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Original Article

Knee joint bilateral symmetry evaluation in high-level handball players prior to their return to playing

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Abstract
Lower limb muscle asymmetries have been thoroughly examined in many studies, which highlighted their detrimental role in sport performance as a risk factor for injury to players. Specifically, in handball, asymmetries in muscle activation and balance asymmetries cause injuries and generally appear as a factor of possible injury of the lower limbs. The asymmetry between two limbs should be evaluated to determine whether limb recovery is successful. The purpose of this study was to evaluate the symmetry in muscular strength and dynamic balance, in high-level handball players through the isokinetic assessment of knee joint and one – legged hops using the limbsymmetry index (LSI). The sample consisted of 15 handball players, i.e. 9 men and 6 women. All of them were high-level players who competed in teams from the two top leagues of Greece (Handball Premier for men and A1 Division for women) had previous injuriesof the lower extremities and abstained, for at least 7 days, from playing activities. Isokinetic dynamometry was performed at: 60°/s, 180°/s and 300°/s., angular velocities, while the LSI measurements used included: a) one-legged single hop, b) one-legged triple hop, c) one-legged cross-over triple hop and d) one-legged timed hops. Descriptive and inferential statistics were used. Theobtained results showed that at the angular velocity of 60°/s 9 cases were outside normative limits. At 180°/s, 13 cases were outside normative limits at 300°/sec we had 15 cases outside normative limits. Concerning LSI, 8 players showed positive results. High correlation scores were not observed. Strong relationships were found only between triple cross-over hop and timed hops. In conclusion, based on both assessments, it was determined that these players were not completely ready for their safe return to sport.
***Key Words*:**Lower Limbs, Injuries, Rehabilitation, Asymmetries, Isokinetic Assessment, Limb Symmetry Index,

Introduction

Lower limb muscle asymmetries have been thoroughly examined in many studies, which highlighted their detrimental role in sport performance as a risk factor for injury to players (Bell et al., 2014; Bishop et al., 2018; Hofmann et al., 2007). To assess, whether lower limb recovery is successful, and to assure a safe return to the same activity, the asymmetry between two limbs should be evaluated (Di Stasi et al., 2013).
According to many studies, muscle activation and balance asymmetries cause injuries and are a factor of possible injury of the lower extremities (Dos Santos, et al., 2014; Rauh et al., 2007). Regarding the main causes of lower limb injuries, Fousekis et al. (2010) considered that, asymmetries in muscle strength, proprioception and joint stability are important factors. Performing a complete assessment of asymmetriesbetween two limbs is very useful, prior to return to the training process and will significantly reduce the possibility of injury (Dos Santos et al., 2014). Strength asymmetry between the two limbs, increases the risk of re-injury (Di Stasi et al., 2013; Paterno et al., 2010). In addition, strength asymmetry may appear either as an asymmetry between the right and left limb, or as a ratio difference between flexor and extensor muscles of the same limb (Knapik et al., 1991).

Tsiokanos et al., (2002) have report that isokinetic evaluation can produce comparable and repetitive results. Therefore, isokinetic dynamometers are very popular and allow to easily evaluate maximum strength.Several studies used the isokinetic assessment of knee joint to assess players' return to sport after an injury. This assessment isused in handball, especially after an anterior cruciate ligament injury (Myklebust et al., 2003). According to the literature, the deficit between two limbs and, in particular, the deficit between flexors and extensors of the knee, ranges from 10% to 15%. This deficit is the normative limit for safe return to competitive activity after an injury (Dauty et al., 2007; Dvir, 2004; Foreman et al., 2006; Texeira et al., 2014). Xaverova et al. (2015) have reported that, although the relationship concerning asymmetry between two extremities and the occurrence of injury is not clear, we should, accept a deficit of less than or equal to 10%as a limit. The normative limit of the ratio between the hamstrings and quadriceps (H / Q ratio) at the angular velocity of 60°/s ranges from 50% to 70%, for the angular velocity of 180°/s it ranges from 60% to 80% , for the angular velocity of 300°/s it ranges from 60% to 80% (Coombs and Carbutt, 2002; Gerodimos et al., 2003; Kyritsis et al., 2016; Texeira et al., 2014; Wright et al., 2009).

