FUNCTIONAL RECOVERY AT DISCHARGE FROM REHABILITATION FOLLOWING ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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List of Abbreviations

ACL	Anterior Cruciate Ligament
ACLR	Anterior Cruciate Ligament Reconstruction
ACLD	Anterior Cruciate Ligament Deficit
RTS	Return to Sport
LSI	Limb Symmetry Index
HHD	Hand Held Dynamometry
IKDC	International Knee Documentation Committee
KOOS	The Knee Injury and Osteoarthritis Outcome Score
ACL-RSI	The Anterior Cruciate Ligament Return to Sport Index
TSK	The Tampa Scale of Kinesiophobia
QoL	Quality of Life
ADL	Daily Living
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index
AOSSM	The American Orthopaedic Society for Sports Medicine
PROM	Patient Reported Outcome Measures
OA	Osteoarthritis
BPTB	Bone-Patellar Tendon-Bone
HT	Hamstring tendon
WHO ICF	World Health Organisation International Classification of Functioning Disability and Health
H/Q ratio	Hamstring/ Quadriceps Ratio
ICC	Intra Class Correlation Coefficient
SEM	Standard Error of Measurement
SDD	Smallest Detectable Difference
SD	Standard Deviation
LOA	Limits of Agreement
N	Newton
Nm	Newton meter
TE	Time Elapsed

Abstract

Functional performance, as well as objective and subjective measures, and psychological factors tests are used in clinically based settings to assess knee function, as well as to determine when patient is ideally suited to return to sport (RTS). Success following ACLR has been defined as a return to pre-injury or healthy levels of function and activity. Therefore, outcomes should be assessed according to this standard. The aim of this thesis is to investigate single-leg hop for distance, isometric muscle strength, self-reported knee function and psychological factors for ACLR patients at discharge from rehabilitation. The LSI (limb symmetry index) is used to assess the performance of the injured limb compared the non-injured limb as a percentage score according to the performance, however, non-injured leg weakness could overestimate the injured leg performance. The reference values from a healthy population and associated age-leg-matched scores may be used for developing more accurate outcome measures.

20 healthy active male participants volunteered to take part to evaluate the reliability and validity of testing the strength of the knee extensors and flexors muscles to discover the reliability and validity of the Handheld Dynamometer within this context. 35 patients who had undergone ACL reconstruction were recruited to translate and culturally adapt the IKDC and ACL-RSI to make them suitable for Arabic speaking patients with ACL injuries. 255 healthy active male participants in three age categories (18-24; 25-34 and 35-44 years) were recruited to complete the KOOS, IKDC questionnaires and to perform the single-leg hop test and to measure isometric quadriceps and hamstring muscle strength for both legs, using a hand-held dynamometer (HHD) to establish normative data scores. In addition, the study included 47 ACLR patients with a mean age of (29.26 ± 6 years) at time of discharge from rehabilitation (5-6 months) after ACLR to investigate single-leg hop for distance, isometric muscle strength, self-reported knee function and psychological factors. The results showed that none of the ACLR patients passed the current literature based RTS criteria at discharge from rehabilitation following ACLR when we compared the injured leg to matched leg-age of heathy control subjects, which suggests that the performance criteria is probably too stringent to pass before returning to sport, or the rehabilitation programme was insufficient to achieve these criteria which could lead to poor outcome measures after ACLR.

It can be concluded that the results from LSI should be used tentatively, as this approach can hide bilateral deficits due to the non-injured leg also possibly being affected by the injury and

the length of time of relative inactivity. Therefore, normative data is recommended for analysing ACLR patients' performance. In the current study, using normative data as a comparison revealed that the participants did not meet the normal required performance for both the injured and non-injured leg six months post ACLR. In general, it has been found that the ACL-reconstructed leg is weaker than the uninjured leg, but the uninjured leg is weaker than the leg of healthy matched controls.

Chapter 1

1 Introduction

1.1 Overview of the problem

Anterior cruciate ligament reconstruction (ACLR) is carried out so that patients can resume their preinjury sports or recreational activities (Bauer, Parsonage, Knapp, Iemmi, & Adelaja, 2014; Feucht et al., 2016) and it may reduce the risk of post-traumatic knee osteoarthritis (Richmond, Lubowitz, & Poehling, 2011). Approaches to rehabilitation and the likelihood of patients returning sport, may be improved if the links between subjective and objective measures, psychological factors, and functional performance are better understood. This is important considering that not all of patients return to participating at their preinjury activity level (Ardern, Taylor, Feller, & Webster, 2014). Moreover, the impact on QoL may continue in the long term after an ACL injury (Filbay, Culvenor, Ackerman, Russell, & Crossley, 2015), and 35% of the ACLR patients develop osteoarthritis 10 years after ACL injury (Lie, Risberg, Storheim, Engebretsen, & Øiestad, 2019).

According to Ardern et al (2014), while approximately 80% of ACLR patients return to sport (RTS), only 65% do so to preinjury level, and only 55% return to competitive level sports. This may be due to poor quality rehabilitation, along with not being properly prepared to RTS, which can lead to re-injury of the ACL or related injuries, and limit the individual's ability (Ebert et al., 2018; Grindem, Snyder-Mackler, Moksnes, Engebretsen, & Risberg, 2016). High-level competitive sports involving pivoting sports pose a particular risk after ACLR, with over a fourfold risk of reinjury within two years post-operative (Grindem et al., 2016), with around 20% of athletes suffering a second ACL injury (Wiggins et al., 2016).

Rehabilitation is key to the successful return to preinjury levels of sporting activity. There is a specific stepwise progression for rehabilitation that clinicians can rely on, which invokes a number of impairment-based tests to check that the patient is ready to RTS (Burgi et al., 2019; Grindem et al., 2016; Kyritsis, Bahr, Landreau, Miladi, & Witvrouw, 2016; Rambaud, Ardern, Thoreux, Regnaux, & Edouard, 2018); however, the criteria for progression and RTS is not standardised and there is disagreement regarding follow-up reporting for patients and measuring physical performance and outcomes (Ahmad et al., 2017; Greenberg, Greenberg, Albaugh, Storey, & Ganley, 2018); moreover, there is a lack of RTS criteria and unclear guidelines on readiness to RTS (Barber-Westin & Noyes, 2011; Burgi et al., 2019; Losciale, Zdeb, Ledbetter, Reiman, & Sell, 2019).

Due to the aforementioned shortcomings concerning readiness to RTS, there has been an increase in research studies into RTS criteria, as it is thought that this will reduce the risk of a repeat ACL injury. RTS criteria often involve a set of guidelines or a "criteria" for clearing the athlete for RTS during the final stage of rehabilitation (Dingenen & Gokeler, 2017), and although these criteria differ, they have some common features and risk factors. According to a recent systematic review and multidisciplinary consensus, RTS criteria should include a minimum of a series of strength tests and hop tests, as well as measuring quality of movement (van Melick et al., 2016). Therefore, studies have included a wide range of risk factors and between fifteen and twenty different RTS tests (Ellman et al., 2015; Panariello, Stump, & Allen, 2017), yet few patients pass all of them (Gokeler, Welling, Zaffagnini, Seil, & Padua, 2017; Herbst et al., 2015). The true value of any RTS criteria is only if it can accurately assess if patients have returned to pre-injury level or reached a high-performance level of sport, along with assessing the level of risk of a second ACL injury occurring (Webster & Hewett, 2019).

Functional performance tests are used in clinically based settings to assess knee function, as well as to determine when patient is ideally suited to RTS. The type of functional performance test used is in accordance with the patients being assessed, and hop tests are usually used for ACLR patients (Clark, 2001; Hopper et al., 2002; Reid, Birmingham, Stratford, Alcock, & Giffin, 2007; Thomeé et al., 2011).

Hop tests are used to provide performance scores and as a proxy for the assessment of muscle strength of the lower extremities. According to several researchers, a positive relationship exists between muscle strength and performance in single-leg hop tests (Barber, Noyes, Mangine, McCloskey, & Hartman, 1990; Noyes, Barber, & Mangine, 1991; Wilk, Romaniello, Soscia, Arrigo, & Andrews, 1994). Assessing the quadriceps and hamstrings' maximum strength is also essential to monitoring recovery following an ACLR (Moisala, Jarvela, Kannus, & Jarvinen, 2007), and the results can be used as a baseline to determine and develop tailor made treatment plans for individual patients (Felson, Lawrence, Dieppe, & et al., 2000).

As complete physical recovery and a return to the preinjury sport and recreational activity levels may not be necessarily coincide following ACLR (Ardern, Taylor, Feller, & Webster, 2012b), it is important to examine what other factors influence a return to sport. According to recent research, psychological factors and subjective self-reported knee function have been found to play a key role in identifying those who return to sport, therefore it is not only the physical aspect that is an issue (Ardern, Taylor, et al., 2014).The main reasons for people seeking treatment are the symptoms they are suffering from and functional disabilities, which makes self-reported knee function outcomes an essential aspect of assessing patients' responses to surgery, physical therapy and final outcomes (Frobell et al., 2013).

The fear of movement which could cause re-injury is a psychological factor which can have a major impact on RTS after ACLR (Kvist, Ek, Sporrstedt, & Good, 2005; Webster, Feller, & Lambros, 2008). In fact, a high level of fear of the movement which could cause re-injury, as well as lower psychological preparedness, has been shown to correlate with low self-reported function (Ardern, Osterberg, et al., 2014).

Knowledge of the level of knee and functional performance, as well as objective and subjective measures, and psychological factors, among patients with ACLR is poor, whether they are recreationally active or professional athletes. This lack of knowledge isn't then available to be used to guide patients with ACL injuries towards more realistic expectations concerning knee function and activity levels, assisting clinicians with adapting treatment measures and rehabilitation. Therefore, this research will investigate functional performance, objective measures, subjective measures of knee function, and psychological factors for ACLR patients at discharge from rehabilitation.

1.2 Significance of the problem

The outcomes of ACL reconstruction should be determined using clinical based outcomes, for example measuring indicators like functional performance and muscle strength. These indicators can be used to track rehabilitation, incorporated into activity protocols, and used to evaluate function in the long term (Kocher et al., 2002). Even so, these objective clinical measures may not correlate with patient satisfaction or subjective function (Hambly & Griva, 2010), which is a downfall, because such subjective analysis is an important tool that can determine a patient's recovery, treatment, and overall function (Kocher et al., 2002). As mentioned previously, not much attention has been paid to the psychological aspect of the rehabilitation process, even though the way that an athlete deals with an injury can have a major impact on their return to competition or likelihood of continuing in sport (Ardern, Taylor, et al., 2014).

