Muscle strength and functional performance tests as indicators of safe return to sports activity after anterior cruciate ligament reconstruction in track and field athletes

Pruebas de fuerza muscular y rendimiento funcional como indicadores de un regreso seguro a la actividad deportiva después de la reconstrucción del ligamento cruzado anterior en atletas de atletismo

Authors

Bashar Banwan Hasan [1]
Mahdi Lafta Rahi [2]
Ahmed Oleiwi Irhayyim [3]
Tawfiq Abdolkarim Hassan [4]

[1] Wasit University (Iraq)
[2] Wasit University (Iraq)
[3] Wasit University (Iraq)
[4] University of Benghazi (Libya)

Corresponding author:
Bashar Banwan Hasan
basharhasan@uowasit.edu.iq

How to cite in APA

Hasan, B., Lafta Rahi, M., OLEIWI IRHAYYIM, A., & Abdolkarim Hassan, T. (2025). Muscle strength and functional performance tests as indicators of safe return to sports activity after anterior cruciate ligament reconstruction in track and field athletes. *Retos*, *65*, 388–399. https://doi.org/10.47197/retos.v65.112509

Abstract

Introduction: Despite modern surgical techniques that allow the knee to return to its normal position before the injury, returning to sports activities at a level similar to what the player was in is still a major challenge.
Objective The purpose of this paper is to set numerical limits based on standardized tests for athletes to return to sports safely after surgery.
Methodology: The sample's study consisted of (20) injured athletes who underwent surgery for the anterior cruciate ligament and underwent rehabilitation at the specialized center for physical therapy and physical rehabilitation for a full year regularly and without interruption.
Results: The current study showed through the results achieved that the difference in the means between the two legs (the injured leg with the healthy leg) is very small, in addition to the torsion coefficient being limited between (±1) and Levene's coefficient being greater than the significance level (0.05), which means that there are no significant differences between the two legs (injured and uninjured).
Discussion: The results of the research should be contrasted with those of other research found in the literature.
Conclusions: The researchers concluded that there is high reliability for the tests used when evaluating the injured after cruciate ligament reconstruction because the results obtained indicated that the injured limbs were similar to the healthy limbs, which enables coaches and sports rehabilitation specialists to rely on these tests as an indicator to judge the return of injured players to sports safely after surgery.

Keywords

Muscle strength; functional performance; tests; return to sports; ACL.

Resumen

Introducción: A pesar de las técnicas quirúrgicas modernas que permiten que la rodilla regrese a su posición normal antes de la lesión, volver a las actividades deportivas a un nivel similar al que el jugador tenía sigue siendo un gran desafío.
Objetivo: El propósito de este trabajo es establecer límites numéricos basados en pruebas estandarizadas para que los atletas regresen de manera segura a los deportes después de la cirugía.
Metodología: El estudio de la muestra consistió en (20) atletas lesionados que se sometieron a cirugía por el ligamento cruzado anterior y realizaron rehabilitación en el centro especializado de fisioterapia y rehabilitación física durante un año completo de manera regular y sin interrupción.
Resultados: El estudio actual mostró a través de los resultados obtenidos que la diferencia en las medias entre las dos piernas (la pierna lesionada y la pierna sana) es muy pequeña, además de que el coeficiente de torsión está limitado entre (±1) y el coeficiente de Levene es mayor que el nivel de significancia (0.05), lo que significa que no hay diferencias significativas entre las dos piernas (lesionada y no lesionada).
Discusión: Los resultados de la investigación deben contrastarse con los de otras investigaciones encontradas en la literatura.
Conclusiones: Los investigadores concluyeron que hay una alta fiabilidad para las pruebas utilizadas al evaluar a los lesionados después de la reconstrucción del ligamento cruzado, ya que los resultados obtenidos indicaron que las extremidades lesionadas eran similares a las extremidades sanas, lo que permite a los entrenadores y especialistas en rehabilitación deportiva confiar en.

Palabras clave

Fuerza muscular; rendimiento funcional; pruebas; regreso a los deportes; LCA.