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To better control the readiness of a player to return to action after an injury, many functional assessments have been developed. Functional tests (e.g. one-legged hops) have been studied to evaluate their usefulness in assessing patients with lower extremity dysfunction and problems (Greenberger and Paterno, 1995). One-legged hops are measurements that are based on sport-specific movements and are used to assess the combination of muscle strength, neuromuscular control, confidence in the tested limb, and the ability to withstand loads that are commensurate with competitive activity. Functional tests are mainly used to measure the performance of knee joint after a recovery (Logerstedt et al., 2012; Reid et all, 2007). According to Greenberger and Paterno (1995), these tests are designed to assess the functional level of a player by, taking into account strength, endurance, power, and muscle coordination. In addition, they include various movements that mimic changes that occur during the dynamic stabilization of knee in game-specific movements (Reid et al., 2007).

These tests include a) one-legged single hop for distance, b) one-legged triple hop for distance, c) one-legged cross-over triple hop for distance and d) one-legged timed hops at a distance of 6 m. Measurements are made at both limbs for comparisons. The result of these measurements, which is expressed as a percentage of the injured limb in relation to the uninjured one, is called limb symmetry index (LSI) (Noyes et al., 1991; Reid et al., 2007). The index of readiness of an injured member has been reported to be a rate greater than or equal to 85% of the contralateral uninjured one (Hamilton et al., 2008; Noyes et al., 1991; Reid et al., 2007). Gustavsson et al. (2006) have report a rate greater than or equal to 90% of the uninjured limb.

In addition, when these four tests are included in a battery of multiple tests, their sensitivity index (which is an indicator that shows the reliability of a measurement) reaches 82% (Gustavsson et al., 2006). Noyes et al. came to the same conclusion (1991), and recommended that these tests must be used in conjunction with other assessment tests. Finally,the reliability of hop tests has been investigated and shown to be highin both injured and uninjured athletes (Ross et al., 2002).

The purpose of this study was to evaluate the symmetry in muscular strength and dynamic balance, in high-level handball players, (priorto their return to sport after an injury of the lower limbs)through the isokinetic evaluation of knee joint and one-legged hops to obtain LSI.In addition, this approach was used to determine, whether there were any statistically significant differences between injured and non-injured limbs.

Materials and methods

Participants

The sample consisted of 15 handball players, i.e. 9 men and 6 women. All of them were high level players and competed in teams from the two top categories of Greece (Handball Premier for men and A1 Division for women). The mean age of the subjects was 22 ± 3.13 years. Prior to their injury, all of them participated in all activities (training and games) of their teams. All players whoparticipated in this study hadlower limbs injuries. These injuriesforced the participants to abstain from the team's activities (training and games)for at least 7 days. Prior to participating in the research process and in the measurements, the participants obtained the consent of either the doctors, physiotherapists or their coaches to return to full playing activity.

Measures

For the purposes of this study, laboratory and field tests were performed. Isokinetic dynamometry was performed in the laboratory, while LSI measurements were performed in the field. In addition, during their presence in the laboratory, the above-mentioned handball players responded to a questionnaire that included some of their personal information (e.g. name, age, team, years of experience with handball, and preferred limb), details about training (training level, training quality and quantity, evaluation of training process) and details about the specific injury (e.g. when, how, treatment after injury, rehabilitation process, and time of absence).

Instruments

The following instrumentswere used in the laboratory and in the field:

(a) In the laboratory: measurements were performed using a Humac Norm 770 CSMi isokinetic dynamometer (Stoughton, MA, USA) at the Human Biological Performance Assessment Laboratory at SPESS - Aristotle University of Thessaloniki.

(b) In the field, distances were measured with 10 m. tape measure and time was measured with a chronometer Accusplit Pro 601X.

