Original Article

The relationship between isokinetic knee flexion and extension muscle strength, jump performance, dynamic balance and injury risk in female volleyball players

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ABSTRACT

The relationship between balance, knee muscle strength, jump height and risk of injury has not been clearly stated in female volleyball athletes. The study was to determine whether a correlation exists between knee joint isokinetic muscle strength, risk of injury, balance and jump height in female volleyball athletes. Twenty-two female volleyball athletes were involved into the study. Knee muscle strength were evaluated with the Biodex 3® isokinetic dynamometer. Jump performances were evaluated with the countermovement (CMJ) jump test using the Vert Jump® Motion Sensitive Sensor. The injury risk for all players were evaluated by the Functional Movement Screen (FMS®). Balance measurements were performed with a dynamometer Biodex Systems 3® device. There was a significant relationship between CMJ height, knee flexion and extension peak torque and H:Q ratio values at two angular velocities, dynamic balance and total FMS® scores ($p < .05$). However, contralateral deficit statistically significant were not related between CMJ height, dynamic balance and FMS® scores ($p > .05$). We suggest that all clinicians and coaches involved in the protective and preventive rehabilitation phase evaluate these parameters and plan their training programs in line with the results obtained in increasing both individual and team performance of athletes.
Keywords: Volleyball; Dynamic balance; Jump performance; Functional movement screen (FMS®); Knee; Isokinetic.

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INTRODUCTION

Volleyball is a sport that is played in a relatively small field, by performing repetitive fast movements and high vertical jumping. During a volleyball match, players must perform service, pass, spike and attack. Spikes and attack movements require intense vertical jumping and landing (Kim & Jeoung, 2016).

One of the main characteristics of volleyball is the necessity of the player to perform vertical jumps great heights in the attack and block movements, which require large power production, especially in the lower extremities. Hence, volleyball requires the development of lower extremity muscle strength, that is, the ability to produce high levels of force at high speeds (Sattler, Sekulic, Esco, Mahmutovic, & Hadzic, 2015) . Due to the importance of muscle strength for strength development in jump performance, force imbalances in the lower extremity may have a negative impact on volleyball players' jumps (Pupo, Detanico, & Santos, 2012; P. Schons et al., 2018).

Jump tests and isokinetic dynamometers are widely used on volleyball players to evaluate the lower extremity muscle strength and power/strength parameters (Sattler, Sekulic, Hadzic, Uljevic, & Dervisevic, 2012; Tsiokanos, Kellis, Jamurtas, & Kellis, 2002) . The vertical jump tests performed on force plates allow specific analysis of the multiarticular ability to generate muscle–tendon unit power in volleyball due to the similarity with the game actions. However, these tests do not allow detailed analysis of the production of force around the specified joints or muscles. On the other hand, the isokinetic dynamometer provides a more detailed evaluation of the torque generating capacity of the muscles involved in specific joint movements (Iossifidou, Baltzopoulos, & Giakas, 2005; P. Schons et al., 2018). Moreover, these devices allow the calculation of muscle strength imbalance or asymmetry and hamstring / quadriceps muscle strength ratio (H: Q ratio) between dominant and non-dominant extremities, defined as contralateral deficits (Bamaç et al., 2008; P. Schons et al., 2018) . This H: Q ratio is used to examine the functional abilities during speed-dependent movements, the stability of the knee joint, and the balance between hamstring and quadriceps muscles (Bamaç et al., 2008; Cheung, Smith, & Wong del, 2012).

In volleyball players, a balanced muscle strength ratio between the agonist and antagonist muscle groups, especially between the knee joint and the dominant and non-dominant sides, is extremely important for lower extremity stability and preventing knee injuries (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998) . Therefore, the determination of contralateral deficit and H: Q ratio in these athletes will play a key role in increasing performance and preventing injuries.

