was observed between the right leg Q angle and the following variables: lower extremity length (Rho = -0.247*, p = .015), thigh length (Rho = -0.317**, p = .002), leg length (Rho = -0.280**, p = .006), hip circumference (Rho = -0.272**, p = .007), waist circumference (Rho = -0.262**, p = .010), foot length (Rho = -0.347**, p = .001), and horizontal jump distance (Rho = -0.245*, p = .016). These findings suggest an inverse relationship between the right leg Q angle and these anthropometric and performance variables, with the negative correlation coefficients indicating that as

Table 1. Relationships between the right leg Q angle and other variables in all participants (n=96)

Variables	Rho	p
Lower extremity length (cm)	-.247*	.015
Thigh length (cm)	-.317**	.002
Leg length (cm)	-.280**	.006
Hip circumference (cm)	-.272**	.007
Waist circumference (cm)	-.262**	.010
Foot length (cm)	-.347**	.001
Horizontal jump distance (cm)	-.245*	.016

Note. ** – significant at p<.01; * – significant at p<.05; cm: centimeter, Rho: correlation coefficient.

Table 2. Relationships between the left leg Q angle and other variables in all participants (n=96)

Variables	Rho	p
Lower extremity length (cm)	-.154 N.S	.133
Thigh length (cm)	-.195 N.S	.056
Leg length (cm)	-.169 N.S	.099
Hip circumference (cm)	-.263**	.010
Waist circumference (cm)	-.318**	.002
Foot length (cm)	-.343**	.001
Horizontal jump distance (cm)	-.249*	.014

Note. N.S. – non-significant (p>.05); ** – significant at p<.01; * – significant at p<.05; cm: centimeter, Rho: correlation coefficient.

the right leg Q angle increases, the corresponding variable values tend to decrease.

Table 2 delineates the correlations between the Q angle of the left leg and other parameters across all participants. A statistically significant negative correlation was identified between the left leg Q angle and hip circumference (Rho = -0.263**, p = .010), waist circumference (Rho = -0.318**, p = .002), foot length (Rho = -0.343**, p = .001), and horizontal jump distance (Rho = -0.249*, p = .014). In contrast, no significant associations were observed between the left leg Q angle and lower extremity length, thigh length, or leg length (p > .05). These results indicate that increases in the left leg Q angle are associated with decreases in hip circumference, waist circumference, foot length, and horizontal jump distance, whereas no substantial relationship exists with the other examined variables.

Table 3 illustrates the relationship between horizontal jump distance and various parameters across all participants. A significant positive correlation was observed between horizontal jump distance and lower extremity length (Rho = 0.311**, p = .002), thigh length (Rho = 0.278**, p = .006), leg length (Rho = 0.385**, p = .000), and foot length (Rho = 0.478**, p = .000). These results suggest that increases in horizontal jump distance are associated

Table 3. Relationships between horizontal jump distance and other variables in all participants (n=96)

Variables	Rho	p
Lower extremity length (cm)	.311**	.002
Thigh length (cm)	.278**	.006
Leg length (cm)	.385**	.000
Hip circumference (cm)	-.002 N.S	.984
Waist circumference (cm)	.168 N.S	.102
Foot length (cm)	.478**	.000

Note. N.S. – non-significant (p>.05); ** – significant at p<.01; * – significant at p<.05; cm: centimeter, Rho: correlation coefficient.

with a greater lower extremity length, thigh length, leg length, and foot length. However, no statistically significant correlation was detected between horizontal jump distance and hip or waist circumference (p > .05). Overall, these findings indicate that while certain anthropometric measures are positively related to horizontal jump performance, hip and waist circumference do not exhibit a significant impact on this performance metric.

Discussion and conclusions

Upon a comprehensive review of the literature, it was observed that similar investigations have predominantly centered on professional or amateur athletic populations. However, there remains a paucity of data on the relationship between anthropometric characteristics and Q angle, particularly in relation to horizontal jump distance in healthy young adult males and females, highlighting a gap in the current research.