Introduction

Anterior cruciate ligament tears are common injuries among athletes and physical activity practitioners. Despite modern surgical techniques that allow the knee to return to its normal position before the injury, returning to sports activities at a level similar to what the player was in is still a major challenge (Hewett et al., 2013). After ACL reconstruction surgery, rehabilitation is important to return to the same levels of sport activities or activities of daily living as those before ACL injury. The goals of rehabilitation for patients after ACL reconstruction are to improve any knee deficiencies and to restore function(Coppola & Collins, 2009). Studies have shown that there are high rates of recurrence of the injury at 15%, especially in the (24) months following surgery. This indicates that there is a deficiency in the physical rehabilitation process and estimating the injured person's condition and ability to safely return to sports activities, because he was unable to restore muscle function and normal strength, which may cause the injury to recur again (Ebert et al., 2018). In general, athletes need a year or more before they can return to their sports activities after physical therapy specialists conduct tests to measure the stability, strength, and ability of the knee to perform its function and the extent of readiness to return to sports activities (Cervenka et al., 2018).

The physical rehabilitation process is a very important process that improves knee stability, strengthens the surrounding muscles, and increases the range of motion For the joint, it also improves psychological satisfaction among players who have undergone surgery (Hasan & Matty, 2024).

Many researchers have conducted scientific studies to evaluate the physical rehabilitation process and set tests and standards for a safe return to sports activity after surgery. Various studies indicate muscle strength, knee stability, and functional performance testing as standards for returning to sports after ACL reconstruction (Rambaud et al., 2018).

When analyzing 14 scientific studies, stated that there is a rate of failure of ACL reconstruction in the long term. In the clinical follow-up that they conducted for more than 10 years, the reported rate of ACL re-tear was 6.2%, at least 1 out of 9 patients who underwent ACL reconstruction surgery will suffer from a recurrence of the injury in the long term (Crawford et al., 2013).

It is worth noting that the time period is of great importance before returning to sports, so it is necessary to emphasize the sufficient time period before returning to sports practice, some studies reported a significant decrease of 51% for each month in which the return to sports was delayed until (9) months after surgery, after which no further decrease in risk was observed, delaying the return to sports for (9) months gives sufficient time for the athlete to rehabilitate and train in all the necessary sports-specific exercises to avoid instability and re-injury in the future (Grindem et al., 2016). Another study indicated that young athletes are highly susceptible to re-injury, so the Nagelli & Hewett study called for postponing the return of young athletes to play in particular for two years after ACL reconstruction, due to the increased incidence of a second ACL injury within two years after surgery and the fact that the biological health and function of the knee joint remain at stake for about two years (Nagelli & Hewett, 2017). The weakness of rehabilitation programs and non-compliance with the components of the rehabilitation program may expose the player to the recurrence of the injury, in addition to the lack of numerical values for specific tests that can be relied upon in the aspect of the return of injured players to practicing sports in Iraq, as far as the researchers know. Hence, the importance of the research came as a scientific attempt to set numerical values for specific tests that can be relied upon in evaluating the condition of injured athletes to return to practicing their athletics activities after undergoing anterior cruciate ligament reconstruction operations and their full commitment to the components of the rehabilitation programs prepared by specialists to contribute to making the return of athletes to practicing sports safe and without risks of recurrence of the injury again. The researchers seek to answer the following question: What are the numerical limits through which it is possible to indicate the ability of the injured athlete to return to practicing sports safely? The study aims to set standardized tests for the return of athletes to practicing sports activities after surgery in a safe manner. The researchers also assumed that the tests used in the study have the ability to determine the safe return to practicing sports activities after surgery.

Method

This study uses a pre-experimental design with a pre-test and post-test method to measure the effectiveness of the rehabilitation program that the volunteers underwent in improving their physical abilities related to the injured knee joint. This design was chosen because it allows the researcher to focus the analysis on the changes occurring within the treatment group without the need to compare with a control group. Analyzing the changes between the pre-test and post-test provides a measurable overview of the effectiveness of this method in a targeted and significant manner.