In volleyball, technical-tactical, conditional and mental abilities and psychological characteristics constitute the basis of performance. It is known that the balance skill which is at the centre of the performance is important in the performance of many sports skills successfully, changing direction, stopping, starting, keeping, moving the object, and maintaining the body at a certain position (Erdoğan et al., 2017). During the match with the opponent and during sudden change in the distortion of the balance must be restored as soon as possible. If the balance is not achieved in a short period of time, the athlete cannot perform the desired performance and he/she may face the danger of sport injury (Evangelos et al., 2012) . The dynamic balance is important when demonstrating a skill in complex movements for high sporting performance. The dynamic balance can be defined as the neutralization of the external forces acting on the body by the soft tissues of the muscles and joints. The balance control is dynamic while the person is in motion (Ibis, Aktuğ, & Iri, 2018; İbiş, İri, & Aktuğ, 2015). Thus, dynamic balance has a more complex mechanism than static balance. Considering the requirements of volleyball, (spike, block etc.), dynamic balance performance can be considered extremely important (Agostini, Chiaramello, Canavese, Bredariol, & Knaflitz, 2013). Balance performance is closely related to lower extremity muscle strength.

There are many studies examining the relationship between lower extremity muscle strength and balance performance (Muehlbauer, Gollhofer, & Granacher, 2015; Myers, Christopherson, & Butler, 2018) . However, in the literature, the number of studies investigating the relationship between volleyball players' isokinetic knee muscle strength and balance performance is insufficient (Akarçeşme & Aktuğ, 2018).

The determination of the relationship between the risk of injury in volleyball players, knee flexion/extension contralateral deficit, H: Q ratio, balance performance, jump height and prevention of injuries may play a key role in increasing individual and team performance. In the literature, while the relationship between knee muscle strength and jump height (P. Schons et al., 2018; Schons, Fischer, Rosa, Berriel, & Peyré-Tartaruga, 2018) , risk of injury and knee muscle strength (Cheung et al., 2012; Kabacinski, Murawa, Mackala, & Dworak, 2018) , balance and injury risk (Clifton, Harrison, Hertel, & Hart, 2013; Pourheydari, Sheikhhoseini, & Hosseini, 2018) in volleyball players are clearly stated, the relationship between balance, knee muscle strength, jump height and risk of injury has not been clearly stated. Therefore, the aim of this study is to investigate the relationship between knee joint isokinetic muscle strength, risk of injury, balance and jump height in volleyball players.

MATERIALS AND METHODS

Design

This study used a cross-sectional and correlational design to analyse the association between knee flexion and extension muscle strength, jump performance, balance and injury risk in professional female volleyball players. During the competitive season (2017–2018), each of the athletes visited the Human Performance Laboratory where knee flexion and extension torque, conventional ratio and contralateral deficit at two different angular velocities (60° ˚/ s and 180° ˚/ s) on both legs were measured in an isokinetic dynamometer. Jump performances of athletes were evaluated with the countermovement (CMJ) jump test using the Vert Jump Brand Motion Sensitive Sensor. In addition, A correlation test was used to analyse the associations between the ability to generate maximal torque of the knee joint and the ability to generate power and height in the vertical jump. The injury risk for all players were evaluated by the athletic trainer and physical therapist using the Functional Movement Screen (FMS®). In addition, balance measurements were performed with a dynamometer Biodex Systems 3® device.

Participants

Twenty-two female professional volleyball players participated in this study. All players competed in Halkbank sports club in Sultan League (Turkey). Mean and standard deviation of age, body mass, height and experience in sport of the participants were 19.94 ± 4.13 years old, 64.78 ± 7.30 kg, 1.80 ± 0.08 m and 9.38 ± 3.41 years, respectively. All the participants were free from any active injury (no medical consultation or interruption of training in previous 6 months) and any previous surgery on the lower extremities. All female athletes exhibited right lower extremity dominance. The dominant lower extremity was defined as the limb with which the player performs take-off during jump. Our study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Human Research Ethics Committee before the commencement of the assessments The Ethics Committee of the University of Ankara Yıldırım Beyazıt with the decision dated 21 November 2018 and numbered 77 approved the study and all participants were informed about the procedures of the study by written form. The risks and benefits of the study were explained before the signature of the free and informed consent form.