Pekel et al. (2004) reported positive correlations between various anthropometric measures—such as diameter, circumference, and length—and performance parameters, including speed, power, and strength, in children aged 10-13 years. Likewise, in a study of elite handball players (Yıldırım, & Özdemir, 2010a), forearm circumference, calf length, body height, body fat percentage, waist circumference, biacromial and biiliac diameters, wrist diameter, chest depth, and flexibility were identified as significant contributors to horizontal jump performance. Research conducted with football players also revealed a strong association between horizontal jump performance and anaerobic power. In the study by Günay, Erol, and Savaş (1994), a positive correlation was established between anaerobic power and thigh length. Furthermore, a study of male basketball players (Ulusu, et al., 2018) concluded that individuals with greater leg and arm lengths demonstrated superior horizontal jump distances.

The significant positive correlation observed between the lower extremity measurements—including thigh, leg, and foot lengths—and horizontal jump distance in our study is consistent with the findings of previous research. However, in contrast to these earlier studies, we did not identify a significant correlation between hip and waist circumferences and horizontal jump performance. This discrepancy may be attributed to the distinct demographic characteristics of our sample, which comprised general population of young adults aged 18-30 years, in contrast to the athletic populations typically examined in the existing literature.

Weiss, Hammond, Schilling, and Ferreira (2012) demonstrated that Q angle measurements obtained via goniometer are generally reliable. In our study, we similarly utilized a goniometer to assess the Q angle. Nevertheless, Skouras et al. (2022) has raised concerns regarding potential measurement inaccuracies when using a goniometer, particularly due to minor shifts in the patellar midpoint, with deviations ranging between 1-5 mm. Özüdoğru et al. (2024) evaluated range of motion of lower extremity joints in healthy participants using an electrogoniometer and reported excellent reliability for this measurement method. Furthermore, Byl, Cole, and Livingston (2000) highlighted that body positioning plays a crucial role in Q angle measurements, with the standing position exerting a greater influence on the ankle and hip joints compared to the supine position. This positional effect results in an increased Q angle when measured in the standing posture. Based on these findings, they advocated for the supine position to minimize potential positional biases, a recommendation we implemented in our study to enhance measurement accuracy. Panoutsakopoulos, Kotzamanidou, Giannakos, and Kollias (2022) explored the correlation between normative ankle joint range of motion and vertical jump performance in adult handball players. They reported a strong correlation between ankle joint range of motion—measured with the knee at 40 degrees of flexion—and vertical jump performance. Similarly, Kotsifaki, Korakakis, Graham-Smith, Sideris, and Whiteley (2021), in a study conducted with physically active individuals, found that horizontal jump distance was predominantly determined by the hip (44%) and ankle (43%) joints, accounting for 87% of the variance. During the landing phase, joint contribution was primarily from the knee (65%), followed by the hip (24%) and ankle (11%).

In their study, Davis et al. (2006) examined a sample of 78 recreational athletes, comprising 55 males and 23 females, with a mean age of 21.9 years. Their findings identified a weak yet positive correlation between femur length and vertical jump height in both sexes, with correlation coefficients of r=0.18 for males and r=0.11 for females. These results suggest a modest association between femur length and jumping performance, differing slightly by sex, though remaining statistically marginal in both groups.

Furthermore, Davis et al. (2006) also reported a weak but positive correlation between tibia length and vertical jump height in both male and female participants, with correlation coefficients of r=0.18 for males and r=0.15 for females. These findings indicate a slight association between tibia length and vertical jump performance across sexes, although the strength of this relationship remains limited in both groups.

In their study, Horton and Hall (1989) investigated 50 males and 50 females with no history of knee-related conditions and found a moderate negative correlation between femur length and the Q angle, with a correlation coefficient of r=-0.304. These results suggest that as femur length increases, the Q angle tends to decrease, highlighting a notable inverse relationship between these two anatomical parameters.

In another study, Caruso et al. (2012) examined 177 participants, including 143 athletes or individuals engaged in regular exercise and 34 sedentary individuals. The study revealed a weak positive correlation between thigh length and vertical jump height, with a correlation coefficient of r=0.29. These findings suggest a modest association between thigh length and jumping performance, regardless of the level of physical activity.

Moreover, Caruso et al. (2012) reported a weak yet positive correlation between leg length and vertical jump height, with a correlation coefficient of r=0.21. This suggests a modest association between leg length and jumping performance, indicating that a greater leg length may have a slight impact on vertical jump ability.

Aouadi et al. (2012), in their study with 33 male volleyball players training 12-16 hours per week, identified a strong positive correlation between lower limb length and vertical jump performance, with a correlation coefficient of r=0.83. These findings indicate a significant association, suggesting that a greater lower limb length is highly predictive of enhanced vertical jump ability in athletes engaged in intensive training regimens.