To date, no study has utilised the four main components together, that is, the hop test, muscle strength, self-reported function and psychological factors of ACLR patients. Most of the previous studies have been restricted to two or three outcomes measures, for example a number of studies have used the hop test, muscle strength and self-reported function (Ageberg et al., 2012; Koutras, Papadopoulos, Terzidis, Gigis, & Pappas, 2013; Lepley, 2015; Logerstedt et al., 2014; Schmitt, Paterno, & Hewett, 2012; Soo-Jin, Jin-Goo, & Seung-Kil, 2015; Xergia, Pappas, Zampeli, Georgiou, & Georgoulis, 2013). Self-reported function and psychological factors have been investigated by others (Ardern et al., 2016; Ardern, Osterberg, et al., 2014; Ardern et al., 2012b; Chmielewski et al., 2011; Filbay, Ackerman, Russell, & Crossley, 2016; Kvist et al., 2005; White, Zeni, & Snyder-Mackler, 2014), and a several studies have assessed hop test and muscle strength (Baltaci, Yilmaz, & Atay, 2012; Hamilton, Shultz, Schmitz, & Perrin, 2008; Ithurburn, Paterno, Ford, Hewett, & Schmitt, 2015; Laudner et al., 2015; Noyes et al., 1991; Sharma, Dunlop, Cahue, Song, & Hayes, 2003; Thomeé et al., 2012; Wilk et al., 1994; Xergia et al., 2013). Hop test and self-reported function have been addressed by (Grindem et al., 2011; Logerstedt et al., 2012; Reinke et al., 2011b; Serrão, Gramani-Say, Lessi, & Mattiello, 2012), whereas muscle strength, self-reported function and psychological factors have been studied by (Ardern, Taylor, Feller, Whitehead, & Webster, 2013; Lentz et al., 2014; Lentz et al., 2012), and only two studies have examined strength and self-reported function (Pietrosimone et al., 2016; Zwolski et al., 2015). Therefore, investigation involving hop tests, muscle strength, self-reported knee function and psychosocial factors for individuals following ACLR is required to assess success following ACLR and rehabilitation in order to return to sports.

The ‘gold standard’ in the literature is often stated as being a limb symmetry index (LSI) of higher than 85% (Clark, 2001), and recent research suggests that patients should be given the go ahead to resume activities once side-to-side differences in muscles strength; self-reported knee function, and physical function during performance tasks are equal to or less than 10% in comparison to the contralateral non-injured limb (Di Stasi, Logerstedt, Gardinier, & Snyder-Mackler, 2013; Logerstedt et al., 2012; Schmitt et al., 2012). Therefore, deficit of less than 10% between the injured and non-injured limb is seen as being acceptable. However, according to a review conducted by Lepley (2015) that focused on six months post reconstruction, for those that assessed distance hopped, only five out of nine studies reviewed were in accordance with clinical criteria with performance deficits of ≤10% for the non-involved limb (Aune, Holm, Risberg, Jensen, & Steen, 2001; Gobbi, Tuy, Mahajan, & Panuncialman, 2003b; Keays, Bullock-Saxton, Keays, & Newcombe, 2001; Krych et al., 2015; Schmitt et al., 2012). Concerning strength deficits, out of 37 studies included in the review, only five were in accordance with clinical recommendations at six months post-surgery, which shows that patients often returned to activity with side-to-side quadriceps strength deficits higher than 10% (Keays, Bullock-Saxton, & Keays, 2000; Keays et al., 2001; Konishi & Fukubayashi, 2010; Soon, Neo, Mitra, & Tay, 2004; Wojtys & Huston, 2000). For self-reported knee function in the review, only one study out of five contained self-report function deficits that were in accordance with the clinical criteria of being ≤10% six months post-surgery (Beard & Dodd, 1998). Importantly, up to 31 % of those returning to sport following an ACL reconstruction are injured again- either in the reconstructed leg or the unaffected leg (Leys, Salmon, Waller, Linklater, & Pinczewski, 2012; Salmon, Russell, Musgrove, Pinczewski, & Refshauge, 2005; Shelbourne, Gray, & Haro, 2008).

Measurements of a patient's performance can be compared to normative values obtained from normal individuals to assess the extent of the impairment. Few studies have presented the normative values for muscle strength, functional performance and self-reported knee function, but the usefulness of these values is limited by several factors, such as the subjects involved, the muscle actions tested, the level of activity and the specific devices used. Moreover, the subjects tested in the studies have been younger than most of the ACLR individuals. It is important, however, to obtain normative data from a healthy population to determine acceptable levels of asymmetry in non-injured people, but this data should consider gender and age. To date, there is no study compare the ACLR individuals (injured and contralateral leg) with matched leg-age-gender of the healthy group. Thus, the secondary purpose of the study is to quantify the normative values and the level of leg asymmetry for quadriceps and hamstring muscle strength, single-leg hop for distance and self-reported knee function in a non-injured active population according to age group criteria.

1.3 Purpose of the thesis

1.3.1 Main aims

- To investigate the functional recovery at discharge from rehabilitation following Anterior Cruciate Ligament Reconstruction ACLR and compare it with matched age group from healthy active population.

1.3.2 Specific aims

- To investigate the reliability and validity of isometric strength testing of the knee flexor and extensors (quadriceps and hamstring muscles), within-day and between-days using hand-held dynamometry (HHD).
- To translate and culturally adapt the IKDC and ACL-RSI to make them suitable for Arabic speaking patients with ACL injuries.
- To establish normative scores for single-leg hop for distance, isometric muscle strength, self-reported knee function in an active population according to age groups.
- To investigate the relationship between single-leg hop for distance, isometric muscle strength, self-reported knee function and psychological factors of ACLR patients at discharge from rehabilitation.

1.4 Research Questions

The thesis sets out to answer the following questions:

(Q1) Is there an agreement between repeated measurement scores for knee extensors and flexors muscles, using the HHD?

Null hypothesis: *There is no agreement between repeated measurement score, for knee extensors and flexors muscles, using the HHD.*

(Q2) Is there an agreement between repeated measurement scores for Arabic versions of IKDC, ACL-RSI and TSK questionnaires?

Null hypothesis: *There is no agreement between repeated measurement scores for Arabic versions of IKDC, ACL-RSI and TSK questionnaire.*

(Q3) Are there differences between Right and Left leg in a healthy active population, in the outcome measures?

Null hypothesis: *There are no significant differences between Right and Left leg of healthy active population, in the outcome measures*.

(Q4) Are there differences in the outcome measures between injured and uninjured leg in ACLR patients at discharge from rehabilitation?

Null hypothesis: *There are no significant differences between injured and uninjured leg of ACLR patients at discharge from rehabilitation, in the outcome measures*.

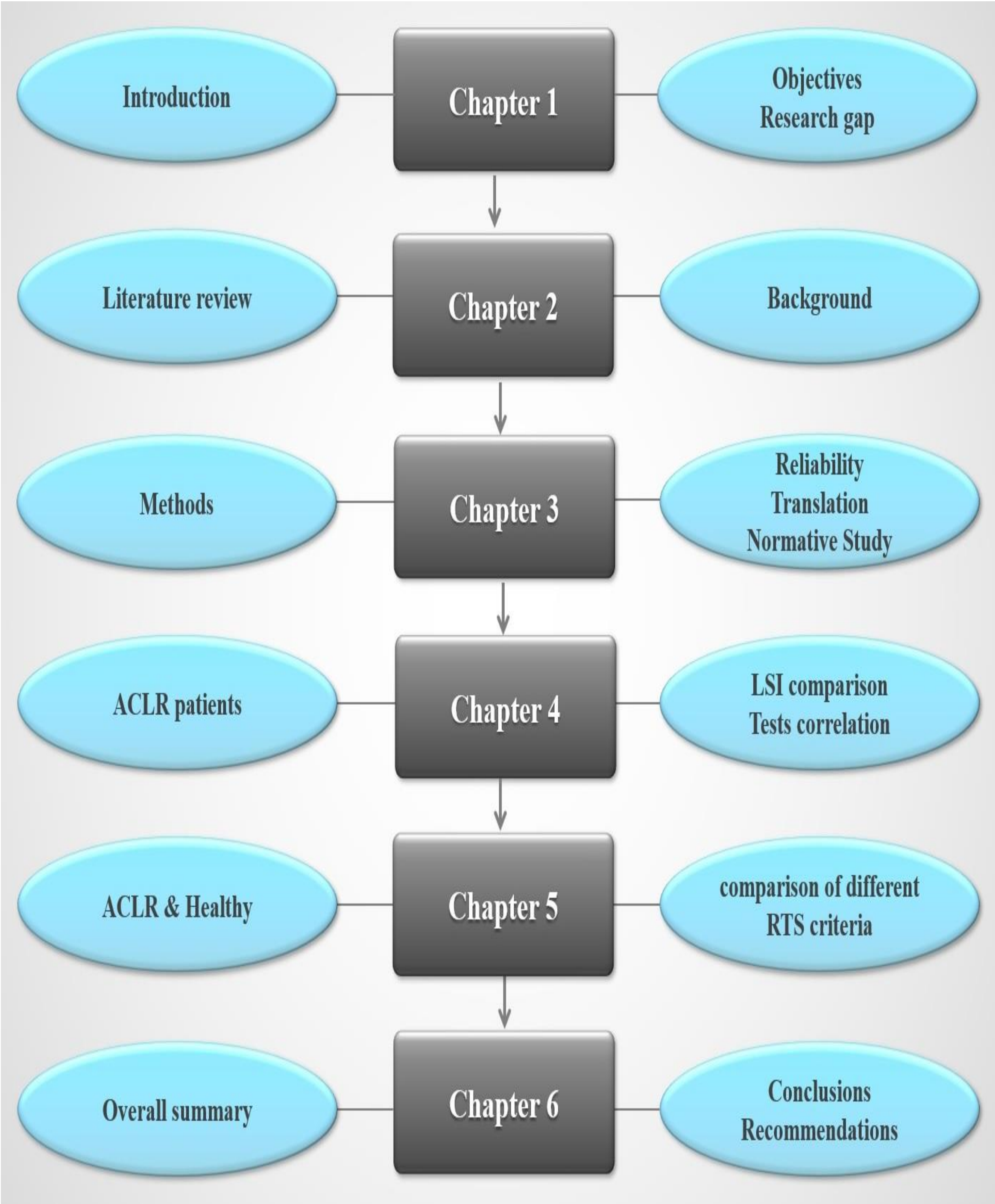
(Q5) Are there any correlations between single-leg hop for distance, isometric muscle strength, self-reported knee function, and psychological factors of ACLR patients at discharge from rehabilitation?