Participants

The research sample consisted of (20) injured athletes who underwent surgery for the anterior cruciate ligament and underwent rehabilitation at the Specialized Center for Physical Therapy and Physical Rehabilitation for a full year, regularly and without interruption, taking into account the exclusion of people who suffer from any persistent pain or noticeable disability in their operated knee or the opposite knee or lower limbs in general or stiffness in the joint and limited range of motion that could affect their ability to participate well in the study. People who underwent any other surgery in the ipsilateral or opposite lower limb before this surgery were also excluded. These individuals had participated in the same ACL rehabilitation program, which comprised a variety of exercises such as range of motion, strengthening, proprioception and balance, agility and coordination, plyometric, core strengthening, and functional exercises.

Procedure

Before starting the study, all eligible subjects were invited and given details of the aims of the current study by one of the researchers. Then, subjects were instructed on how each test was done. A day after the education course, the (muscle strength test, illinoi agility test and y-balance test) performed tests and then (Jump Tests) performed those a day after. It is noteworthy, the subjects were given 3 trials to practice and familiarize before each test and also to prevent injury, subjects a warm-up for 10 minutes consisting of dynamic stretching for lower limbs and knee flexion and extension 5 times for each leg by isokinetic dynamometer at 60 degrees/second. Moreover, after completion of each test, subjects took rest for 5 minutes to reduce the effect of fatigue and get ready to perform the next test.

Evaluation of tests

Muscle strength test for healthy and injured knee joint MUSCLE STRENGTH TEST

- Muscle strength measurement for knee joint: (Bandinelli et al., 1999)
- The dynamometer was used to measure muscle strength using the following test:
- Test name: Extending the leg forward from the knee joint with the maximum possible force from a sitting position on a fixed chair.
- Purpose of the test: Measure the maximum strength of the quadriceps femoris muscle.
- Initial position: The tester takes a sitting position on the chair, and fixes the device on the wall on one side and the foot on the other side.
- Description of performance: The tester extends the knee joint forward with the maximum possible force, so the device indicator moves equal to the maximum fixed force of the quadriceps femoris muscle, then the device reading is taken. The same measurement is repeated for the other joint.
- Recording: Three attempts and the best reading is taken to the nearest kilogram.

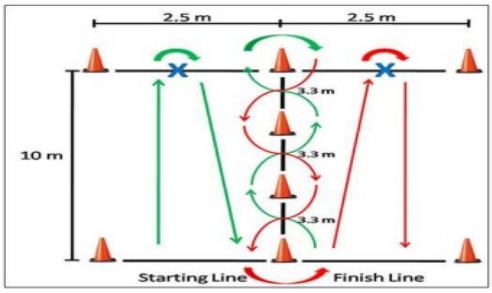
Figure 1. Shows the muscle strength test

Illinoi Agility Test: (Getchell, 1979)

Subjects were asked to sprint forwards 10m from the start line to the first cone and touch the tip with their right hand, shuffle 5 m left to the second cone and touch with their left hand, then shuffle 10 m to the right to the third cone and touch with their right, shuffle 5 m back left to the middle cone and touch with their left hand before finally back pedaling to the start line. Time began upon subjects passing through the timing gates and stopped upon them passing through on return.

The test will not be counted if the subject crosses one foot in front of the other while shuffling, fails to touch the base of the cones, or fails to face forward throughout the test. Take the best time of three successful trials.

Figure (2) shows the Illinois Agility Test

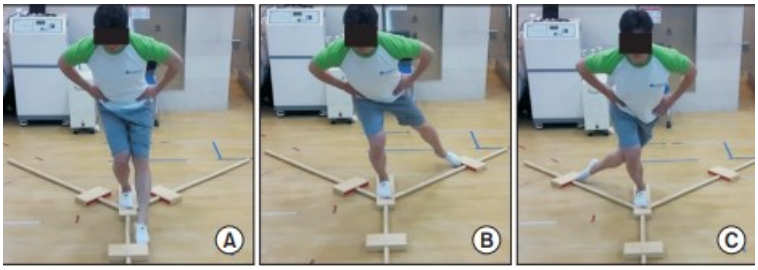


Dynamic Balance Test Y-BALANCE TEST: (Kim et al., 2023)