Contarlı and Özmen (2021), in their investigation involving gymnasts, assessed the correlation between the Q angle and vertical jump height, concluding that no statistically significant correlation existed between these two parameters. Furthermore, their findings indicated that the Q angle bore no meaningful correlation with dynamic balance performance**.** Our study's findings revealed an inverse relationship between Q angles (of both the right and left legs) and several anthropometric parameters, including hip and waist circumference, foot length, and horizontal jump distance. Notably, for the right leg, a negative correlation was observed between Q angle and measurements of lower extremity length, thigh length, and leg length. Interestingly, this correlation did not reach statistical significance for the left leg in relation to these specific parameters. The observed discrepancy between the right and left leg Q angle correlations with anthropometric characteristics suggests potential side-specific biomechanical variations.

Notably, as the Q angle increased in both legs, horizontal jump distance decreased, underscoring a direct negative impact of Q angle on jump performance. This suggests that the Q angle may be a critical determinant in horizontal jump efficacy.

Thus far, there are no studies that explicitly examine the relationship between the Q angle and long jump performance performed with two feet. Therefore, this study brings a new perspective to the literature and can serve as a fundamental reference source for future research. We recommend that future studies focus on athletic populations, investigate potential sex differences, and evaluate the relationship between the Q angle and the dominant leg. This will provide a more detailed understanding of the biomechanical effects of the Q angle on performance.

References

Aouadi, R., Jlid, M., Khalifa, R., Hermassi, S., Chelly, M. S., Van Den Tillaar, R., & Gabbett, T. (2012). Association of anthropometric qualities with vertical jump performance in elite male volleyball players. *The Journal of Sports Medicine and Physical Fitness*, *52*(1), 11-17.

Ayan, V., & Kavi, N. (2016). The study of the somatotypes and the horizontal jump performance characteristics of the female swimmers aged between 8 and 14. *International Journal of Sport Culture and Science*, *4*(Special Issue 1), 23-30. https://doi.org/10.14486/IntJSCS510

Byl, T., Cole, J.A., & Livingston, L.A. (2000). What determines the magnitude of the Q angle? A preliminary study of selected skeletal and muscular measures. *Journal of Sport Rehabilitation*, *9*(1), 26-34. https://doi.org/10.1123/jsr.9.1.26

Caia, J., Weiss, L.W., Chiu, L.Z., Schilling, B.K., Paquette, M.R., & Relyea, G.E. (2016). Do lower-body dimensions and body composition explain vertical jump ability? *The Journal of Strength and Conditioning Research*, *30*(11), 3073-3083. https://doi.org/10.1519/JSC.0000000000001406

Caruso, J.F., Daily, J.S., Mason, M.L., Shepherd, C.M., McLagan, J.R., Marshall, M.R., Walker, R.H., & West, J.O. (2012). Anthropometry as a predictor of vertical jump heights derived from an instrumented platform. *The Journal of Strength and Conditioning Research*, *26*(1), 284-292. https://doi.org/10.1519/JSC.0b013e31821d97c0

Chester, R., Smith, T.O., Sweeting, D., Dixon, J., Wood, S., & Song, F. (2008). The relative timing of VMO and VL in the aetiology of anterior knee pain: A systematic review and meta-analysis. *BMC Musculoskeletal Disorders*, *9*, 1-14. https://doi.org/10.1186/1471-2474-9-64

Contarlı, N., & Özmen, T. (2021). Relationship between Q angle, dynamic balance and vertical jump height in gymnasts. *The ÇOMÜ Journal of Sports Sciences*, *4*(3), 32-43.