Null hypothesis: *There are no correlations in the outcome measures of ACLR patients at discharge from rehabilitation.*

(Q6) Are there differences between LSI return to sport criteria and the comparison with age matched group criteria from a healthy active population?

Null hypothesis: *There are no significant differences between injured leg for ACLR patients at discharge from rehabilitation, with uninjured leg for ACLR patients and age matched group from an active population, in the outcome measures*.

1.5 Thesis Structure



Chapter 2

2 Literature review

2.1 Anterior Cruciate Ligament (ACL) Injury

ACL injury can be disastrous to the individual and have a major impact on their level of sports participation, general activity levels, and their quality of life in the long run. Hence, Ardern et al. (2012b) conducted a survey with 314 ACL reconstruction (ACLR) patients two to seven years post reconstruction, and they discovered that only 41% had engaged in competitive sport during the follow-up period, and only 29% were participating at pre-injury competitive levels (Ardern et al., 2012b). In addition, a systematic review by Ardern, Taylor, et al. (2014) showed that after reconstruction, only 65% of non-elite athletes returned to pre-injury levels of sport, and only 55% returned to a competitive level of sport. Previous research conducted by Ardern, Webster, Taylor, and Feller (2011b) also showed that only 33% of subjects returned to pre-injury levels and were competing 12 months post ACLR surgery. In addition, Shah, Andrews, Fleisig, McMichael, and Lemak (2010) found in their study with American Football players that 37% of players who had undergone ACL surgery did not RTS. Myklebust, Holm, Maehlum, Engebretsen, and Bahr (2003) discovered that from among elite Norwegian handball players who had undergone ACLR, 58% returned to competition at the same level, but 42% either competed at a lower level or did not return to competitive sport. Worse still, Lohmander, Ostenberg, Englund, and Roos (2004) found that over half of female Swedish football players were unable to return to sport following an ACL injury, and only 15% returned to pre-injury levels of activity.

In addition to problems around RTS, an ACL injury may increase the risk of early onset osteoarthritis of the knee (Zabala, Favre, & Andriacchi, 2015). Moreover, a number of researchers state that most individuals who have suffered an ACL injury will experience early onset osteoarthritis, which includes both limited function and the pain (Ahlden et al., 2012; Li et al., 2011; Lohmander, Englund, Dahl, & Roos, 2007; Lohmander et al., 2004; Myklebust et al., 2003; Oiestad, Engebretsen, Storheim, & Risberg, 2009). In research conducted by Lohmander et al. (2004) with female soccer players who had experienced ACL, they found radiographic patellofemoral or tibiofemoral OA in 51% 12 years post injury. Ahlden et al. (2012) conducted the largest known study involving 18,000 patients with a history of ACL reconstruction, who they found using the Swedish National ACL Register. Ahlden et al. (2012)

found that patients who underwent a second surgery had significantly analysed KOOS scores from the registry respondents one, two, and five years postoperatively, and they found poorer knee related quality of life in comparison to those who had only one ACLR surgery. The participants who underwent a second ACLR also gained no significant improvements in their symptoms or pain, and their activities of daily living had not improved five years post-operatively compared with before the surgery (Ahlden et al., 2012). Oiestad et al. (2009) claims that a patient who suffers an ACL injury, but without injuring the meniscus, has up to 13% chance of developing knee osteoarthritis more than 10 years after the injury, whereas if the meniscus was damaged, this rose to 21% to 48%. Similar results have been reported by Li et al. (2011) as they found an OA prevalence of 38.6% during their 7.86 (average) year follow up. Other studies have found up to 80% of ACL injured knees to display radiographic evidence of osteoarthritis five to 15 years after the initial injury, especially when concomitant meniscal damage has occurred (Kiapour & Murray, 2014; Neuman et al., 2008).

Patients that undergo ACLR that have severe radiographic osteoarthritis have a poorer quality of life with regard to health, and so there is a significant clinical impact (Filbay, Ackerman, Russell, Macri, & Crossley, 2014). Furthermore, a retrospective study by Leiter, Gourlay, McRae, de Korompay, and MacDonald (2014) showed that ACLR knees had a much higher incidence and severity of osteoarthritis in comparison to non-ACL-injured knees.

2.1.1 Prevalence of ACL Injury

Shields and Twycross (2003) explain that in the field of epidemiology, prevalence provides a measurement for specific populations to acknowledge the extent of a certain condition; incidence, on the other hand, reveals the rate of new cases during a particular timeframe. One of the most frequently affected ligaments that results from sports injuries is the ACL, especially among younger, more active populations (Beynnon, Johnson, Abate, Fleming, & Nichols, 2005; von Porat, Roos, & Roos, 2004).

(Table 2.1) shows the prevalence of ACL injuries every year among the populations of different countries; however, this prevalence has not been thoroughly investigated in limited number of western countries.

Table 2.1: The annual population prevalence of ACL injury in different countries:

Country	Annual population prevalence	Place of study	Period of study	References
England	2 per 100,000 24 per 100,000	Nationwide study	1997-1998 2016-2017	Abram et al., 2019
USA	75 per 100,000 30 per 100,000 38 per 100,000	administrative database Southern California area San Diego area	2005-2013 2001-2005 1985-1988	Herzog et al., 2017 Csintalan et al., 2008 Miyasaka et al., 1991
Australia	77 per 100,000	Nationwide study	2000-2015	Zbrojkiewicz et al., 2018
Denmark	38 per 100,000 30 per 100,000	Nationwide study City of Aarhus	2005-2007 1986	Lind et al., 2009 Nielsen and Yde, 1991
Sweden	78 per 100,000 81 per 100,000	Nationwide study City of Helsingborg	1987-2009 2001-2002	Nordenvall et al., 2012 Frobell et al., 2007
New Zealand	37 per 100,000	Nationwide study	2000-2005	Gianotti et al., 2009
Norway	34 per 100,000	Nationwide study	2004-2006	Granan et al., 2008
Finland	61 per 100,000	Nationwide study	1987-1997	Parkkari et al., 2008

In England alone, there were 133 270 cases of ACL reconstruction (124 489 patients) between 1997–1998 and 2016–2017, and the rate of ACL reconstruction increased 12 fold from two per 100,000 people in 1997–1998 to 24.2 per 100,000 people in 2016–2017 (Abram, Price, Judge, & Beard, 2019). However, these data included National Health Service (NHS) only, the number of procedures performed in the private sectors did not include which may affects the rate of ACLR in England. In addition, these data are based on coding data system, which have not been validated therefore, the absolute accuracy for coding system cannot be confirmed. Moreover, these are observational data only and the causes of the ACL injuries cannot be determined.

ACL are the most common types of knee injury in the US, affecting around 30 in every 100,000 people annually (Csintalan, Inacio, & Funahashi, 2008), hence there are 100,000 new injuries every year (Griffin et al., 2000); moreover, Evans et al. (2014) claim that the incidence of this injury has doubled since the year 2000. Csintalan et al. (2008) explain that figures for the US are based on the number of patients aged 12 to 85 years who have received healthcare and were diagnosed with an ACL in hospitals, although a much higher prevalence (75 per 100,000) has been claimed by Herzog, Marshall, Lund, Pate, and Spang (2017).

In Denmark, New Zealand and Norway, typical prevalence rates for ACL are 30 to 38 cases for every 100,000 of the population (Gianotti, Marshall, Hume, & Bunt, 2009; Granan, Bahr, Steindal, Furnes, & Engebretsen, 2008; Lind, Menhert, & Pedersen, 2009; Nielsen & Yde, 1991).

A higher rate of prevalence has been reported in Sweden, with approximately 80 cases per 100,000 of the population considering those aged 10 to 64 years (Frobell, Lohmander, & Roos, 2007), with around 5,000 new ACL injuries every year (Lohmander et al., 2007). Similarly, Nordenvall, Bahmanyar, Adami, Mattila, and Fellander-Tsai (2014) have reported 78 per 100,000 in a large nationwide study conducted in Sweden from 1987 to 2009 involving almost 65,000 patients (Nordenvall et al., 2014). Most of these ACL injuries occurred while playing sport (75%), with football (60%) the leading cause of sports related injuries (Frobell et al., 2007). Furthermore, national statistics in Sweden show an average of 3,000 ACL reconstructions annually (Lohmander et al., 2007), which is equal to 60% of all cases of ACL injury.

The rate of ACLR in Australia increased 43% from 54 per 100,000 people in 2000 to 77.4 per 100,000 in 2015 (Zbrojkiewicz, Vertullo, & Grayson, 2018), and in Finland the figures were 60.9 per 100,000 based on a cohort study of 46,000 youths (Parkkari, Pasanen, Mattila, Kannus, & Rimpela, 2008).

The increasing numbers of women now partaking in professional sports also has a significant impact, and figures suggest that ACL injuries occur more often in female athletes compared to male athletes, at an incidence ratio of two to nine (Nordenvall et al., 2014), and most of these injuries are the result of non-contact incidents (Kobayashi et al., 2010). A number of studies highlight the various reasons for this higher rate of incidence among female athletes, such as due to anatomic differences and hormonal and biomechanical influences, as well as environmental factors; however, the aetiology is still not properly understood (Griffin et al., 2000; Hewett, Paterno, & Myer, 2002; Huston, Greenfield, & Wojtys, 2000), and the higher risk of ACL injury among females is probably as a result of a combination of factors, rather than a single issue.

2.1.1.1 Prevalence of ACL Injury in Saudi Arabia

The prevalence of ACL injury among the Saudi Arabian population remain unknown due to failures in documenting and reporting, although the total number of the injuries associated with football are reportedly high among Saudi Arabian athletes (Almutawa, Scott, George, & Drust, 2013).

Alshewaier (2016) found a high prevalence of ACL injuries among younger and active individuals in Riyadh (the capital city of Saudi Arabia), as the total number of ACL injuries reported between January 2012 and January 2013 was 2,351 out of 4,425 knee injuries. This equates 31 ACL injuries per 100,000 of the population of Riyadh. However, these figures for Riyadh may be underestimated as only the main hospitals in Riyadh were included in the study; in addition, there is a lack of systematic collection of injury information in Saudi Arabia (Almutawa, Scott, George, & Drust, 2014). Another study based on a questionnaire distributed to the students of Physical Education College at Umm Al−Qura University found a prevalence rate of 5.3% (Alghamdi et al., 2017).