Procedures

All handball players who were part of our sample, started their evaluation in the laboratory with the isokinetic assessment. This assessment was performed on the first day.
The next day, the subjects continued their evaluation in the field, by participating in the assessment process of one-legged hops, using the LSI, after warming-up for 20 min.

Description of Assessments

Isokinetic assessment of the knee joint:

In the isokinetic assessment of the knee joint, the measurement of strengthof flexors and extensor muscles in the knee at a specific angular velocity was performed. Prior to the isokinetic assessment procedure, the subjects warmed up on a stationary bicycle for 10 min. After placing the subject in isokinetic dynamometer chair in a sitting position, we immobilized him/her andfollowed the adjustment procedures according to the dynamometer instructions. The assessment protocol used in this study included three angular velocities, i.e. 60°/s, 180°/s and 300°/s. At each angular velocity three repetitions of flexion and extension were performed and the interval between angular velocity changes was 30 s. Prior to the first measurement, three trial attempts were performed to familiarize the examinee with the measurement. The same procedure was repeated for the other limb.

Assessment using LSI:

LSI testsincluded a) one-legged single hop for distance, b) one-legged triple hop for distance, c) one-legged cross-over triple hop for distance and d) one-legged timed hops at a distance of 5 m.

1) One-legged single hop for distance: The subject stood at one limb, jumped in length and had to land on the same limb. Two attempts were made, and the hop length was measured and recorded. The same procedure was repeated for the other limb. For an attempt to be considered valid, during landing, the subject had to: a) not move the limb, b) not have any kind of support, and c) not allow the other limb to come in any contact with the ground. If any of the above-mentioned conditions occurred, the measurement was considered invalid and repeated.

2) One-legged triple hop for distance: The subject stood on one limb and made three hops in length, without interruption between hops, and always landing on the same limb. Two attempts were made, and the total length of the hops was measured and recorded. The same procedure was repeated for the other limb. For an attempt to be considered valid, during landing, the subject had to: a) not move the limb, b) not have any kind of support, and c) not allow the other limb to come in any contact with the ground. If any of the above-mentioned conditions occurred, the measurement was considered invalid and repeated.

3) One-legged cross-over triple hop for distance: The subject stood on one limb and then attempted three diagonal hops in length passing over a line made of self-adhesive sticker, on the right and left side, at a distance of approximately 15 cm away of the line, without interruption between hops, and always landing on the same limb. Two attempts were made, and the total length of the hops was measured and recorded. The same procedure was repeated for the other limb. For an attempt to be considered valid, during landing, the subject had to: a) not move the limb, b) not have any kind of support, and c) not allow the other limb to come in any contact with the ground. If any of the above-mentioned conditions occurred, the measurement was considered invalid and repeated.

4) One-legged timed hops at a distance of 6 m. The subject stood on one limb, and performed successive long hops without interruption between hops and always landing on the same limb. The subject tried to cross the six measures set by the self-adhesive sticker, as fast as he/she could. Two attempts were made, and the time for each attempt was timed and recorded. The same procedure was repeated for the other limb. For an attempt to be considered valid, during landing, the subject had to: a) not move the limb, b) not have any kind of support and c) not allow the other limb to come in any contact with the ground. If any of the above-mentioned conditions occurred, the measurement was considered invalid and repeated.

To evaluate the symmetry of lower extremities, the evaluation of LSI was as follows.

The calculation of the LSI of the injured limb in relation to the uninjured one was performed by calculating the average of the two attempts recorded in the tests. Then, the tests aimed at distance, the LSI was calculated using the following formula:

LSI = (INL /NNL) ×100.

For the test aimed at best time, the LSI was calculated using the following formula:

LSI = (NNL / INL) ×100.

Where LSI is the limbsymmetry index, INL are the values for the injured limb and NNL are the values for the non-injured limb. LSI values were calculated separately for each of the four tests.

Statistical Analysis

Descriptive statistics and correlation analysis were used toanalyze the results. Specifically, the frequency and proportion of the values were used as well as the mean value and standard deviation (SD). In addition, owing to the abnormal distribution of the sample, the non-parametric Mann - Whitney U test was used to identify statistically significant differences between injured and non-injured limbs. Correlation analysis was performed to demonstrate the relationship between the tests of LSI with each other. The significance level was set at 0.05 and statistical analysis of the study's data was performed using SPSS 25 (IBM SPSS Statistics 25.0).