Daneshmandi, H., Saki, F., Shahheidari, S., & Khoori, A. (2011). Lower extremity malalignment and its linear relation with Q angle in female athletes. *Procedia—Social and Behavioral Sciences, 15*, 3349-3354. https://doi.org/10.1016/j.sbspro.2011.04.298

Daugherty, H.J., Weiss, L.W., Paquette, M.R., Powell, D.W., & Allison, L.E. (2021). Potential predictors of vertical jump performance: Lower extremity dimensions and alignment, relative body fat, and kinetic variables. *The Journal of Strength and Conditioning Research*, *35*(3), 616-625. https://doi.org/10.1519/JSC.0000000000003962

Davis, D.S., Bosley, E.E., Gronell, L.C., Keeney, S.A., Rossetti, A.M., Mancinelli, C.A., & Petronis, J.J. (2006). The relationship of body segment length and vertical jump displacement in recreational athletes. *The Journal of Strength and Conditioning Research*, *20*(1), 136-140. https://doi.org/10.1519/R-16354.1

Günay, M., Erol, A., & Savaş, S. (1994). Relationship of strength, flexibility-agility and anaerobic strength with height, body weight and some anthropometric parameters in football players. *Hacettepe University Journal of Sports Sciences*, *5*(4), 3-11.

Havaslı, F., Demir, M., Çiçek, M., & Yoldaş, A. (2017). Association between Q angle and predisposition to gonarthrosis. *Anatomy*, *11*(1), 21-25. https://doi.org/10.2399/ana.16.055

Homyk, A., Orsi, A., Wibby, S., Yang, N., Nayeb-Hashemi, H., & Canavan, P.K. (2012). Failure locus of the anterior cruciate ligament: 3D finite element analysis. *Computer Methods in Biomechanics and Biomedical Engineering*, *15*(8), 865-874. https://doi.org/10.1080/10255842.2011.565412

Horton, M.G., & Hall, T.L. (1989). Quadriceps femoris muscle angle: Normal values and relationships with gender and selected skeletal measures. *Physical Therapy*, *69*(11), 897-901. https://doi.org/10.1093/ptj/69.11.897

Khajooei, M., Quarmby, A., Kaplick, H., Mayer, F., & Engel, T. (2022). An analysis of lower extremity kinematics in response to perturbations during running using statistical parametric mapping. *Journal of Biomechanics*, *143*(5), 111276. https://doi.org/10.1016/j.jbiomech.2022.111276

Kotsifaki, A., Korakakis, V., Graham-Smith, P., Sideris, V., & Whiteley, R. (2021). Vertical and horizontal hop performance: Contributions of the hip, knee, and ankle. *Sports Health: A Multidisciplinary Approach*, *13*(2), 128-135. https://doi.org/10.1177/1941738120976363

Milić, V., Radenković, O., Čaprić, I., Mekić, R., Trajković, N., Špirtović, O., Koničanin, A., Bratić, M., Mujanović, R., Preljević, A., Murić, B., & Kahrović, I. (2025). Sports injuries in basketball, handball, and volleyball players: Systematic review. *Life, 15*(4), 529. https://doi.org/10.3390/life15040529

Orsi, A.D., Chakravarthy, S., Canavan, P.K., Peña, E., Goebel, R., Vaziri, A., & Nayeb-Hashemi, H. (2016). The effects of knee joint kinematics on anterior cruciate ligament injury and articular cartilage damage. *Computer Methods in Biomechanics and Biomedical Engineering*, *19*(5), 493-506. https://doi.org/10.1080/10255842.2015.1043626

Otman, A.S., Demirel, H., & Sade, A. (2014). *Tedavi hareketlerinde temel değerlendirme prensipleri: Pelikan yayıncılık*. [Principles of basic assessment in therapeutic movements.] Ankara: Pelikan Yayıncılık.

Özudoğru, A., Canlı, M., Kuzu, Ş., Ceylan, İ., Alkan, H., & Tuncay, F. (2024). Validity and reliability of KFORCE Sens® electrogoniometer in the evaluation of ankle, knee and hip range of motion. *Health Sciences Investigations Journal*, *6*(2), 977-982. https://doi.org/10.46829/hsijournal.2024.12.6.2.977-982

Panoutsakopoulos, V., Kotzamanidou, M. C., Giannakos, A. K., & Kollias, I. A. (2022). Relationship of vertical jump performance and ankle joint range of motion: Effect of knee joint angle and handedness in young adult handball players. *Sports*, *10*(6), 86. https://doi.org/10.3390/sports10060086

Pekel, H.A., Balcı, Ş.S., Bağcı, E., Pepe, H., & Güzel, N.A., (2004). The evaluationreletionship [Sic!] between some anthropometric and performance related physical fitness parameters in children athletes. In The 10th Ichper SD Europe Congress (pp. 110). Antalya, Turkey

Raveendranath, R., Nachiket, S., Sujatha, N., Priya, R., & Rema, D. (2011). Bilateral variability of the quadriceps angle (Q angle) in an adult Indian population. *Iranian Journal of Basic Medical Sciences*, *14*(5), 465.