During professional football competitions, 12 cases of ACL injury were reported in Saudi Arabia during the 2014-2015 season, which is a high figure when compared to the English premier league (7 cases), the Italian league (4 cases) and the Spanish league (2 cases) (Al-Gannas, 2015). There may be several reasons for this, such as limited healthcare provision for players, and lower quality football pitches and training equipment in Saudi Arabia (Almutawa et al., 2014), although these are assumptions and the actual reasons are unknown (Al-Gannas, 2015). Additional factors include the hot weather leading to increased risk of ACL injuries due to high levels of fatigue (Silvers & Mandelbaum, 2011), as if a physical activity is performed for longer than 30 minutes under extreme heat, performance impairment is likely (Maughan, Shirreffs, & Watson, 2007). Furthermore, hot weather conditions cause higher blood lactate levels, and increased rates of muscle glycogen depletion (Jentjens, Wagenmakers, & Jeukendrup, 2002).

Almutawa et al. (2014) claim that the quality of recording injury information in the Saudi health system is sub-standard, and incomplete records and missing information compromises the quality of data that can be used in research or for information purposes. For example, clinical history details of ACL injuries were sometimes inadequate, and in some cases, the knee injury has not been properly specified in the patient’s notes.

2.1.2 Potential Consequences of ACL

The main problem following an ACL injury is perceived or actual instability of the knee, including the sensation of it giving way, and this can be tested clinically through a pivot shift test. This instability causes the patient to face difficulties when attempting to engage in sporting activities (Cimino, Volk, & Setter, 2010). In addition to the primary issue of instability, secondary impairments are a reduction in the ability to balance; weakened muscle strength, and impairment of proprioception and range of movement of the knee joint (Huston et al., 2000;

Keays, Bullock-Saxton, Newcombe, & Keays, 2003; Wilk et al., 1994; Zatterstrom, Friden, Lindstrand, & Moritz, 1994). Disrupting the ACL can result in functional impairment; meniscal damage, as well as degeneration of the knee joint over time (Daniel et al., 1994). According to Jonsson, Riklund-Ahlstrom, and Lind (2004), it is the internal tibial rotation of a knee that occurs in a ACL-deficient that can lead to degeneration of the knee joint. Tears to the ACL usually occur alongside other injuries, and it has been reported that 50% of acute cases happened along with sprains to other ligaments; meniscal tears; articular cartilage damage; bone bruises, and sometimes even intra-articular fractures (Beynnon et al., 2005). (Nagano, Ida, Akai, & Fukubayashi, 2009) state that around 60-70% of all ACL injuries have been found to occur concurrently with meniscal lesions, and localised swelling straight after the injury.

Reduced quality of life (QoL) due to pain and a reduction in knee function are often associated with ACL injuries (McAllister et al., 2003; Rotterud, Risberg, Engebretsen, & Åroen, 2012; Rotterud, Sivertsen, Forssblad, Engebretsen, & Aroen, 2013; Shapiro, Richmond, Rockett, McGrath, & Donaldson, 1996). In addition, there can be psychological effects, for example, fear of a repeat injury after recovery, as commonly reported by athletes (Filbay et al., 2015; McAllister et al., 2003). A systematic review carried out by Filbay et al. (2015) included over 470 ACL-deficient patients and examined the impact of ACL injuries and their management with regard to QoL. Over two thirds of the studies examined in the review used the Knee injury and Osteoarthritis Outcome Score (KOOS) to measure QoL in patients. The review found a strong positive correlation between QoL and: pain (Spearman correlation test, ($R = 0.86$, $p = 0.01$); symptoms such as swelling ($R = 0.79$, $p = 0.02$); functioning in daily living ($R = 0.79$, $p = 0.02$); and functioning in sports and recreational activities ($R = 0.74$, $p = 0.04$).

Concomitant cartilage and meniscus injury, whether surgically repaired or not, have been found to be more likely to cause early-onset knee osteoarthritis than isolated ACL ruptures (Claes, Hermie, Verdonk, Bellemans, & Verdonk, 2013; Keays, Newcombe, Bullock-Saxton, Bullock, & Keays, 2010; Magnussen, Mansour, Carey, & Spindler, 2009; van Meer et al., 2015). Furthermore, worse outcomes were reported by patients with baseline meniscal damage 16 years post ACLR, including the ability to perform physical activities, reduced knee function, and higher levels of pain (Gerhard et al., 2013). In New York state, more than 60% of ACLR between 1997 and 2006 (70,547 operations) included concomitant surgery, and one in two ACLRs included concurrent surgery to the meniscus (Lyman et al., 2009). Concomitant meniscus surgery along with ACLR has been linked to worse outcomes two to 15 years post-surgery, including higher pain levels, and reduced knee functioning and QOL in comparison to patients who did not have meniscus surgery (Barenius et al., 2014; Cox et al., 2014; Dunn et al., 2015; Neuman et al., 2008). These research studies therefore imply that individuals who experience associated or additional injuries are at a higher risk of poor QOL outcomes after ACLR surgery.

Therefore, there appears to be a close link between knee-related QoL and the clinical aspects of ACL injuries, such as pain, the resulting symptoms, and knee function. Moreover, the impact on QoL may continue in the long term (5-25 years) after an ACL injury, regardless of whether the knee has been operated on or not (Filbay et al., 2015), in particular due to joint degeneration and complications, for example osteoarthritis.

Some of the clinical features that result from an ACL injury are: functional disability; meniscal tears, repeat ACL injury, psychological effects and degeneration of the knee joint, and these can result in poor QoL. Therefore, effective treatment is needed so that the symptoms of ACL injury can be reduced, along with assist the patients to regain knee stability and function and preventing long term complications, as well as improving their QoL.

2.1.2.1 Repeat ACL Injury

Patients are often worried about a repeat injury occurring after suffering from an ACL knee injury. Repeat ACL injuries following surgery involve either rupturing of the primary graft, as well as injury to the contralateral ACL. Graft failure may result from atraumatic or traumatic mechanisms. Graft rupture rates are estimated to up to 23% (Lind et al., 2009; Salmon et al., 2005) and 21% of the ACLR patients having surgery in the injured knee within one year return to sport (Ithurburn, Longfellow, Thomas, Paterno, & Schmitt, 2019). However, the observational design of this study limits any causative factors underlying the increase rate of the second injury. Although, their findings cannot be generalised to all individuals after ACLR as they only included young active subjects. According to Lind et al. (2009), ACLR graft failure can be defined by the need to carry out revision surgery.

In addition, some large-scale research studies have found a revision rate of two percent at the two year follow-up point (Andernord et al., 2015; Bjornsson et al., 2015), and four to five percent at the five year follow-up point after the initial ACLR (Lind, Menhert, & Pedersen, 2012; Persson et al., 2014; Webster, Feller, Leigh, & Richmond, 2014). Leys et al. (2012) have reported on outcomes at 15 years post ACLR among a typical sample of patients, and they discovered second ACL injuries, such as ipsilateral and contralateral tears among of 31% of the sample (Leys et al., 2012). In addition, Wright, Magnussen, Dunn, and Spindler (2011) conducted a systematic review of five year outcomes post ACLR, and they found a 17.2% second-injury rate, as well as a higher percentage suffering a contralateral injury (11.8%) compared to an ipsilateral graft failure (5.8%). Recently, in a ten-years follow up study Sandon, Engstrom, and Forssblad (2019) reported that 28.7% of the players who returned to play had additional ACL injury and 20% having contralateral ACL injury (Sandon et al., 2019).

Salmon et al. (2005) carried out a five-year follow-up of 612 ACLR patients, and they found comparable ACL graft rupture rates to be 6% and contralateral ACL injury rates to be 6%, which is significantly higher than the incidence rate of ACL injuries in healthy uninjured athletic individuals. In addition, a number of studies have found that there is little statistically significant difference in repeat injury rates for autogenous bone-patellar tendon-bone (BPTB) compared to hamstring tendon (HT) grafts (Salmon et al., 2005). Pinczewski et al. (2007) carried out a prospective cohort study and found no significant differences between the rates of graft ruptures for BPTB and HT grafts; although BPTB grafts revealed a higher rate of contralateral ACL ruptures at 22%, in comparison to HT grafts 10% ($p = 0.02$).

An ACL graft rupture is most likely to occur within the first 12 months after an ACLR (Salmon et al., 2005). Salmon et al. (2005) found in their five year follow up study that there is not much difference in the timing of ACL graft ruptures between BPTB and HT grafts. The likely timing of ACL repeat injuries is probably due to poor graft healing during the first 12 months, which is relevant to deciding the most appropriate time of medical release for athletes to return to sport following an ACLR, as much greater care seems to be required during the first twelve months after an ACLR.

It can be seen that the studies on second ACLR injury rates differ with regard to the rates and percentages of revision, ranging from 2% to 31%, and there are likely to be several reasons for this, for example, the variables in the sample such as the exact surgical procedure, details on postinjury activity levels, as well as the age of the participants (Paterno, 2015).