The YBT was employed as a dynamic balance test to assess the function of the lower extremities. In both clinical and research settings, this test is often employed. Performance on this exam can be measured as the maximum reach distance in a particular direction (anterior (ANT), posteromedial (PM) and poster lateral (PL)) or a a calculated composite score (average reach distance across all directions) (Bulow et al., 2021). After the practice trials, the first test trial's distance from the YBT apex of the most proximal edge of the reach indicator was measured, while Participants moved in three directions: ANT, PM, and PL. The support leg was the dominant limb (Fig.3). From the anterior superior iliac spine to the farthest point of the ipsilateral medial malleolus in a supine position, all reach distances were measured and normalized as a percentage of each participant's stance-limb length (%LL)(Bulow et al., 2021). In this study, each direction three times was repeated and the average of them was calculated.

Normalized reach distance = (reach distance / limb length) x 100

Figure (3) shows the dynamic balance test

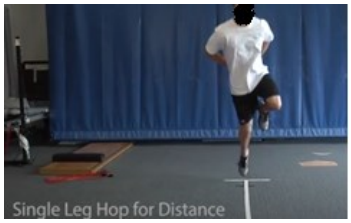


Jump Tests: (Ebert et al., 2021; Noyes et al., 1991)

- Single-leg jump test (distance for hop Single):

In this test, the aim is to jump as far as possible on a single leg, without losing balance and landing firmly. The distance is measured from the start line to the heel of the landing leg. The goal is to have a less than 10% difference in hop distance between the injured limb and uninjured limb.

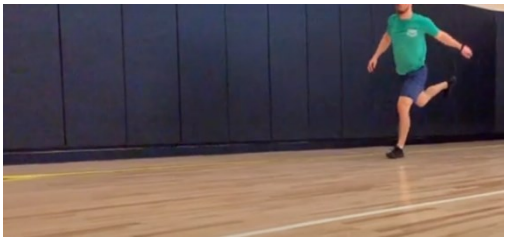
Figure (4) shows the Single-leg jump test



- Single-leg triple jump test (distance for hop Triple)

In the triple hop test, the aim is to jump as far as possible on a single leg three consecutive times, without losing balance and landing firmly. The distance is measured from the start line to the great toe of the landing leg. The goal is to have a less than 10% difference in hop distance between the injured limb and uninjured limb.

Figure (5) shows the Single-leg triple jump test



- One-legged hop over-cross test (distance for hop over-cross):

In the crossover hop test, the aim is to jump as far as possible on a single leg three consecutive times, without losing balance and landing firmly. Between each hop, the athlete has to jump across a midline, hence including side-to-side movement in this test. The distance is measured from the start line to the heel of the landing leg. The goal is to have a less than 10% difference in hop distance between the injured limb and uninjured limb.

Figure (6) shows the One-legged hop over-cross test

- One-legged jump test 06 meters (6m time hope):

In the 6 meter timed hop test, the aim is to jump as fast as possible on a single leg over a distance of 6 meters, without losing balance and landing firmly. The goal is to have a less than 10% time difference in the time taken to hop through between the injured limb and uninjured limb.

- Vertical Jump Test with the Injured Leg: (Kotsifaki et al., 2022)

The tester stands on a box 30 cm high on the healthy foot, then descends on the injured foot. At the moment of touching the ground, the tester jumps as high as possible and the distance between the ground and the highest point reached by the tester's head is calculated.

Figure 7. Shows the Vertical Jump Test with the Injured Leg

Characteristics and psychometrics of the tests:

In this step, the researchers sought to survey the opinions of a number of specialists in sports and health, relying on sources, references, and some previous studies, in order to analyze and think logically to know the most important tests adopted in such studies. This survey resulted in identifying a set of tests that the arbitrators agreed to measure the variables under study. As for the stability of the tests, it was done by applying them to a sample estimated at 5 injured athletes and reapplying them within (7) days. The researchers used the Pearson correlation coefficient, and through the recorded results, it became clear that the tests enjoy high stability and validity.

Results

Insert the result text with Cambria font, size 11, justified and single line spacing.

This section presents the results of preliminary or partial research, which require rapid dissemination. The analysis of the results obtained that must correspond to the objectives set out in the article is presented. This section can be used by tables and figures to represent data.