Results

For the sample of 15 players (6 women and 9 men) who suffered an injury during theseason ofour study, the average age was 22 ± 3.13 years. All of them were high-level players (Handball Premier and A1 Division for women) and had an average body height and body weight of 180.46 ± 7.7 cm and 81.73 ± 10.18 kg respectively. A total of 6 players were back players, 4 were wing players, 4 were line players, and one was a goalkeeper.

Isokinetic Assessment

The assessment of the knee joint using an isokinetic dynamometer was performed at three angular speeds, i.e. 60°/s, 180°/s and 300°/s. The deficit between the two limbs in the extensors and flexors of the knee was recorded and evaluated, the ratio of flexor-extensor muscles for both lower limbs was also evaluated. The statistical analysis of data using the non-parametric Mann-Whitney U test showed that there were no statistically significant differences between the injured and non-injured limbs. Specifically, at the angular velocity of 60°/s, $p = 0.539$, at the angular velocity of 180°/s, $p = 0.624$, at the angular velocity 300°/s, $p = 0.713$.

Table 1 shows the results of the isokinetic assessment of the knee joint, expressed in means and standard deviations. Specifically, the results of the isokinetic assessment are shown in terms of deficit between the two limbs (injured and non-injured) in the extensors and flexors of the knee. In addition, the ratio of flexors-extensors for each limb (injured and non - injured) is shown separately.

Table 1. Results of the Isokinetic Assessment of the Knee Joint.

Isokinetic Assessment of the knee joint				
Angular velocities	Extensors deficit	Flexors deficit	Ratio H/Q of the injured limb	Ratio H/Q of the non-injured limb
	(%) Mean – S.D.	(%)Mean – S.D.	(%)Mean – S.D.	(%)Mean – S.D.
60°/sec	12,9% ± 9,3%	14,6% ± 10,5%	57,6 %± 14%	59,7% ± 9,7%
180°/sec	11,06% ± 9,7%	15% ± 9%	62,4% ± 12,8%	64,8% ± 11,2%
300°/sec	20,1% ± 19,1%	11,01% ± 13,9%	61,5% ± 18,1%	60,8% ± 21,3%

Table 2 shows the analysis of the results of the isokinetic assessment in terms of deficit between the two limbs (injured and non-injured) in the extensors and flexors of the knee in relation to the acceptable normative limits of 10% and 15%.

Table 2. Evaluation Analysis of Deficits in Relation to Normative Limits of 10% and 15%.

Evaluation analysis of deficits in relation to normative limits				
	Extensors		Flexors	
Angular velocities	Deficit > 10%	Deficit > 15%	Deficit > 10%	Deficit > 15%
60°/sec	53,3 %	26,6 %	60 %	46,6 %
180°/sec	40 %	26,6 %	73,3 %	46,6%
300°/sec	33,3 %	20 %	46,6 %	40 %

Table 3 shows the analysis of the results of isokinetic assessment in terms of the ratio of flexors-extensors for each limb (injured and non-injured) in relation to the normative limits per angular velocity.

Table 3. Analysis of the Ratio of Knee Flexors–extensions Results in Relation to the Normative Limits

	Within normative limits(Frequency - %)		Out of normative limits (Frequency - %)	
Angular velocities	Injured	Non-injured	Injured	Non-injured
60°/s	9 (60%)	12 (80%)	6 (40%)	3 (20%)
180°/s	5 (33,3%)	12 (80%)	10 (66,7%)	3 (20%)
300°/s	6 (40%)	9 (60%)	9 (60%)	6 (40%)

Table 4 shows the results of the evaluation of the symmetry of the lower limbs using LSI. More specifically, the values of the LSI expressed as means and standard deviations are shown. Table 4 also shows the analysis of results regarding the normative limit of 85% of the injured limb, in relation to the non-injured limb.