Testing procedures

Testing sessions were performed on 4 days with 24 h between them. On the first day, the purposes and methodological procedures of the study were presented to the athletes, and the informed consent form was signed. After that, body mass and height of the players were measured with a Tanita BC-418 Segmental Body Analysis System (Tanita Corporation, Tokyo, Japan) and a standard steel stadiometer (System NY, Shirley), respectively. On the second day, the CMJ test and injury risk of all players were performed by using Vert Jump® and FMS®, respectively. On the third day, the isokinetic strength test of the knee muscle groups was performed using an isokinetic dynamometer. On the fourth day, balance measurements were performed with a dynamometer Biodex Systems 3®.

Vertical Jump Test

Jump performances of athletes were evaluated with the CMJ test using the Vert Jump Brand Motion Sensitive Sensor. The highest CMJ height reached in a unit training room was recorded using the device placed on the waist with the help of a belt, which contain sensors that respond to all movements of the athlete during training. In addition to measuring the explosive force properties of the leg muscles, CMJ test which measures the elastic force feature affecting the explosive force was applied as the knees were fully extended and in the upright position, and performing squats swiftly then jumping.

Functional Movement Screen (FMS®)

Functional movement patterns were evaluated by athletic trainer and physiotherapist specifically trained using standard FMS® Test Kits (Functional Movement Systems Inc., Virginia, USA). FMS® is an analysis system that evaluates muscle strength imbalance in athletes and functional performances on the non-dominant side. It aims to determine the stability and mobility that can be ignored in asymptomatic active population and athletes. It consists of 7 basic parameters determined by Gray Cook (Deep Squat, Hurdle Step, In-Line Lunge, Shoulder Mobility, Active Straight Leg Raise, Trunk Stability Push-Up, and Rotary Stability). The athletes were given the verbal directions that gave information about the head, body, knee and feet position determined by Gray Cook. For each parameter, athletes were scored between 0-3 values. The total score was found to be 21 points. 3 points were given to complete the movement completely and without compensation and 2 or 1 points were given according to the activation of compensation mechanism and balance disorders. In case of any pain at the end of the movement or at the end of the movement, the athletes were given 0 points. The data were recorded with two different cameras, from the front and the side angle (Cook, Burton, & Hoogenboom, 2006a, 2006b). After the recorded data was examined by athletic trainer and physiotherapist, total FMS® scores were given to the athletes.

Isokinetic Evaluation

Using the Biodex System 3 device (Biodex Medical Systems, Inc., Shirley, NY, USA) we conducted the isokinetic test of concentric hamstrings and quadriceps strength at the following angular velocities: 60˚/s and 180˚/s. The following testing protocol was used: isokinetic bilateral, pattern: extension/flexion, mode: isokinetic, contraction: concentric, 4 series with angular velocities of 60˚/ s (3 trials repetitions as a warmup), 180˚/s (3 trials repetitions as a warmup), 180˚/ s (10 repetitions) and 60˚/s (5 repetitions) both for extension and flexion. During testing, the participants sat on an optimally positioned Biodex chair with stabilization straps at the trunk, hips and thigh while holding their arms across their chest. The knee joint rotation axis coincided with the rotation axis of the dynamometer. The volleyball players were warmed up for a total of 10 minutes before the test along with the stretching movements towards the lower extremity. Females performed maximal concentric knee flexion and extension of their dominant and non-dominant lower extremities, respectively, in the angular range of motion from 90˚ (flexion) to 0˚ (extension). The measurements were given a resting time of 3 min between both legs and 60 sec between each angular velocity. The dynamometer was calibrated prior to each test session according to the manufacturer's standard machine protocol. The mean peak torque (PT) values of the flexors and extensors of each leg were analysed after normalization by body mass. The H:Q ratio was calculated by dividing the concentric peak torque of hamstrings by that of quadriceps during the same contraction speed. Bilateral muscle strength difference was defined according to a previous study (Lockie, Schultz, Jeffriess, & Callaghan, 2012).