Reznick, E., Embry, K.R., Neuman, R., Bolívar-Nieto, E., Fey, N.P., & Gregg, R.D. (2021). Lower-limb kinematics and kinetics during continuously varying human locomotion. *Scientific Data*, *8*(1), 282. https://doi.org/10.1038/s41597-021-01057-9

Schulthies, S.S., Francis, R.S., Fisher, A.G., & Van De Graaff, K.M. (1995). Does the Q angle reflect the force on the patella in the frontal plane? *Physical Therapy*, *75*(1), 24-30. https://doi.org/10.1093/ptj/75.1.24

Skouras, A.Z., Kanellopoulos, A.K., Stasi, S., Triantafyllou, A., Koulouvaris, P., Papagiannis, G., & Papathanasiou, G. (2022). Clinical significance of the static and dynamic Q-angle. *Cureus*, *14*(5), e24911. https://doi.org/10.7759/cureus.24911

Taş, B., Ok, E., Akdenız, H., & Bingül, B.M. (2024). The relationship of Q angle with jump and landing mechanics in female volleyball players. *Spor ve Rekreasyon Araştırmaları Dergisi*, *6*(1), 46-55. https://doi.org/10.52272/srad.1488742

Ugarkovic, D., Matavulj, D., Kukolj, M., & Jaric, S. (2002). Standard anthropometric, body composition, and strength variables as predictors of jumping performance in elite junior athletes. *The Journal of Strength and Conditioning Research*, *16*(2), 227-230. https://doi.org/10.1519/1533-4287(2002)016%3C0227:SABCAS%3E2.0.CO;2

Ulusu, H., Keser, E., & Gündüz, T. (2018). The investigation of the relationship between the antropometric characteristics and some performance values of basketball players. *Journal of Engineering Sciences and Design*, *6*, 32-39. https://doi.org/10.21923/jesd. 359667

Usgu, S., Yakut, Y., & Kudaş, S. (2020). Effects of functional training on performance in professional basketball players. *Spor Hekimliği Dergisi, 55*(4), 321-331. https://doi.org/10.5152/tjsm.2020.193

Vazini Taher, A., Pavlović, R., Ahanjan, S., Skrypchenko, I., & Joksimović, M. (2021). Effects of vertical and horizontal plyometric exercises on explosive capacity and kinetic variables in professional long jump athletes. *Pedagogy of Physical Culture and Sports, 25*(2), 108-113. https://doi.org/10.15561/26649837.2021.0205

Weiss, L., Hammond, K., Schilling, B., & Ferreira, L. (2012). Efficacy of goniometry-based Q-angle for measuring change. *Medicine and Science in Sports and Exercise*, *44*(5S), 947.

Wild, J., Bezodis, N.E., Blagrove, R.C., & Bezodis, I.N. (2011). A biomechanical comparison of accelerative and maximum velocity sprinting: Specific strength training considerations. *Professional Strength and Conditioning*, *21*, 23-37.

Yıldırım, İ., & Özdemir, V. (2010a). An investigation of the anthropometric characteristics of elite male handball players. *Ondokuz Mayis University Journal of Sports and Performance Researches*, *1*(1), 6-13. https://doi.org/10.17155/spd.19184

Yıldırım, İ., & Özdemir, V. (2010b). The effects of anthropometric measures of elite male handball team players on the vertical and horizontal jump distance. *Selçuk University Journal of Physical Education and Sport Science*, *12*(1), 63-72.

Zileli, R., & Söyler, M. (2021). The examination of the relationship between sprint and vertical jump in soccer players. *MANAS Sosyal Araştırmalar Dergisi*, *10*(1), 485-491. https://doi.org/10.33206/mjss.726101

Submitted: January 20, 2025
Accepted: May 22, 2025
Published Online First: June 30, 2025

Correspondence to:
Res. Assist. Emre Uğuz, M.Sc.
Kırşehir Ahi Evran University, Faculty of Medicine,
Department of Anatomy
Bağbaşı Campus 40100 Kırşehir
E mail:emre.uguz@ahievran.edu.tr
Phone: +90 551 396 02 89