Table 4. LSI Means and Standard Deviations (percentages) and their Analysis (Number and percentages)

Limb Symmetry Index					
LSI test	Results	Values ≥85%		Values <85%	
	Means – S.D.	Frequency	Percentage	Frequency	Percentage
Single hop	92,1% ± 20,8%	11	73,3%	4	26,7%
Triple hop	95,7% ± 9,8%	12	80%	3	20%
Triple cross-over hop	90,8% ± 15,5%	9	60%	6	40%
Timed hops	92,8% ± 15%	10	66,6%	5	33,4%

By analysing the results of the 4 one-legged hops of LSI, we determine that, in terms of the relationship between single hop and triple hop, the results from the non-parametric correlation analysis, (owing to the abnormal distribution of two variables, determined using the Spearman rs correlation coefficient), showed that there was no strong relationship between these two trials. Specifically, we obtained rs = 0.57 and p = 0.26.

Regarding the relationship between single hop and triple cross-over hop, the results of the non-parametric correlation analysis, (owing to the abnormal distribution of two variables), obtained with the Spearman rs correlation coefficient showed that there was no strong relationship between these two tests. Specifically, we obtained rs = 0.4 and p = 0.13.

Regarding the relationship between single hop and timed hops, the results of the non-parametric correlation analysis, (owing to the abnormal distribution of two variables), obtained with the Spearman rs correlation coefficient showed that there was no strong relationship between these two tests. Specifically, we obtained rs = 0.45 and p = 0.85.

Concerning the relationship between triple hop and triple cross-over hop, the results of the non-parametric correlation analysis, (owing to the abnormal distribution of two variables), obtained with the Spearman rs correlation coefficient showed that there was not a very strong relationship between these two tests. Specifically, we obtained rs = 0.62 and p = 0.12.

Regarding the relationship between triple hop and timed hops, the results of the non-parametric correlation analysis, (owing to the abnormal distribution of two variables), obtained with the Spearman rs correlation coefficientshowed that there was no strong relationship between these two tests. Specifically, we had rs = 0.45 and p = 0.86.

Finally, regarding the relationship between triple cross-over hop and timed hops, the results of the non-parametric correlation analysis, (owing to the abnormal distribution of two variables), obtained with the Spearman rs correlation coefficient showed that there was a strong relationship between these two tests. Specifically, we obtained rs = 0.79 and p = 0.00.

Discussion

The isokinetic assessment and specifically the assessment of the knee joint, performedat three angular speeds, 60°/s, 180°/s and 300°/s. The deficit between the two limbs in the extensors and flexors of the knee was recorded and evaluated as well as the ratio of flexors-extensor muscles for both lower limbs, toidentify any asymmetries between them. According to Gerodimos et al. (2003), the ratio of flexors-extensors of the knee joint is one of the most important parameters of isokinetic assessment. Its importance is based on the role it plays in intermuscular coordination and joint stability. The statistical analysis of results regarding the ratio of flexors-extensions (H/Q ratio) showed that at 60°/s the total average (injured and non-injured) was 58.65% ± 11.85% with 9 cases (injured and non-injured) outside normative limits.At this angular velocity, the results of thisstudy, agree with those of Xaverova et al. (2015), in which the researchers evaluated high level handball players, and with those of Ergun et al. (2004) and Texeira et al. (2014).

In addition, at 180°/s we obtained thetotal average (injured and non-injured) of 63.6% ± 12% and 13 cases out of 30 (injured and non-injured) were outside normative limits. The specific results differ from the measurements of other researchers at this angular velocity and more specifically from the measurements of Pincivero, Coelho and Campy (2003), and Texeira et al. (2014). Moreover, these results agree with those of Andrade et al. (2012) and Xaverova et al. (2015). This difference in the results of our study in relation to those of other researchers may exist because in all the other studies the sample consisted of healthy populations, while the sample of this study assessed handball players who were returning to the same competitive activity after an injury.