Balance assessment

Balance measurements were performed with a dynamometer Biodex Systems 3 ® device (Biodex Balance Systems SD, Biodex Medical Systems, Shirley NY, 11967, USA). The platform has a mobility degree of 1-12. Level 12 is the most stable platform, while Level 1 is the most mobile platform. When a general distinction is made according to the mobility of the platform, they can be classified as 1-4 levels difficult, 5-8 levels medium, and 9-12 levels easy. In determining the balance performance in our study, taking into consideration that volleyball players are at the elite level, 4 level (difficult) dynamic balance test was used. Balance measurements include anterior/ posterior stability index (APSI), medial/lateral stability index (MLSI), and overall stability index (OSI) scores. These indices indicate standard deviations from the centre of the platform. The OSI score is calculated by combining APSI and MLSI scores. All three indices were automatically calibrated by a computer software. A high index score indicates poor balance. The OSI balance score is thought to be the best indicator of the patient's ability to hold the platform in place. The foot position of the athletes remained constant throughout the measurement. In our study, the tests were performed directing the participants to use one foot, stand up straight and keep the eyes open. The balance tests were performed as in 3 intervals with a duration of 30 s. each and with rest intervals of 15 s. and the best value was included in the study (Testerman & Vander Griend, 1999).

Statistical analysis

SPSS 24 (IBM SPSS Statistics 24.0, IBM SPSS® software, US) package program was used in the analysis of the data. The data presented normality according to the Shapiro–Wilk test. Spearman Correlation Analysis test was used to verify the relationship among the data concerning knee flexion and extension muscle strength, jump performance, balance and FMS® scores. In all of the statistics, *p* significance level was accepted as $p < .05$ (Lakens, 2017).

RESULTS

For each predictor and criterion variable, Table 1 provides mean ± SD and min-max of current study values.

There was positive correlation between the knee flexor and extensor PT of the dominant and nondominant limb at 60°/s and 180°/s with CMJ height ($p < .05$). However, association between knee extension PT and CMJ performance was stronger than knee flexion PT at two angular velocities ($p < .01$) (Table.2).

The OSI values of both sides presented negative association with knee flexor and extensor PT of the dominant and nondominant limb at 60°/s and 180°/s ($p < .05$) (Table.2).

There was a significant relationship between CMJ height and knee flexion and extension PT values at two angular velocities and total FMS® scores ($p < .05$) (Table.2).

Significant correlations were found between FMS® scores, CMJ height, APSI and OSI balance scores, and dominant side flexion and extension PT values at both angular velocities ($p < .05$) (Table.2).

The H:Q ratio values in both speeds were significant associated with CMJ height and FMS® scores ($p < .05$). However, contralateral deficit statistically significant were not related between CMJ height, all dynamic balance and FMS® scores ($p > .05$) (Table.2).

Table.1. The Relationship Between Isokinetic Knee Muscle Strength, Jump performance, Dynamic Balance and Functional Movement Screen (FMS®) Values.