Avoid ambiguous phrases such as: "maybe if... then"; "I could... yes... then" so as not to mislead the reader from the importance of his work.

Use of verb tenses in the present tense.

If you use tables and figures (table 1), you should take into account the following indications.

Table 1. Group characteristics

Experimental Group (n=20)			
Variable	Average DT	Average DT	P value
Age (year)	26	6.401	-0.06
Height (cm)	177.83	5.34	0.10
Body mass (kg)	23.54	7.19	0.58
Period for rehabilitation	9.25	1.25	0.37
Gender (Male/female)		Male	
Affected limb	Right: 14	Left: 6	

Table 2. Represents the simple Pearson correlation coefficient between the results of the test and the retest.

Test	First application		Second application		Stability	Validity	Correlation Degree
	Arithmetic mean	Standard deviation	Arithmetic mean	Standard deviation			
Muscle strength	*32.05*	*0.53*	*33.00*	*0.97*	0.98	0.99	Strong
Y-balance test	*78.750*	*0.10*	*75.69*	*1.10*	0.90	0.95	Strong
Illinoi agility test	*15.6*	*1.648*	*15.9*	*1.914*	0.88	0.90	Strong
Distance for hop Single	180.1	1.897	181.0	1.112	0.98	0.99	Strong
Distance for hop Triple	6.4	0.431	6.6	0.586	0.95	0.96	Strong
Distance for hop over-Cross	5.44	0.322	5.14	0.113	0.94	0.96	Strong
Side hop test (rep)	42	4.55	44	4.111	0.95	0.98	Strong
6m time hope	1.95	3.765	1.90	4.123	0.97	0.98	Strong
Vertical Jump	2.23	1.11	2.18	0.912	0.96	0.98	Strong

Table 3. Shows a comparison of the muscle strength results for the injured leg (left) with the uninjured leg (right) and again for the injured leg (right) with uninjured leg (left)

Injured leg	Unit of measurement	Arithmetic mean of the injured leg	Standard deviation	Arithmetic mean of unjured leg	Standard deviation	Arithmetic mean of difference	Skewness	Levene	Sig
Left leg	Kg	*32.000*	2.000	*32.000*	*1.870*	*0.000*	*0.410-*	*0.577*	*0.157*
Right leg	Kg	*30.800*	*2.280*	*30.200*	*3.033*	0.600	*0.452-*	*0.806*	*0.761*

Table 4. Shows a comparison of the balance results for the injured leg (left) with the uninjured leg (right).

Injured leg	Test	Left	Right	Differences	Arithmetic mean		T	Sig	Type sig
					Injured	Uninjured			
Left leg	ANT (cm)	*93*	*91*	*2*	*78.750*	*79.500*	*-0.103*	*0.921*	Non sig
	PM (cm)	*79*	*80*	*1*					
	PL (cm)	*77*	*79*	*2*					
Right leg	ANT (cm)	*58*	*60*	*2*	*75.25*	*76.755*	*0.263*	*0.894*	Non sig
	PM (cm)	*89*	*90*	*1*					
	PL (cm)	*79*	*80*	*1*					

Table 5. Shows the results of the Illinois Agility Test.

Injured leg	Unit of measurement	Arithmetic mean of the injured leg	Standard deviation	Arithmetic mean of healthy leg	Standard deviation	Arithmetic mean of difference	Skewness	Sig	Type sig
Left leg	Sec	15.76	*0.33*	*15.81*	*0.39*	-0.547	*0.55*	0.56	Non sig
Right leg	Sec	*15.92*	*0.63*	*15.75*	*0.74*	*-0.784*	*0.38*	0.495	Non sig

Table 6. Shows a Jump Tests for the injured leg with the uninjured leg.