Finally, at 300°/s we obtained the total average of 61.15% ± 11.85% and 15 cases (injured and non-injured) were outside normative limits. At this angular velocity the obtained results agree with those in other studies (Andrade et al., 2012; Hewett et al., 2007). The analysis of data with the non-parametric Mann-Whitney U test showed that there were no statistically significant differences between the injured and non-injured limbs. According to various studies, when the angular velocity increases, the ratio of flexors to extensors increases, i.e., the participation of flexors increases (mainly in men and less in women) (Andrade et al. 2012; Hewett et al., 2007; Xaverova et al. 2015).

This occurs because knee flexors consist of a relatively larger number of fast-twitch muscle fibers than knee extensors, which results in faster firing during fast movements (Garrett et al., 1984). However, in this study the ratio of flexors to extensors at the angular velocity of 300°/s is lower than the corresponding ratio at the angular velocity of 180°/s. The above-mentionedfact in combination with the results of the assessment using an isokinetic dynamometer at all angular velocities, where flexor deficits appeared, suggested that the players in this study, although they followed a rehabilitation program, probably had a power deficit in their flexors. Therefore, this deficiency could possibly lead to new injuries, because the increased activation of knee flexors, during dynamic movements is important factor for injury protection (Hewett et al., 2008). In terms of symmetry and whether all players under evaluation were able to return safely to the same competitive activity, none of them fully met the criteria of isokinetic assessment of the knee joint for safe return.

LSI specifically evaluated the symmetry of two limbs. Using the 4 tests performed by executing one-legged hops during the LSIassessment, the symmetry between injuredand non-injured limb was assessed. The value greater or equal to 85% of the percentage of non-injuredwas considered as positive a result for the injured limb.

The results in Table 4 show, that in two evaluations, (i.e. triple cross-over hops and timed hops), the highest frequency was below the limit of 85%. In addition, the inferential statistical analysis showed that in the abovementioned tests (i.e. triple cross-over hop and timed hops), there was a strong relationship between them. This occurred probably owing to the degree of difficulty of the two specific tests because, these tests submitted the subjects, to demanding physical and psychological tests of controlling their limb. In addition, according to LSI, 8 players (53.4%) showed positive results in terms of symmetry of their two limbs, (i.e.the result of injured limb greater or equal to 85% of the non-injured limb) and, therefore, could safely return to playing activity.

Regarding the correlation analysis, to examine any correlations between various LSI evaluations, no high correlation scores were observed in most performed comparisons. The only strong relationships were observed between the triple cross-over hop and timed hops.

Conclusions

Regarding the main causes of lower limbs injuries in handball, asymmetries in muscle strength, proprioception, and dynamic balance seem to be important factors. The complete assessment of these asymmetries between the two limbs should be mandatory prior to return to the training process and willconsiderably reduce the possibility of injury.

Thus, in this study, we attempted to assess these factors and evaluate the rehabilitation process. Concerning the isokinetic assessment of the knee joint, at all three angular velocities, in terms of the deficit between the two limbs and consequently in whether the players under evaluation were able to return safely to the same activity, none of these players, fully met the criteria for a safe return.In addition, the combination of the results of the assessment of flexors to extensors ratio at all angular velocities, where flexors deficits appeared, indicated that the players in this study, probably had a power deficit in their flexors.

In contrast, concerning the dynamic balance assessment, using the one-legged hops LSI test, 8 players showed good results in terms of values above the normative limit and in terms of symmetry. Thus, in this particular assessment, these players met the criteriafor a safe return to the same competitive activity. This probably occurred, because these players made extensive use of the dynamic balance during their recovery programs.

In addition, statistically significant differences between injured and non-injured limbs were not observed except between the triple cross-over hop and timed hops.

Overall, in relation to this sample and by taking into account both assessments, the players were not completely ready for the safe return to sport owing to lack of muscle strength, although some of them presented good dynamic balance and functionality.These results indicatedthat these players, although they followed a rehabilitation program before returning to playing activity, did not completed recover. Thisresult may be due to poor rehabilitation program or short recovery time owing to pressure for early return either from team members (e.g. coaches, managers, doctors, and physiotherapists) or from the players themselves. Finally, the lack of scientific and documented evaluation of rehabilitation, during their recovery and upon their return to the same competitive activity is probably an additional factor. Of course, additional in-depth analysis is needed toobtain clearer results concerning the safe return to sport, especially at this level.