Variables **Spearman's rho**	**FMS Total Score**	**APSI (D)**	**APSI (ND)**	**MLSI (D)**	**MLSI (ND)**	**OSI (D)**	**OSI (ND)**	**CMJ (cm)**
D 60˚ s^{-1} F PT (N/m)	**0.504***	-0.405	-0.383	-0.372	-0.343	**-0.643****	**-0.575***	**0.559***
ND 60˚ s^{-1} F PT (N/m)	0.426	-0.368	-0.261	-0.355	-0.358	**-0.509***	**-0.609****	**0.544***
D 60˚ s^{-1} E PT (N/m)	**0.673****	-0.212	-0.298	-0.458	-0.416	**-0.694****	**-0.534***	**0.693****
ND 60˚ s^{-1} E PT (N/m)	0.430	-0.243	-0.064	-0.417	-0.430	**-0.482***	**-0.654****	**0.651****
D 180˚ s^{-1} F PT (N/m)	**0.555***	-0.170	-0.117	-0.164	-0.170	**-0.588***	**-0.482***	**0.487***
ND 180˚ s^{-1} F PT (N/m)	0.459	-0.222	-0.204	-0.458	-0.342	**-0.500***	**-0.469***	**0.504***
D 180˚ s^{-1} E PT (N/m)	**0.694****	-0.294	-0.174	-0.224	-0.318	**-0.605****	**-0.496***	**0.673****
ND 180˚ s^{-1} E PT (N/m)	0.396	-0.110	-0.168	-0.324	-0.289	**-0.497****	**-0.593***	**0.651****
D H:Q 60˚ s^{-1}	**0.502***	-0.146	-0.193	-0.189	-0.212	**-0.474***	**-0.474***	**-0.656****
ND H:Q 60˚ s^{-1}	0.358	-0.160	-0.153	-0.377	-0.342	**-0.542***	**-0.620****	-0.431
D H:Q 180˚ s^{-1}	**0.515***	-0.189	-0.090	-0.110	-0.022	**-0.463***	**-0.493***	**-0.654****
ND H:Q 180˚ s^{-1}	0.357	-0.307	-0.302	-0.286	-0.259	**-0.469***	**-0.497***	-0.340
CLD 60˚ s^{-1} F	0.356	-0.265	-0.225	-0.355	-0.255	-0.337	-0.198	-0.236
CLD 60˚ s^{-1} E	0.179	-0.280	-0.129	-0.226	-0.325	-0.266	-0.181	-0.281
CLD 180˚ s^{-1} F	0.290	-0.282	-0.226	-0.267	-0.342	-0.207	-0.225	-0.357
CLD 180˚ s^{-1} E	0.296	0.216	-0.181	-0.203	-0.281	-0.268	-0.217	-0.192
FMS Total Score	1.000	-0.204	-0.204	**-0.602****	-0.177	**-0.653****	-0.171	**0.917****

** p < .05, ** p < .01, FMS: Functional Movement Screen, D: Dominant Side, ND: Nondominant Side, PT: Peak Torque, N: Newton, m: meter, F: Flexion, E: Extension, APSI: Anterior/ posterior stability index, MLSI: Medial/lateral stability index, OSI: Overall stability index, H:Q: Hamstring/Quadriceps ratio, CLD: Contralateral deficit.*

Table. 2. Isokinetic Knee Muscle Strength, Jump Performance, FMS® and Dynamic Balance Values of Athletes.

Variables	Mean (SD)	Min	Max
FMS Total Score	15.94 (1.95)	12.00	18.00
CMJ Height (m)	62.35 (7.17)	49.00	70.00
APSI (D)	0.80 (0.29)	0.30	1.70
APSI (ND)	0.78 (0.29)	0.40	1.30
MLSI (D)	0.68 (0.23)	0.20	1.10
MLSI (ND)	0.78 (0.35)	0.20	1.80
OSI (D)	1.12 (0.30)	0.60	1.60
OSI (ND)	1.15 (0.43)	0.40	2.10
D 60˚ s^{-1} F PT (N/m)	80.98 (17.03)	62.90	129.70
ND 60˚ s^{-1} F PT(N/m)	78.81 (11.11)	62.60	104.50
D 60˚ s^{-1} E PT(N/m)	157.13 (35.02)	55.20	215.50
ND 60˚ s^{-1} E PT(N/m)	149.21 (35.07)	54.80	209.70
D 180˚ s^{-1} F PT (N/m)	61.08 (19.42)	12.90	107.50
ND 180˚ s^{-1} F PT(N/m)	58.29 (17.22)	34.90	112.30
D 180˚ s^{-1} E PT(N/m)	108.66 (23.93)	53.70	151.50
ND 180˚ s^{-1} E PT(N/m)	101.38 (29.71)	65.90	200.90

SD: Standard Deviation, FMS: Functional Movement Screen, D: Dominant Side, ND: Nondominant Side, PT: Peak Torque, N: Newton, m: meter, F: Flexion, E: Extension, APSI: Anterior/ posterior stability index, MLSI: Medial/lateral stability index, OSI: Overall stability index.