It has been found that young adults, adolescents and individuals returning to high impact sports are at a gretaer risk of having to undergo ACLR revision surgery (Andernord et al., 2015; Lind et al., 2012; Persson et al., 2014), and adolescents face a greater risk of a contralateral ACL rupture compared to adults (Leroux et al., 2014; Webster et al., 2014). Paterno, Rauh, Schmitt, Ford, and Hewett (2014b) found that 29.5% of athletes age under 25 suffered a second ACL injury within 24 months of RTS; 20.5% sustained a contralateral injury, and the graft was re-injured among 9%. Wiggins et al. (2016) conducted a systematic review and report that younger patients (<25 years) and those returning to high activity levels, particularly in high-risk sports, face an increased risk, the rate for secondary ACL injuries was 23%; for ipsilateral reinjuries 10%, and contralateral injury rates were 12%, although they note that these figures can be put down to several reasons, as their younger age range is probably involves other risk factors (Webster & Feller, 2016). For example, it is more likely that younger patients will return to high-risk sports involving cutting, jumping, and pivoting movements. In addition, neuromuscular and physical impairments are predictive of second ACL injuries among young athletes (Paterno, Rauh, Schmitt, Ford, & Hewett, 2012b; Paterno et al., 2014b). Webster et al. (2014) carried out research in Australia and found that the average contralateral ACL injury rate five years after having a primary ACLR was 8%, yet but this figure rose to 29% for those age under 20 years (Webster et al., 2014). Suffering a graft re-rupture or contralateral ACL rupture 15 years after the primary ACLR can be as high as one in four patients (Bourke, Salmon, Waller, Patterson, and Pinczewski (2012). Furthemore, Leroux et al. (2014), claim that patients who undergo a re-revision procedure usually suffer more cartilage injuries and end up with lower activity levels than those having their first revision surgery. There is also a problem in that it is difficult to determine the exact rate of ACL graft re-ruptures because some incidences may remain undiagnosed or not lead to surgical reconstruction. In addition, patients needing ACLR revision usually suffer more meniscal and chondral damage compared to patients undergoing their first ACLR (Ahn, Lee, & Ha, 2008; Brophy, Haas, Huston, Nwosu, & Wright, 2015; Kievit, Jonkers, Barentsz, & Blankevoort, 2013; Thomas, Kankate, Wandless, & Pandit, 2005; Widener, Wilson, Galvin, Marchant, & Arrington, 2015).

Activities involving cutting, pivoting or side-stepping put extra strain on the ACL and risk a repeat ACL injury. Differences have been found between graft ruptures and contralateral ACL injuries with regard to the mechanism of injury when it comes to repeat ACL injuries. For example, Salmon et al. (2005) discovered a threefold increase in the incidence rate for ACL graft ruptures in those knees that had originally been injured due to a contact mechanism. Furthermore, Salmon et al (2005) did not find initial contact injury to be predictive of contralateral ACL injuries. A return to moderate to strenuous levels of sporting activity increases the risk of contralateral ACL injury, and this high increase may be due to altered biomechanical movement patterns, as well as lower extremity function not being properly assessed during rehabilitation.

Revision surgery has revealed poorer outcomes compared to primary ACLR, including the onset of osteoarthritis, higher levels of pain, worse symptoms, lower activity levels, and poorer QOL (Gifstad, Drogset, Viset, Grøntvedt, & Sofie Hortemo, 2012; Kievit et al., 2013; Lind et al., 2012). If a high number of chondral lesions is discovered at the time of revision ACLR, the patient is more at risk of developing osteoarthritis following the revision (Salmon, Pinczewski, Russell, & Refshauge, 2006). Although patient expectations for revision ACLR are lower than for primary ACLR, 96% expect there to be no risk or a slight increase in risk of subsequently developing osteoarthritis compared to the healthy knee 10 years after the ACLR revision (Feucht et al., 2016). Furthermore, 88% of patients expect to return to the same level of sport as before the ACLR, and all patients expect to have a normally functioning, or almost normal, knee following the revision surgery (Feucht et al., 2016). However, it is likely that only half of all patients will return to pre-injury levels of sport following ACLR revision (Grassi et al., 2015), and 37% to 80% of patients suffer knee osteoarthritis four to eight years after revision ACLR (Kamath, Redfern, Greis, & Burks, 2011).

2.1.2.2 Knee Osteoarthritis

Osteoarthritis is a progressive synovial joint disease, which causes changes to articular cartilage, subchondral bone, synovium, peri-articular muscles, the meniscus and ligaments (Lane et al., 2011). Osteoarthritis is a major cause of disability around the world (Cross et al., 2014), with one out of three individuals age over 60 affected (Felson, 2004).

The majority of ACL injuries affect individuals age 15 to 46 years (Ramski, Kanj, Franklin, Baldwin, & Ganley, 2013), and it is likely that athletes affected will start to have symptoms of osteoarthritis in their late thirties (Culvenor et al., 2015; Ratzlaff & Liang, 2010). Nordenvall et al. (2014) found the average age of post-traumatic osteoarthritis to be 32 years old, following ACL reconstruction. Recently, Culvenor, Eckstein, Wirth, Lohmander, and Frobell (2019) found that patellofemoral cartilage thickness loss was observed after ACL injury in young people aged 18 -35 years, which is much earlier than the normal age that osteoarthritis occurs due to age.

There are many injuries associated with ACL injuries, in particular meniscus tears, for example, a study found that as many as 65% of ACL injuries happen together with a meniscus tear or other injury, which also increases the risk of early onset osteoarthritis (Nordenvall et al., 2014). According to Nordenvall et al. (2014), meniscus injuries present the biggest risk factor with regard to suffering from early onset osteoarthritis. Thus, ACL injuries alone are not viewed as a risk factor for osteoarthritis, although the likelihood of associated risk factors does increase the risk. It has been found that injuries to other ligaments, the menisci, cartilage, and subchondral bone, or cancellous bone are likely to cause the development of osteoarthritis in the future (Lohmander et al., 2007). However, (Lohmander et al., 2007; Nordenvall et al., 2014) did not include the diagnostic methods for OA and meniscus injuries in their study.

Up to 80% of patients with an ACL injury will develop osteoarthritis, typically around 15 years after the injury occurs (Lange et al., 2007). Moreover, Holm, oiestad, Risberg, and Aune (2010) found that 64% of ACLR patients were diagnosed with osteoarthritis 14 years after the operation; in addition, they found that early onset osteoarthritis affected 23% of patients within five years of ACLR. Ratzlaff and Liang (2010) studied a sample of soccer players that had suffered ACL tears, and they found that 80% of them had radiographic osteoarthritis 12-14 years later- whether they had undergone reconstruction or not; therefore, the results show that ACL reconstruction surgery does not prevent osteoarthritis. The treatments currently available for treating osteoarthritis only deal with the symptoms.

Lie et al. (2019) carried out a systematic review and discovered that the osteoarthritis prevalence >10 years post-ACL tear did not differ between those who had undergone surgery (8%–68%) compared to those treated non-surgically (24%–80%), suggesting little impact from treatment options, and these findings agree with a randomised controlled trial study conducted by Frobell et al. (2015) who found no difference between surgically and non-surgically treated participants at five years follow-up. However, while these findings are confirmed by recent systematic reviews and meta-analyses, no RCT studies have been included in these reviews (Chalmers et al., 2014; Harris et al., 2017). Studies have shown that ACLR is not a prophylactic treatment that impacts the development of OA (Luc, Gribble, & Pietrosimone, 2014; Paschos, 2017), which could explain the similarities between treatment options. Furthermore, these studies have not explored the impact of graft type (Magnussen, Carey, & Spindler, 2011; Xie et al., 2015).

However, the typically short period of time period between ACL injury and developing osteoarthritis is concerning, especially considering the high rate of ACL injuries among adolescents and active populations and subsequent ACLR surgeries (Renstrom et al., 2008).

Ackerman et al. (2015) discovered that knee osteoarthritis leads to greater psychological stress among young and middle-aged adults, along with lower health-related QOL and problems around employment in comparison to an age-matched population; although there has been a lack of research into the impact of symptomatic early knee osteoarthritis on individuals.

therefore, discovering the exact risk factors in young patients may lead to better prevention and improved forms of treatment for osteoarthritis (Thorstensson, Petersson, Jacobsson, Boegard, & Roos, 2004).

2.1.2.3 Psychological Outcomes

The psychological impact of an ACL rupture and reconstructive surgery often appears during the acute postoperative period, (Brewer et al., 2007; Heijne, Axelsson, Werner, & Biguet, 2008; Langford, Webster, & Feller, 2009; Tripp, Stanish, Ebel-Lam, Brewer, & Birchard, 2007), and may continue for several years post ACLR, sometimes having a negative effect on long-term outcomes (Ardern, Taylor, Feller, & Webster, 2012a; Te Wierike, van der Sluis, van den Akker-Scheek, Elferink-Gemser, & Visscher, 2013). Studies have revealed that patients who do not return to pre-injury levels of sport one-year after ACLR, have a higher fear of reinjury, experience more negative emotions, and have lower confidence levels in comparison to patients that return to sport (Baez, Hoch, & Hoch, 2019; Kvist et al., 2005; Webster et al., 2008). In a ten-year follow up study of ACLR soccer players Sandon et al. (2019) found that 49% did not return to play and 32% of them because of fear of re-injury. However, not all patients completed the study and loss to follow up is a serious limitation as 50% of their patient's dropout.

Langford et al. (2009) describe the emotional disturbances experienced by individuals who did not return to sport six- and 12-months post ACLR, and in comparison, individuals who had returned to sport were not affected, despite knee symptoms and knee functioning being similar. Fear of re-injury is a typical psychological outcome after undergoing ACLR (Ardern, Osterberg, et al., 2014; Gignac et al., 2015; Kvist et al., 2005; Tripp et al., 2007), which is a problem because fear of re-injury has been linked to poorer knee related QOL outcomes (Kvist et al., 2005), delay in returning to sport and lower RTS rate (Nwachukwu et al., 2019); in addition, psychological factors prior to ACLR are suggestive of postoperative outcomes (Everhart, Best, & Flanigan, 2015). In particular, pessimism (Swirtun & Renström, 2008), with negative predictions regarding future knee self-efficacy (Thomeé et al., 2008) linked to poor outcomes post-operatively. It has also been found that an external locus of control can cause patients not to feel in control of their health and this has been linked to reduced self-perceived functioning before ACLR (Nyland, Johnson, Caborn, & Brindle, 2002). Thomeé et al. (2008) discovered lower knee self-efficacy one year post ACL injury, and other studies have shown worse functional outcomes and health-related QOL two years after ACLR (Nyland, Cottrell, Harreld, & Caborn, 2006). These findings emphasise how ACL injury and reconstructive surgery can have a negative psychological impact that persists in the long run and has an impact on knee function, QOL, and RTS.

2.1.2.4 Quality of Life (QOL)

Quality of life is affected both at the time of an acute injury as well as during the early postoperative periods, and the negative impact if this sometimes persists until knee functioning returns to pre-injury levels, or until the person accepts that their knee function is restricted. According to (Lynch et al., 2015a), ACLR are usually performed with the aim of making knee functioning pain free, and to reduce swelling or restriction of movement, so that the patient can engage in physical activity; however, for some individuals, it is not possible for them to return to normal levels of activity as a result of persistent knee problems, or fear of re-injury (Ardern, Taylor, et al., 2014). McCullough, Phelps, Spindler, Matava, Dunn, Parker, and Reinke (2012) discovered poorer knee-related QOL outcomes two years after ACLR among individuals who did not return to pre-injury levels of sport, and similarly, Ardern, Taylor, et al. (2014) discovered the same negative impact one to seven years post ACLR. However, 41% of potential participants did not respond to patient-reported outcomes. It is possible that, non-responders may have better impact than responders.