References

Andrade, M. D. S., De Lira, C. A. B., Koffes, F. D. C., Mascarin, N. C., Benedito-Silva, A. A., & Da Silva, A. C. (2012). Isokinetic hamstrings-to-quadriceps peak torque ratio: The influence of sport modality, gender, and angular velocity. *Journal of sports sciences*, *30*(6), 547-553.

Bell, D.R., Sanfilippo, J.L., Binkley, N., & Heiderscheit, B.C. (2014). Lean mass asymmetry influences force and power asymmetry during jumping in collegiate athletes. *Journal of strength and conditioning research/National Strength & Conditioning Association*, *28*(4), 884-891.

Bishop, C., Turner, A., & Read, P. (2018). Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *Journal of Sports Sciences*, *36*(10), 1135-1144.

Coombs, R., & Garbutt, G. (2002). Developments in the use of the hamstring/quadriceps ratio for the assessment of muscle balance. *Journal of Sports Science & Medicine*, *1*(3), 56-62.

Dauty, M., Dupré, M., Potiron-Josse, M., & Dubois, C. (2007). Identification of mechanical consequences of jumper's knee by isokinetic concentric torque measurement in elite basketball players. *Isokinetics and Exercise Science*, *15*(1), 37-41.

Di Stasi, S., Myer, G.D., & Hewett, T.E. (2013). Neuromuscular training to target deficits associated with second anterior cruciate ligament injury. *Journal of Orthopaedic & Sports Physical Therapy*, *43*(11), 777-792, A1-11.

Dvir, Z. (2004). *Isokinetics: muscle testing, interpretation, and clinical applications*. Edimburg: Churchill Livingstone.

Ergün, M., Işlegen, C., & Taşkıran, E. (2004). A cross-sectional analysis of sagittal knee laxity and isokinetic muscle strength in soccer players. *International Journal of Sports Medicine*, *25*(08), 594-598.

Foreman, T.K., Addy, T., Baker, S., Burns, J., Hill, N., & Madden, T. (2006). Prospective studies into the causation of hamstring injuries in sport: a systematic review. *Physical Therapy in Sport*, *7*(2), 101-109.

Fousekis, K., Tsepis, E., & Vagenas, G. (2010). Lower limb strength in professional soccer players: profile, asymmetry, and training age. *Journal of Sports Science & Medicine*, *9*(3), 364-373.

Garrett Jr, W.E., Califf, J.C., & Bassett, F.H. (1984). Histochemical correlates of hamstring injuries. *The American Journal of Sports Medicine*, *12*(2), 98-103.

Gerodimos, V., Mandou, V., Zafeiridis, A., & Ioakimidis, P. (2003). Isokinetic peak torque and hamstring/quadriceps ratios in young basketball players: effects of age, velocity, and contraction mode. *Journal of Sports Medicine and Physical Fitness*, *43*(4), 444-452.

Greenberger, H.B., & Paterno, M.V. (1995). Relationship of knee extensor strength and hopping test performance in the assessment of lower extremity function. *Journal of Orthopaedic & Sports Physical Therapy*, *22*(5), 202-206.

Gustavsson, A., Neeter, C., Thomeé, P., Silbernagel, K. G., Augustsson, J., Thomeé, R., & Karlsson, J. (2006). A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. *Knee surgery, sports traumatology, arthroscopy*, *14*(8), 778-788.

Hamilton, R. T., Shultz, S. J., Schmitz, R. J., & Perrin, D. H. (2008). Triple-hop distance as a valid predictor of lower limb strength and power. *Journal of athletic training*, *43*(2), 144-151.

Hewett, T.E., Myer, G.D., & Zazulak, B.T. (2008). Hamstrings to quadriceps peak torque ratios diverge between sexes with increasing isokinetic angular velocity. *Journal of Science and Medicine in Sport*, *11*(5), 452-459.