Table. 3. H:Q Ratios and Contralateral Deficit Values of Athletes.

	H:Q Ratio		Contralateral Deficit (%)	
Angular Velocity	Dominant Side Mean (SD)	Nondominant Side Mean (SD)	Flexion Mean (SD)	Extension Mean (SD)
60° s^{-1}	0.53 (0.01)	0.57 (0.02)	5.50 (1.12)	6.45 (1.58)
180° s^{-1}	0.63 (0.24)	0.65 (0.32)	9.34 (2.23)	8.56 (2.09)

SD: Standard Deviation, H:Q: Hamstring/Quadriceps ratio, CLD: Contralateral deficit.

DISCUSSION

The aims of the current study were to identify possible associations between knee PT values in different speeds, jump performance, balance and injury risk in professional female volleyball players.

In our study, it was seen that there was a significant changing relationship between volleyball players' isokinetic knee flexion and extension muscle strength, jump performance, dynamic balance and FMS® scores. It was determined that there was a significant positive correlation between dominant and nondominant side knee flexion and extension PT values at 60˚/ s and 180˚/ s angular velocities and CMJ height; however, a stronger correlation was found between knee extension PT values and CMJ height. On the other hand, athletes with stronger knee flexor and extensor muscle strength were found to have great jump performance.

The influence of the strength of knee extensors on jump performance is evidenced when we observe the high correlation values found in studies with volleyball players (Bosco, Mognoni, & Luhtanen, 1983; Laudner et al., 2015; Sattler et al., 2016; Yapici, Findikoglu, & Dundar, 2016). On the other hand, knee flexor muscles seem to exert less influence on the performance of jumps. Yapici et al.(2016) reported that the peak torque and total work of knee flexors showed significant correlations (r = 0.42 to r = 0.74) with jump power, but the correlations are smaller than those found with concentrically analysed knee extensors. Laudner et al (2015) showed that the correlation of knee flexors PT/W also showed lower correlation values (r = 0.39 - 0.58) with jump height compared to the knee extensors that presented higher correlation values (r = 0.63 - 0.74) with height of jump. Schons et al. (2018) found that a strong positive association between the knee extensor PT of the dominant limb at 180˚/ s with CMJ power (r = 0.610). These results are similar to those found in the present study. These results showed that knee flexor muscles seem to exert less influence on the performance of jumps. This finding can be explained by the fact that the extensors act as agonists for the knee joint in the impulsion phase and it takes on most of the strength needed to reach higher power and height values in the jumps.

The results showed that found a negative correlation between dominant side knee flexion and extension PT values in two angular velocities and OSI of the dominant side. A high overall balance index score indicates a high loss of balance. In our study, the reason why knee flexion and extension muscle strength have a negative relationship with balance performance is that the decrease in the overall balance index score is in fact the increase in the balance performance. This result reveals that the dynamic balance performance of the athletes increased as knee flexion and extension muscle strength increased. In a similar study, the effect of quadriceps and hamstring muscle strength on static and dynamic balance was examined. It was determined that quadriceps muscle strength had a positive relationship with balance performance and that hamstring muscle had no effect on balance performance (Çelenk et al., 2015). Akarçeşme and Aktuğ (2018), stated that the performance of the balance, which is one of the requirements of high performance, is associated with muscle strength of quadriceps and that Volleyball branch-specific training played an important role in increasing the performance of knee muscle strength and balance. It was stated in the literature that the relationship between lower extremity muscle strength and balance performance might be due to increased muscle coordination and motor unit contraction rate in muscles and increased capacity of synergies and antagonists of extensor and flexor muscles (Akarçeşme & Aktuğ, 2018). In the literature, the number of studies investigating the relationship between volleyball players' isokinetic knee muscle strength and balance performance is insufficient. Further studies should be conducted on this subject.