Injured leg		Unit of measurement	Arithmetic mean of the injured leg	Standard deviation	Arithmetic mean of healthy leg	Standard deviation	Arithmetic mean of difference	Skewness	Levene	Sig
Single-leg jump	Left leg	cm	180.6000	2.07364	180.8000	.83666	*2*	*0.360*	*.4720*	*.1520*
	Right leg	cm	181.20	1.92354	179.60	1.6733	*1.6*	*.4980*	1.334	*.1040*
Single-leg triple jump	Left leg	Meter	*6.400*	*0.038*	*6.400*	*0.109*	*0.000*	*0.744-*	*0.524*	*0.0782*
	Right leg	Meter	*6.394*	*0.045*	*6.396*	*0.045*	*0.002*	*0.347-*	*0.913*	*0.064*
One-legged hop over-cross	Left leg	Meter	*5.386*	*0.128*	*5.062*	*0.133*	*0.324*	*0.115-*	*0.766*	*0.097*
	Right leg	Meter	*5.244*	*0.215*	*5.344*	*0.174*	*0.100*	*0.399-*	*0.860*	*0.098*
One-legged jump 6m	Left leg	Second	*1.940*	*0.096*	*1.914*	*0.073*	*0.026*	*0.263*	*0.225*	*0.236*
	Right leg	Second	*1.942*	*0.037*	*1.922*	*0.046*	*0.020*	*0.588-*	*0.312*	*0.247*
Vertical Jump	Left leg	Meter	*2.180*	*0.052*	*2.172*	*0.042*	*0.008*	*0.923-*	*0.114*	*0.099*
	Right leg	Meter	*2.162*	*0.038*	*2.164*	*0.040*	*0.002*	*0.976-*	*0.511*	*0.326*

Discussion

The current study showed through the results of the above tables that the difference in the means between the two legs (the injured leg and the healthy leg) is very small, in addition to the torsion coefficient being limited to (±1) and Levene's coefficient being greater than the significance level (0.05), which means that there are no significant differences between the two legs (the injured leg and the healthy leg). This indicates that the injured leg is consistent with the healthy leg, as the results clearly indicate that the injured athletes have reached their normal state and are fully recovered and can safely return to their specialized activities in athletics events.

In the muscle strength tests, the results of the study showed, as shown in Table (3), that there were no differences between the injured leg and the healthy leg, which is consistent with the study of (Hasan et al., 2024; Konishi et al., 2012) and the study of (Çınar-Medeni et al., 2019), where they indicated that the results may be affected by the restoration of motor unit recruitment after anterior cruciate ligament surgery. They also compared the strength of the isokinetic knee muscles six months after ACL reconstruction between the injured and uninjured limbs. They did not observe any difference between the two limbs due to the fact that the athletes performed the ACL rehabilitation protocol that yielded positive and significant results. A systematic review conducted by Barber Westen and colleagues investigated the criteria for return to sport in several studies and concluded that in order to be given permission to return to sport, the athlete must have less than 10% deficit in the strength of the quadriceps and hamstrings in the isokinetic test at 180 degrees/s. In the dynamic balance test, the results of this study showed in Table (4) that the balance exercises included in the rehabilitation program have clear effects on dynamic balance, which is consistent with the study (Kim et al., 2023). In addition, it has been shown that if dynamic balance is poor, this will lead to an increased rate of ACL re-injury (Paterno et al., 2010). Akbari believes that those who underwent surgery showed that the rehabilitation program can partially enhance balance stability in the initial stage of rehabilitation. Therefore, they recommended including these exercises in the rehabilitation process after surgery (Akbari et al., 2015). One of the causal factors that positively affected the motor balance test (YBT) in the current study was the increase in strength in the lower extremities, especially the quadriceps muscle, after balance exercises in the rehabilitation program after ACLR because balance training may improve motor nerve recruitment and increase dynamic balance, motor control and proprioception of the lower extremities and thus enhance muscle strength. This is consistent with what Cooper and Nunes found. (Cooper et al., 2005) (Nunes et al., 2018).