Hoffman, J.R., Ratamess, N.A., Klatt, M., Faigenbaum, A.D., & Kang, J. (2007). Do bilateral power deficits influence direction-specific movement patterns? *Research in Sports Medicine*, *15*(2), 125-132.

Knapik, J.J., Bauman, C.L., Jones, B.H., Harris, J.M., & Vaughan, L. (1991). Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. *The American Journal of Sports Medicine*, *19*(1), 76-81.

Kyritsis, P., Bahr, R., Landreau, P., Miladi, R., & Witvrouw, E. (2016). Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *British Journal of Sports Medicine*, *50*(15), 946-951.

Logerstedt, D., Grindem, H., Lynch, A., Eitzen, I., Engebretsen, L., Risberg, M.A. ... & Snyder-Mackler, L. (2012). Single-legged hop tests as predictors of self-reported knee function after anterior cruciate ligament reconstruction: the Delaware-Oslo ACL cohort study. *The American Journal of Sports Medicine*, *40*(10), 2348-2356.

Myklebust, G., Holm, I., Mæhlum, S., Engebretsen, L., & Bahr, R. (2003). Clinical, functional, and radiologic outcome in team handball players 6 to 11 years after anterior cruciate ligament injury: a follow-up study. *The American Journal of Sports Medicine*, *31*(6), 981-989.

Noyes, F. R., Barber, S. D., & Mangine, R. E. (1991). Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *The American Journal of Sports Medicine*, *19*(5), 513-518.

Paterno, M.V., Schmitt, L.C., Ford, K.R., Rauh, M.J., Myer, G.D., Huang, B., & Hewett, T.E. (2010).Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *The American Journal of Sports Medicine, 38(10), 1968-1978.*

Pincivero, D.M., Coelho, A.J., & Campy, R.M. (2003).Perceived exertion and maximal quadriceps femoris muscle strength during dynamic knee extension exercise in young adult males and females.*European Journal of Applied Physiology, 89(2), 150-156.*

Rauh, M.J., Koepsell, T.D., Rivara, F.P., Rice, S.G., & Margherita, A.J. (2007). Quadriceps angle and risk of injury among high school cross-country runners. *Journal of Orthopaedic & Sports Physical Therapy*, *37*(12), 725-733.

Reid, A., Birmingham, T.B., Stratford, P.W., Alcock, G.K., & Giffin, J.R. (2007). Hop testing provides a reliable and valid outcome measure during rehabilitation after anterior cruciate ligament reconstruction. *Physical Therapy*, *87*(3), 337-349.

Ross, M. D., Langford, B., & Whelan, P. J. (2002). Test-retest reliability of 4 single-leg horizontal hop tests. *Journal of strength and conditioning research*, *16*(4), 617-622.

Dos Santos, G.R.S., Geremia, J.M., Moraes, P.Z., Lupion, R.D.O., Vaz, M.A., & Carpes, F.P. (2014). Bilateral assessment of knee muscle relationships in healthy adults. *Motriz: Revista de Educação Física*, *20*(3), 310-316.

Teixeira, J., Carvalho, P., Moreira, C., & Santos, R. (2014). Isokinetic assessment of muscle imbalances and bilateral differences between knee extensors and flexors' strength in basketball, football, handball and volleyball athletes. *International Journal of Sports Science*, *4*(1), 1-6.

Tsiokanos, A., Kellis, E., Jamurtas, A., & Kellis, S. (2002). The relationship between jumping performance and isokinetic strength of hip and knee extensors and ankle plantar flexors. *Isokinetics and Exercise Science*, *10*(2), 107-115.

Wright, J., Ball, N., & Wood, L. (2009). Fatigue, H/Q ratios and muscle coactivation in recreational football players. *Isokinetics and Exercise Science*, *17*(3), 161-167.

Xaverova, Z., Dirnberger, J., Lehnert, M., Belka, J., Wagner, H., & Orechovska, K. (2015). Isokinetic strength profile of elite female handball players. *Journal of Human Kinetics*, *49*(1), 257-266.