Additionally, we were recorded that H:Q ratios and the contralateral deficits of the athletes. A typical isokinetic concentric H:Q (conventional ratio) for healthy athletes ranges from .50 to .80 depending on angular velocity and indicates the muscle balance between the hamstrings and quadriceps (Hewett, Myer, & Zazulak, 2008; Kong & Burns, 2010). Furthermore, reduced function of the hamstrings due to activities that emphasize loads on the knee extensors may lead to the muscle strength imbalance between the hamstrings and quadriceps which is implicated as a potential risk factor of knee injuries (Kabacinski et al., 2018) . When the percentages of both knee H:Q of the athletes included in the study were examined at the angular velocities of 60 °/s and 180 °/s, it was found that this ratio was between .53 - .57 at 60˚/ s angular velocity and .63 - .65 at 180˚/ s angular velocity (Table.1). Schons et al. (2018) reported a H:Q ratio of .56(6.0) at 60˚/ s angular velocity in their study of Polish first national leagues female volleyball players. It was found that this ratio ranged between .52 - .63 at 60˚/ s angular velocity and .56 - .63 at 180˚/s angular velocity in other studies (Akarçeşme, Aktuğ, Aka, & Ibis, 2017; Celebi, Akarçeşme, & Ekin Dalbayrak, 2018; Cheung et al., 2012; Kabacinski et al., 2018; P. Schons et al., 2018; Teixeira, Carvalho, Moreira, & Santos, 2018) . The muscle strength imbalance between the dominant and nondominant limbs, which are called contralateral deficits, is calculated by calculating the dominant and nondominant peak torque percentage difference. The greatest importance of this analysis is that the contralateral deficit values higher than 15% may cause a greater risk of injury to the individual. In addition to the risk of injury, because these imbalances require coordinated movement of the knee extensors and flexors of the jump movement and a common movement between the lower extremities, it may affect the performance of volleyball players adversely. explain the relationship between conventional rate and jump performance with two main mechanisms. In our study, it was observed that contralateral deficit for movements of knee flexion and extension at 60˚/s and 180˚/s angular velocities varied between 5.50 - 9.34%. We found no asymmetry between dominant and non-dominant sides of knee flexion and extension at both angular velocities and this was consistent with the findings of literature (Akarçeşme et al., 2017; P. Schons et al., 2018; Teixeira et al., 2018). In addition, the results found that a reduced knee conventional ratio at dominant side is associated with a greater CMJ performance was confirmed at 60˚/s ($r = -0.656$, $p = .029$) and 180˚/s ($r = -0.654$, $p = .034$) angular velocities with a strong negative association. Schons et al (2018) one of them is the role of hamstring muscles and structural joint regulation to control the dynamic stability of the knee joint. Another reason is the fact that it is a bigger net mechanical work production in order to consume less of the rotational energy produced by the antagonist muscles. There are only few studies investigating the relationship between knee joint conventional ratio and jump performance in volleyball players. For instance, in the study of Schons et al. (2018) they reported that a reduced knee conventional ratio was negatively correlated with a higher CMJ performance, which is parallel to the results obtained in our study. Li et al. (1996) found a positive correlation between the increase in conventional ratio and knee flexor muscle strength and improved functionality (jump, walk, etc.) in volleyball players and athletes undergoing rehabilitation after anterior cruciate ligament injury. However, differently from study of Li et al. (1996) the inclusion of volleyball players without knee injury confirms the difference between results in our study. Even though the jumping movement requires a coordinated action within and between the lower extremities (Newton et al., 2006),our results showed that the contralateral deficits at both angular velocities were not related to jump performance of professional volleyball players. Laudner et al (2015) were not found significant relationship between jump performance and contralateral deficit in volleyball players and other athletes who had undergone anterior cruciate ligament reconstruction surgery supports our results. Schons et al (2018) stated that there was no significant relationship between jump performance and contralateral deficit calculated at 3 different angular velocities. In the study conducted by D'Alessandro et al (2005) with 30 professional volleyball players, they investigated whether there is a relationship between isokinetic knee flexion and extension work values at angular velocities of 60 ° /s and 300 ° /s and the contralateral deficit evaluated using the hop test. Even though a significant relationship was found in the study, the authors stated that the contralateral deficits measured by using isokinetic dynamometer and deficits measured by using hop test would not be the same, which partially agrees with our study.