In the results of the Illinois Agility Test, it was shown through the results obtained in Table (5) that the injured athletes had a high degree of agility and fluidity of movement on agility exercises in the rehabilitation program protocols. This is very important because it allows injured players to regain their rapid movement and their ability to change direction. The researchers believe that developing agility is done by linking physical abilities in a diverse sequence and the ability to use them successfully indicates the safety of the players. This is consistent with the study (Raya et al., 2013), which explained that this test is a good measure of agility and clearly assesses the injured, thus providing a comprehensive assessment of high-level movement. It is also essential for elite athletes who need the ability to change directions quickly at all levels and increase control over body positions during rapid movements, increase muscle coordination, and reduce the risk of injury or re-injury, as stated by (Miller et al., 2006; Munro & Herrington, 2011). When the test was applied to the study sample, the results of the testers ranged between 16.2-15.2, which indicates that the results were within a good range or above, which indicates the safety and ability of the injured players to perform the test (Rating for males: excellent <15.2, good 16.1-15.2, average 18.1-16.2, below average 18.3-18.2, poor >18.3 (Getchell, 1979). As for the jumping tests: (distance for hop Single, distance for hop Triple, distance for hop over-Cross, 6m time hope), the results obtained by the researchers in Table (6) show that the injured players performed the jumping tests with high fluidity and without hesitation or feeling pain in the injured and healthy leg. This is consistent with the systematic review conducted by Barber-Westin, which states that returning to sports should include jumping tests because they give a clear picture of the similarity between the injured and healthy legs, which shows the athlete's ability to jump with both feet to a very close degree (Barber-Westin & Noyes, 2011). Recent studies also indicate that the various jumping tests are a good indicator for comparing the healthy and injured leg and we know the extent of the development of the injured leg and its reaching a level equal to the strength of the healthy leg or close

to it, and this indicates the readiness of athletes to return to sports after knee surgery (Sueyoshi et al., 2017). Vertical Jump Test: The results of the vertical jump test in Table (6) show a great similarity between the injured leg and the healthy leg, which indicates that the rehabilitation program was comprehensive and brought the injured player to a high degree of readiness to return to sports. This is consistent with what was confirmed by Kim's study that the vertical jump test with one leg has high reliability and provides a clear assessment of measuring the strength, ability and readiness of patients to perform jumping because it is a good and useful method for assessing the level of performance and efficiency of the knee (Banwan Hasan et al., 2024; Lee et al., 2018). Therefore, it can be concluded that box exercises have a significant impact, supporting the quality of muscle explosiveness of the legs (Alda Nia et al., 2024), This is consistent with what the authors concluded in this study.

We would like to add that in order to be cleared for return to sport, the athlete must have:

- Less than 10% deficit in quadriceps and hamstring strength in the isometric test at 180°/s and 300°/s,
- Less than 15% deficit in lower extremity coordination in the single-leg jump test (single jump, triple jump, crossover jump, timed jump (Ebert et al., 2021)
- Less than 3 mm of increased anterior and posterior tibial displacement in the Lachman test or knee arthrometer, greater than 60% of the normal distance of separation between the knees in the video jump and fall test,
- Absence of effusion
- Complete knee ROM
- Normal patellar motion, or only a slight patellar crackle that is not accompanied by pain.
- Non-painful activities without swelling. (Barber-Westin & Noyes, 2011).

Limitation Of Study

The current study has limitations, just like any other study. Due to the fact that this study was conducted as a retrospective cohort. Thus, this design can only investigate associations, not causality. The study's second limitation was small sample size, and also all subjects were males. Because of this, caution should be taken when applying the study findings to a larger heterogeneous population.

Conclusions

The set of tests used in this study showed high reliability when applied to the research sample that underwent surgery, as there were no significant differences between the injured leg and the healthy leg one year after the surgery, which supports its use when evaluating patients after cruciate ligament reconstruction, because the results obtained indicated that the injured limbs were similar to the healthy limbs. This enables coaches and sports rehabilitation specialists to rely on these tests as an indicator to judge the return of injured players to practicing sports activities safely after surgery.

Acknowledgements

The authors would like to thank the volunteers.

Financing

This article did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Authors' and translators' details:

Bashar Banwan Hasan	basharhasan@uowasit.edu.iq	Author
Mahdi Lafta Rahi	mahdilafta@uowasit.edu.iq	Author
Ahmed Oleiwi Irhayyim	ahmedo.irhayyim602@uowasit.edu.iq	Author
Tawfiq Abdolkarim Hassan	tawfikhasan18@gmail.com	Author