A full thickness cartilage lesion at the time of ACLR has been associated with lower Knee injury and Osteoarthritis Outcome Scores (KOOS) and QOL scores two years (Røtterud, Sivertsen, Forssblad, Engebretsen, & Årøen, 2013) and two to five years post ACLR (Rotterud, Risberg, Engebretsen, & Aroen, 2012). Furthermore, poorer Short-Form 36 (SF-36) scores were found at two-year follow-ups among ACLR patients with concomitant chondromalacia of the lateral tibial plateau (Dunn et al., 2015). As pointed out above, a ACLR revisions have been shown to lead to poorer knee-related and health-related QOL outcomes within five years post-surgery compared to primary ACLR (Bjornsson et al., 2015; Dunn et al., 2015; Kievit et al., 2013; Lind et al., 2012). As well as fear of re-injury (Kvist et al., 2005), performance in single-leg triple-leg hop tests (Reinke et al., 2011c), has highlighted poor outcomes.

Poor health-related QOL outcomes have been found to be affected by a range of demographic factors within five years of ACLR, including smoking (Dunn et al., 2015; Kvist, Kartus, Karlsson, & Forssblad, 2014); older age; a high BMI, and lower levels of education (Dunn et al., 2015). In self-report measures, lower pre-operative knee-related and health-related QOL scores are linked to lower scores using the same measures postoperatively (Bryant, Stratford, Marx, Walter, & Guyatt, 2008; Dunn et al., 2015). A number of pre-operative factors can reduce postoperative QOL outcomes, such as: low levels of physical activity (Dunn et al., 2015; Mansson, Kartus, & Sernert, 2013) and anterior knee pain prior to ACLR (Heijne, Ang, & Werner, 2009). In addition, some studies discovered no impact from the type of ACL autograft used, whether patellar tendon, quadruple-stranded or double-bundle hamstring tendon, on Quality of Life Outcome Measures (Questionnaire) for Chronic Anterior Cruciate Ligament Deficiency (ACL-QOL) two years after ACLR (Mohtadi, Chan, Barber, & Oddone Paolucci, 2015); the KOOS-QOL or Euro-QoL 5D (EQ-5D) scores at one and two years (single or double bundle hamstring autografts) (Bjornsson et al., 2015), as well as SF-36 scores at six, 12 and 24 months after ACLR (single or double-bundle) (Nunez et al., 2012; Ochiai, Hagino, Senga, Saito, & Haro, 2012) revealed only slight differences in outcomes. In a three-year follow-up, Fleming et al. (2013) found that differences in graft tension, whether low or high, did not affect knee-related or health-related QOL scores. KOOS-QOL scores were not affected by a concomitant meniscal lesion or partial-thickness cartilage lesion two years post-operatively in research conducted with 3476 patients in Norway and Sweden (Røtterud et al., 2013). Research has also focused on the timing of the operation, and it has been found that an early ACLR within four weeks of injury, rather than opting to delay it until after a structured program of exercise, resulted in similar SF-36 and KOOS-QOL scores two and five years after the occurrence of an ACL rupture (Frobell, Roos, Roos, Ranstam, & Lohmander, 2010a; Frobell et al., 2013).

2.1.3 ACL Mechanisms of Injury

ACL injuries generally occur during sporting and leisure activities (Kobayashi et al., 2010), and for athletes, around 85% of ACL injuries happen while training or during competitive events. Forty percent of all knee injuries that occur while playing football are ACL injuries, whereas for basketball, the figure is lower at around 19% (Arendt & Dick, 1995), and for skiing it is 22% (Viola, Steadman, Mair, Briggs, & Sterett, 1999). These numbers highlight the significant impact of ACL injuries in a range of sports, and additional data report reveals that around 70% of ACL injuries are sports related (Griffin et al., 2000). Furthermore, there may be discrepancies in these figures due to some ACL injuries going largely unreported in studies, depending on location and logistics, leading to underestimating the number of athletes affected (Frobell et al., 2007; Lohmander et al., 2007).

A number of research studies have looked at the incidences of ACL injuries according to different types of sports. For example, Hootman, Dick, and Agel (2007) analysed data over a 16 year period from the National Association (NCAA) on injury surveillance, and when they combined the data, they found that American football players suffered the highest rate of ACL injury (over 50%); basketball players 10%; volleyball players 3%, and wrestlers 3%, with the lowest number of ACL injuries among ice hockey and baseball players, at 1.16%. On the other hand, a meta-analysis showed that the rate of ACL ruptures was highest amongst basketball players, followed by soccer players, and next lacrosse players (Prodromos, Han, Rogowski, Joyce, & Shi, 2007).

Kobayashi et al. (2010) have divided the mechanism of ACL injury into contact and non-contact incidents. Noncontact incident means that the injury is not as a result of contact with another person; whereas contact incidents refers to direct contact with another person, but with a body part apart from a lower limb. (Table 2.2) shows the most common reasons for ACL injuries, and the mechanisms involved according to the type of contact made with the body.

It is thought that around 60-85% of ACL injuries are due to non-contact incidents, such as stopping suddenly after fast running; cutting to move in a different direction; sudden deceleration before to a change of direction, or landing from a jump (Agel, Arendt, & Bershadsky, 2005; Arendt & Dick, 1995; Benis, A, & Bonato, 2018; Boden, Dean, Feagin, & Garrett, 2000; Johnston et al., 2018; Montgomery et al., 2018; Walden et al., 2015). This is because sudden cutting in order to change direction places significant strain on the ACL that is not reduced by the supporting hamstring muscle even at its maximum contraction (Colby et al., 2000; Simonsen et al., 2000).

Ireland (1999) discovered a frequent mechanism involved in non-contact incidents, which she labelled ‘the position of no return’. This position involves a loss of control at the level of the hip and pelvis; knee valgus; internal rotation of the femur; external rotation of the tibia, and external rotation of the foot in a pronated position, and it is most commonly seen in non-contact ACL injuries (Zeller, McCrory, Kibler, & Uhl, 2003).

Benis et al. (2018) used a questionnaire to assess the participants recall of the injury mechanism when they sustained an ACL injury. Most of the respondents stated that they were injured while landing or during a manoeuvre involving a change in direction. However, the study relied on the ability of individuals to accurately recall the details of the injury, and so the definitions used to describe the injury mechanisms are not precise, leading to limitations to this study (Benis et al., 2018).

Video footage was used with over 1500 athletes by Kobayashi et al. (2010) to assess the dynamic alignment at the time of injury. They found that the ‘knee-in and toe-out’ position was most frequently associated with ACL injury among both male and female athletes (approximately 50% of all cases), regardless of the mechanism of injury. Therefore, it is likely that conditions at the time of injury should be taken into account in order to further understand how exactly ACL injuries occur. Kobayashi et al. (2010) assumed that the other factors involved may be static knee alignment in relation to the rest of the body; knee range of motion (ROM), and lower limb muscle strength, as these can affect the dynamic knee alignment of the lower extremities.

The figures shown in (Table 2.2) have been obtained from in-hospital clinical or emergency units that have diagnosed an ACL injury in patients receiving healthcare (Lohmander et al., 2007). 40% of ACL injuries are contact injuries, as illustrated in (Table 2.2). These injuries usually when the knee joint is forced into valgus collapse after direct contact with another player. In this case, the knee is placed in an external rotation with 10-30° knee flexion, and the valgus knee position creates a significant increase in the load applied to the ligament (Kobayashi et al., 2010). Contact injuries can generally be divided into three categories, which are: contact in sports (13.7%), collisions (9.5%) and other accidents (16%).

Table 2.2: The most common causes and mechanisms of ACL injury in athletes (adapted from Kobayashi et al., 2010)

Cause of injury (n = 1,718 athletes)		Mechanism of injury (n = 1,661 athletes)	
Competitions	49.20%	**Non-contact**	60.80%
		Contact	39.20%
Practice sessions	34.80%	**Contact categories:**	
Leisure activities	8.50%	**Contact sports**	13.70%
Other	7.50%	**Collisions**	9.50%
		Accidents	16.00%

2.1.4 ACL Risk Factors

It is essential to understand the risk factors in order to prevent non-contact ACL injuries. These risk factors have been divided into external, or extrinsic, and internal, or intrinsic, factors; a number of which have been investigated and reviewed (Alentorn-Geli et al., 2009; Dai, Herman, Liu, Garrett, & Yu, 2012; Shultz et al., 2012; Smith et al., 2012). External risk factors include the type of sport, the footwear being worn, and the surface being played on, and environmental conditions. The internal risk factors are the individual's anatomical, hormonal and genetic makeup, as well as neuromuscular and biomechanical aspects.

There are certain neuromuscular imbalances that are linked to biomechanical factors, especially ligament, quadriceps or lower limb dominance (Hewett, Myer, & Ford, 2001). Ligament dominance is where the muscles in the lower limb are not absorbing forces enough throughout an activity, which results in too much load on the knee ligaments, particularly the ACL, as it works to resist anterior translation of the tibia and knee valgus motion (Ford, Myer, & Hewett, 2003). Quadriceps dominance occurs due to an imbalance between the strength of the hamstrings and the quadriceps muscles, and this has been found to be a risk factor for ACL injury during sport (Soderman, Alfredson, Pietila, & Werner, 2001). Leg dominance is described as an imbalance between the opposite lower limbs with regard to muscle strength and patterns of muscle recruitment, with one limb having greater dynamic control (Hewett, Stroupe, Nance, & Noyes, 1996; Knapik, Bauman, Jones, Harris, & Vaughan, 1991). The reliance on one limb over the other usually places more stress on the stronger knee, while the other knee has reduced ability to absorb the forces that arise from certain movements during sport (Ford et al., 2003).