In this study, a significant relationship was found between FMS® scores and CMJ performance, dominant flexion and extension PT values and H:Q ratios at both angular velocities. On the other hand, it was noted that the jump performance of the athletes with high FMS® scores ($\geq$ 14) were better, their knee muscle strengths were higher, and their H:Q ratios were more balanced. In accordance with results of our study, Yıldız (2018) identified that FMS® scores presented higher correlation values with CMJ performance in 28 male tennis players ($r = 0.570$, $p = .002$). This result was a result we expected, because the potential performance outputs of the vertical jump capability can be estimated in the FMS® test battery with the Deep Squat, which requires a vertical force production. The athlete must have well both mobility and stability in the ankle, knee and hip areas to perform CMJ. At both angular velocities, a significant relationship was found between dominant side flexion and extension PT values, H:Q ratios and FMS scores. The probable cause of this relationship is that many movements in the FMS® test battery require the strength of the knee muscles, the balance between the agonist / antagonist muscles and the bilateral muscle strength symmetry. Also, studies focusing on the relationship between conventional ratio and risk of injury indicate that this relationship is related to anteroposterior dynamic stability of the joint (Yeung, Suen, & Yeung, 2009). Other results of our study that a very significant relationship between FMS® and dominant OSI and MLSI dynamic balance scores.

In FMS® with Deep Squat, In-line Lunge and Hurdle Step Tests balance assessment can be possible on two leg stance, tandem position and one leg. It was indicated that if balance ability is improved lower body asymmetry would decrease (Sannicandro, Cofano, Rosa, & Piccinno, 2014). Balance ability was also related to injuries (Hrysomallis, 2007) . Due to this, detection of the asymmetries would decrease the occurrence of the injuries. It could be detected that which parts of the body have asymmetry and which parts of the body would take place a problem for the athlete with FMS®. Few studies sought to investigate the relationship between dynamic balance and FMS® scores in volleyball players. For instance, in the study by Pourheydari et al. (2018) with which they evaluated the dynamic balance with Y Balance test of 30 volleyball players, they reported a significant relationship between FMS® total score and dominant side dynamic balance score. In parallel with the results of this study, only the dominant side OSI and MLSI scores and FMS® total score were found in our study. This may be because volleyball players use their nondominant legs less often than their dominant legs during their sporting performance (e.g. jumping, landing). Thus, with this information, in order to the better performance of the athlete in the field, clinicians might be directed to knee muscle strength balance, contralateral deficit, FMS® and dynamic balance evaluations.

The present study has some limitations that must be discussed. Although the focus of the study was high-level female volleyball players, the sample was relatively small. In addition to that, we only analysed the knee flexion and extension muscle performance in concentric contractions in the isokinetic dynamometry test. Finally, this study may be repeated at different jumping types and with different groups based on the gender.

In conclusion, there was a significant relationship was found between knee flexor and extensor muscle strength, H:Q ratio, contralateral deficit, dynamic balance, risk of injury and jump performance in professional female volleyball players. We suggest that all clinicians and coaches involved in the protective and preventive rehabilitation phase evaluate these parameters and plan their training programs in line with the results obtained in increasing both individual and team performance of athletes.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest. We certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on us or on any organization with which we are associated.

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