2.1.4.1 Muscle imbalance

One of the main risk factor of ACL injuries are muscular imbalances, and it is thought that the hamstrings assist in reducing the stress from the tibia sliding forward onto the femur, as well as reducing knee hyperextension, and the production of posterior shearing forces which aid knee stability (Renstrom, Arms, Stanwyck, Johnson, & Pope, 1986). Renstrom et al. (1986) found that the isometric contraction of the hamstring's places reduced strain on the ACL compared to if the knee moves passively during full range of motion. This emphasises the role of the hamstrings and muscle motor stimulation to ensure flexibility and strength (Boden et al., 2000). A hamstring to quadriceps strength ratio that is lower than 60% is likely to lead to the athlete injuring their ACL (Hewett, Lindenfeld, Riccobene, & Noyes, 1999). A muscular imbalance between the quadriceps and hamstrings may result in the knee joint being lax, and research has shown that anteroposterior tibiofemoral laxity increases the risk of suffering an ACL injury. This is because strong hamstrings can mitigate the stress placed on the ACL; however, the hamstrings also need to be flexible in order for the strain and resistance to the function of the ACL to increase too much (Myer, Ford, Paterno, Nick, & Hewett, 2008). If the hamstrings are not flexible enough, they may contribute towards the compressive tibio-femoral joint forces, thereby making the knee more at risk of an ACL injury (Boden, Sheehan, Torg, & Hewett, 2010). Therefore, the quadriceps act as antagonists to the ACL, as they can increase the stress and the strain placed on the ACL if they cannot effectively counteract the strength of an extreme hamstring contraction. Renstrom et al. (1986) discovered that the strain on the anteromedial ACL increased when isometric and isotonic contractions of the quadriceps were in 0-45 degrees of knee flexion, which correlates with the majority of non-contact ACL injuries happening with the knee slight flexed or close to hyperextension. During these positions, the quadriceps effect the muscular balance with the hamstrings and the knee joint (Boden et al., 2000). If the knee is slightly flexed and the hamstrings activated, the angle between the infrapatellar tendon and tibia can be seen to be high, and so when the knee is in full extension, with the quadriceps activated, the shearing forces on the tibia increase anteriorly with a compressive tibiofemoral joint force. This increases the strain that is placed on the ACL (Shimokochi & Shultz, 2008).

To sum up, if the quadriceps create extreme knee extension, this can cause higher stress and loading on the ACL, and this needs to be considered when an athlete is performing an activity that necessitates weight being applied to the posterior heel, or during deceleration. The fact that females' quadriceps to hamstring strength ratio is lower than for males may explain why female are more susceptible to ACL tears than men (Arendt & Dick, 1995). A muscular imbalance between the quadriceps and hamstrings is also known as "quadriceps dominance", and if an athlete is quadricep dominant, they should make sure their knee is stabilised during tasks, as the knee extensors (quadriceps) may be stimulated more than the knee flexors (hamstrings) and gluteal muscles (Hewett, 2009). Thus, to lower the risk of ACL injuries, proper coordination and neuromuscular awareness of the hamstrings and quadriceps is essential (Griffin et al., 2000). The quadriceps and hamstrings need to work in unison to absorb the ground reaction forces affecting the lower extremity effectively, as poor sharing of the forces results in an increase in the compressive forces placed on the knee, leading to possible ACL injury (Boden et al., 2010). According to (Hewett, 2000), a hamstring to quadriceps strength ratio of lower than 60% means the likelihood of ACL injury is increased. Any muscular imbalance between the two legs also puts the athlete at risk of an ACL, as if one leg is weaker than the other, the quadriceps and hamstrings become unbalanced and coordination is reduced, leading to ineffective absorption of forces and placing strain on the knee joint (Hewett, 2009); in fact, a muscle imbalance of 20% or more will increase the risk of injury (Bien, 2011).

2.1.4.2 Previous injury

A previous injury is a major risk factor with regard to suffering a new injury in the place, and this is likely to be because of rehabilitation has not been properly completed and the patient has returned to play too early (Pfeifer, Beattie, Sacko, & Hand, 2018). Steffen, Myklebust, Andersen, Holme, and Bahr (2008) discovered a link between the increase in the risk of injury and the number of previous injuries; in addition, other studies found similar outcomes with professional male football players (Arnason et al., 2004; Hägglund, Waldén, & Ekstrand, 2006; Walden, Hagglund, & Ekstrand, 2006).

Whether it occurred in the contralateral knee or reinjury of the ACL graft a past ACL injury is a major risk factor for subsequent re-injury, whether in the contralateral knee or reinjury of the ACL graft (Gianotti et al., 2009; Orchard, Seward, McGivern, & Hood, 2001; Walden et al., 2006). This is likey to be due to certain factors, in particular, suboptimal surgery; muscle weakness and imbalance; weak ligaments; changed kinematics, as well as lower proprioception after the first injury occurs (Hewett, Di Stasi, & Myer, 2013a; Murphy, Connolly, & Beynnon, 2003). It has been have discovered that the risk of an ACL injury in the future is greater for the uninjured contralateral limb, more so than for the initially injured limb (Boden et al., 2000; Hewett, Myer, & Ford, 2006; Webster & Hewett, 2019). Webster and Hewett (2019) conducted a systematic review and meta-analysis, and they discovered that previous ACL injury increased the risk of a contralateral ACL injury. Therefore, it is essential consider the outcomes and rehabilitation of both knees, as a further ACL injury would be devastating to the athlete. However, Capin, Snyder-Mackler, Risberg, and Grindem (2019) claim that (Webster & Hewett, 2019) did not perform a risk of bias assessment, and the study includes two articles at high risk of bias, therefore this influenced their conclusions (Capin et al., 2019).

Furthermore, the rate of ACL injury within a two year period following ACLR and then return to sport was six times higher in athletes that had a history of ACL injury when compared to athletes who had not suffered an injury (Paterno, Rauh, Schmitt, Ford, & Hewett, 2014a). The time of greatest risk of re-injury is 12 to 24 months post ACLR, typically when the athlete returns to competitive sport (Paterno, Rauh, Schmitt, Ford, & Hewett, 2012a; Paterno et al., 2014a). Among those with a past history of ACL injury, issues with proprioception and deficits in their range of motion are likely to change their coordination when carrying out movements that were previoulsy learnt (Paterno et al., 2012a, 2014a); for example, a prospective study by Walden et al. (2006) with a sample of elite soccer players aimed to discover if ACL reconstruction can significantly predict another injury to the ACL graft or an injury to the contralateral knee, they found that the players with a previous ACL reconstruction have more rate of new knee injuries than other players (Walden et al., 2006). Orchard et al. (2001) also found that a previous ACLR presents a major risk factor for a noncontact ACL injury occuring in the reconstructed and the contralateral knee. For example, those with a previous ACL injury which happened within the past 12 months, were 11.3 times more likely to experience an ACL injury in comparison to their uninjured counterparts (Orchard et al., 2001). In addition, they found that patients who had experienced an ACL injury prior to the previous 12 months were 4.4 times more likely to injure the graft or the contralateral ACL when compared to patients who had not suffered an injury (Orchard et al., 2001). Therefore, more care is required during late as well as early stage rehabilitation to promote a successful recovery prior to players being cleared to return to competitive sport (Walden et al., 2015). Another important issue to prevent another ACL injury is the management of ACL injury, and this will be discussed in the following section.

2.2 Management of Anterior Cruciate Ligament Injury

If a practitioner thinks that an ACL injury has occurred during the initial assessment, the patient should be referred to physiotherapy straight away so that the swelling and pain can be managed, as well as to protect muscle strength and ROM (Cimino et al., 2010). The patient usually uses crutches for a limited amount of time if they are in pain, and knee immobilisers are usually not required (Cimino et al., 2010).

Keays, Bullock-Saxton, Newcombe, and Bullock (2006) found that pre-operative physiotherapy has a positive impact on motor function in ACL- deficient patients, and they highlighted the importance of physiotherapy on a regular basis to increase muscle stabilisation before ACLR, in particular passive muscle elasticity will affect passive joint restraint stiffness. Nakamae et al. (2010) found that ACL remnants, that is, the ligament tissue that remains after injury, have a negative impact on the stability of the knee joint one year following injury, which is an important point when considering the decision to undergo ACL reconstruction within the first year after injury (Kennedy, Jackson, O'Kelly, & Moran, 2010). Proper management of an ACL injury before and after surgery is essential and should involve physiotherapy, although the approach must be adapted according to the patient's condition and level of improvement (Shaarani, Moyna, Moran, & Byrne, 2012).

2.2.1 Conservative Treatment

For the athletic population, surgical reconstruction of the ACL is widely recommended, although there is agreement in the literature that conservative management of ACL ruptures is better for patients who engage in low-demand recreational activities, and who have sustained a partial or isolated ACL rupture (Williams & Bach, 1996). In the past, non-surgical management of an ACL rupture involved recommending the patient attends rehabilitation programmes to work on the strength and endurance, as well as joint mobility and agility exercises (Friden, Zatterstrom, Lindstrand, & Moritz, 1991; Zatterstrom, Friden, Lindstrand, & Moritz, 1992).

Paterno (2017) also conducted a review and suggests that non-operative rehabilitation should be similar to post-operative rehabilitation and include strengthening exercises (mainly the quadriceps and hamstring muscles); neuromuscular or perturbation training; steady and graded progression, working towards sport-specific activities, and it should be guided by meeting strength and functional performance criteria (Paterno, 2017). This approach to rehabilitation may be useful for patients exploring delayed ACLR, because pre-operative quadriceps strength is a useful predictor of short- and long-term function post ACLR (Eitzen, Holm, & Risberg, 2009; Logerstedt, Lynch, Axe, & Snyder-Mackler, 2013).
The main difference in the approach to non-operative and post-operative rehabilitation is the RTS timeframe. Tagesson, Oberg, Good, and Kvist (2008) conducted a randomised control trial and found that patients with an ACL-deficient knee who undertook a rehabilitation program that included strengthening and neuromuscular training reached RTS strength and hop performance criteria around five months after their injury. However, the Lachman test in their study revealed significant differences between injured and non-injured leg in maximal total translation of the tibia before and after rehabilitation. On the other hand, there is no data to show that patients can meet these criteria within such a short time following ACLR, and longer recovery timeframes would be necessary due to surgical trauma. Thus, for patients undergoing non-operative rehabilitation, strength and performance criteria could be used to guide RTS decisions without using a restrictive timeframe.

van Yperen, Reijman, van Es, Bierma-Zeinstra, and Meuffels (2018) conducted a 20-year follow-up study of high-level athletes, and found no significant differences for knee OA, functional outcomes, or meniscectomies between those who underwent operative or nonoperative treatment of ACL ruptures. The nonoperative group showed decreased knee stability in comparison to the operative group, yet this did not cause reduced functional outcomes or comorbidity.

Smith, Postle, Penny, McNamara, and Mann (2014) carried out a systematic review that found little evidence to support ACLR as being better than conservative management. Many patients have decided not to have ACL reconstruction, and some of these have successfully gained good knee function through conservative management. In the recent research by Kovalak, Atay, Çetin, Atay, and Serbest (2017) they concluded that there were no differences between ACLR and only rehabilitation for treatment of patients who contribute only in recreational activities. Therefore, using conservative management of ACL injuries may be a good idea for certain patients who engage in low-demand activities.

For patients who decide not to undergo surgery after suffering an injury, and would prefer a conservative form of treatment, they should commit to activity modification. Some patients may prefer to have a less active lifestyle that does not require their knee to perform physically demanding functions, which makes conservative treatment a viable option; similarly, people who do ‘straight-line’ sports such as jogging, and cycling may benefit from such treatment rather than an ACLR. Moreover, these patients are unlikely to suffer further injuries to the knee that would reduce joint stability (Bogunovic & Matava, 2013).

Rehabilitation for patients modifying their activities should focus on addressing acute impairments; improving joint strength and ensuring the patient does not experience functional instability or any giving way as they perform their chosen leisure activities.

2.2.2 ACL Reconstruction Surgery

ACLR is usually seen as vital for individuals who play sports involving rapid jumping and changes in direction, and various procedure options have been investigated, with some studies recommending surgical options (Fink, Hoser, Hackl, Navarro, & Benedetto, 2001). Most referrals to an orthopaedic surgeon for ACL reconstruction are arranged as a matter of routine according to the patient’s preference, the recommendations of the surgeon, the person’s age, the severity of the injury, and the cost of surgery and rehabilitation with consideration of the activity levels (Gokeler et al., 2016; Macaulay, Perfetti, & Levine, 2012); thus, younger and more active patients usually request surgery rather than conservative rehabilitation. Individuals who plan to carry on playing sports that require acceleration, deceleration, pivoting, cutting, and fast changes in direction need to be carefully assessed due to the increased level of strain on the ACL as a result of these movements (Cimino et al., 2010). In addition, the chance of the joint giving way must be considered, as this can lead to additional damage to other ligaments, or meniscal damage (Cimino et al., 2010). Moreover, the success of ACLR surgery relate to two factors, timing of ACLR and the graft used which will be discussed in the next section (Beynnon & Johnson, 1996).

2.2.2.1 Timing of ACL Reconstruction

While the timing of the surgery in relation to the occurrence of the injury is important, there is no consensus on what the optimal time is to attain the most positive outcome (Evans, Shaginaw, & Bartolozzi, 2014). Smith, Davies, and Hing (2010) carried out a systematic review and discovered that no differences in the outcomes of surgery exists between early surgery (less than three weeks after the injury) and delayed surgery (more than six weeks after injury). However, Smith et al., (2010) also note several methodological limitations in the six studies they reviewed, including limited sample sizes; poor randomisation, and lack of blinding, therefore, there is doubt over the conclusions and further randomised control trials need to be carried out. Patient preferences also has a major impact on the timing of surgery, for example, athletes typically choose for the surgery to be carried out as soon as possible so that they can resume normal. On the other hand, individuals who are not concerned with intense physical ability may delay the timing of surgery because of work commitments or social issues. However, it should be borne in mind that increased delays in carrying out reconstruction surgery can have a negative impact on the result (Evans et al., 2014). Shelbourne, Wilckens, Mollabashy, and DeCarlo (1991) carried out a retrospective review the impact of surgery timing on reconstruction outcomes for 169 patients with ACL injuries. They discovered higher levels of arthrofibrosis in patients who had undergone surgery within the first week of injury in comparison to those who delayed surgery for three weeks ($p < 0.05$). Arthrofibrosis is a major complication that can arise following acute ACL reconstruction, which can lead to scar tissue and a resultant limited range of motion compared to the unaffected knee joint (Mayr, Weig, & Plitz, 2004).

The causative factors of the complications associated with early reconstructive surgery, including arthrofibrosis, were examined by Mayr et al. (2004), who found a strong correlation between detrimental pre-operative knee symptoms such as swelling and pain, and the occurrence of arthrofibrosis. ACLR patients with these symptoms four weeks post-operatively showed the same extent of arthrofibrosis as patients who had undergone earlier reconstruction (Mayr et al., 2004). In a recent study by Hagmeijer et al. (2019) they investigated the relationship between ACLR time, OA and arthroplasty at 18 year follow up, they found that the secondary meniscal injury is the most common injury among ACL patients who undergoing delayed ACLR or conservative treatment. However, there is a likely a selective bias for patients with low activity level to elect for delayed ACLR or conservative treatment. Moreover, the cut-off point of 6 months was set for delayed ACLR which is more than the literature definition for delay ACLR.

2.2.2.2 Grafts Used in ACL Reconstruction

A graft is used in ACL reconstruction surgery to replace the ruptured cruciate ligament (Herrington, Wrapson, Matthews, & Matthews, 2005), often a patellar tendon graft (bone-patellar-tendon-bone) (BPTB), or a four strand semitendinosus gracilis graft (quadrupled hamstring) (HT) (Feller, Webster, & Gavin, 2001). Beard et al., (2001) found no major differences to be reported in the outcomes of ACL reconstruction between these two grafts one-year post-surgery. Similarly, a review of thirteen studies by (Herrington et al., 2005) of these two commonly used grafts reveals that there is little evidence that one graft has better patient outcomes than the other post-ACL reconstruction surgery. However, the percentage of early tibiofemoral osteoarthritis was shown to be much higher in post-reconstruction using a patellar tendon (62%) compared to post-grafting with a hamstring tendon (33%) ($p = 0.002$) (Keays, Bullock-Saxton, Keays, Newcombe, & Bullock, 2007).

The way that graft width effects quadriceps muscle strength up to three months following ACL surgery was examined by Shelbourne and Johnson (2004), who investigated over 500 patients. They measured quadriceps muscle strength, and the width of the patellar tendon graft was measured before and after reconstruction. Shelbourne and Johnson (2004) discovered a correlation between reductions in the width of the graft and reduced quadriceps muscle strength following ACLR surgery, which highlights the importance of considering the width of the graft to maximise the outcome. The most commonly used clinical grafts and the advantages and disadvantages of each of them are shown in (Table 2.3). In addition to the timing of surgery and the type of graft used, the type of rehabilitation that patients receive after surgery has a major impact on outcomes (Saka, 2014), and so ACL reconstruction surgery is usually followed by physiotherapy to assist patients in gaining normal knee function (Saka, 2014).

In addition, in the treatment of ACL injuries, there is no gold standard, and individual surgeons usually makes the graft selection based on their own opinion (Bonasia & Amendola, 2012; Macaulay et al., 2012). Whatever graft is chosen, deficits in knee extensors can still remain (Knezevic, Mirkov, Kadija, Nedeljkovic, & Jaric, 2014b; Konishi, Aihara, Sakai, Ogawa, & Fukubayashi, 2007; Mirkov et al., 2017), as well as issues with flexor strength (Kramer, Nusca, Fowler, & Webster-Bogaert, 1993; Tengman, Brax Olofsson, Stensdotter, Nilsson, & Hager, 2014), and this may continue in the long term- even 25 years after surgery (Tengman et al., 2014). Another factor along with the timing of surgery and the type of grafts that affects the outcomes after ACLR links to the post-operative physiotherapy rehabilitation, which is detailed in the following section (Saka, 2014).

Table 2.3: Advantages and disadvantages of the different types of grafts used in ACL reconstruction

Graft	Advantages	Disadvantages	References
Bone-patellar-tendon-bone (BPTB)	Bone to bone biological healing	Anterior knee pain, large incision required	(Markolf et al., 1996)
Quadrupled hamstring	Small incision required, less pain in the anterior knee	Hamstring weakness, soft-tissue healing required, bone tunnel widening	(Hamner, Brown, Steiner, Hecker, & Hayes, 1999)
Quadriceps tendon	Bone to bone healing, thick, can be used as two bundles	Anterior knee pain, large incision, patella fracture bone plug is taken, soft tissue healing required	(Harris, Smith, Lamoreaux, & Purnell, 1997; Staubli, Schatzmann, Brunner, Rincon, & Nolte, 1999)
Patellar tendon allograft	Bone to bone healing	Incorporation takes a longer time	(Chan et al., 2010)
Achilles allograft	No particular advantage	Longer time for incorporation, soft-tissue healing required	(Lewis & Shaw, 1997; Louis-Ugbo, Leeson, & Hutton, 2004)
Tibialis anterior allograft	No particular advantage	Longer time for incorporation, soft-tissue healing required	(Chan et al., 2010)

2.2.3 Post-operative Physiotherapy Rehabilitation

Physiotherapy following ACLR can involve a number of rehabilitation programmes according to the healthcare provider and the country where the patient resides (Trees, Howe, Dixon, & White, 2011). The aim of rehabilitation, as well as a return to normal activities, is to control symptoms such as pain and swelling; reach normal ROM; prevent muscle atrophy, and restore a normal gait and proprioception (Saka, 2014). The most popular approach used by practitioners involves a process of assessing the best and most suitable type of programme for the patient, based on their experience and the condition of the patient. This creates issues, however, due to the lack of consensus over matters such as the optimal time to begin rehabilitation; the best types of modalities to employ; the necessary duration of rehabilitation, and the forms of exercise that should be promoted.

There have been improvements recently in the consistency of ACLR procedures, therefore, (Myer, Paterno, Ford, Quatman, & Hewett, 2006) claims that differences in rehabilitation have a more significant impact on outcomes than the actual ACLR surgery itself, which highlights the need for rehabilitation to be further assessed. Rehabilitation has been going through some major changes recently due to increased recognition of its importance (Myer et al., 2006), empirically defined predictors of recovery following ACLR are increasingly being focused on (Adams, Logerstedt, Hunter-Giordano, Axe, & Snyder-Mackler, 2012). Even so, further steps are necessary in order to fully understand the relationship between rehabilitation and ACLR outcomes.

According to Edwards et al. (2018), and based on their research, rehabilitation is the strongest predictor of RTS 10 to 14 months post-surgery, with patients who have undergone full rehabilitation eight times more likely to RTS in comparison to those who have not, yet much of the previous research has only addressed strength and performance symmetry. Moreover, a number of variables, such as psychological factors, for example fear of reinjury and confidence, have been shown to affect physical performance and RTS (Ardern, Osterberg, et al., 2014; Ardern et al., 2013; Christino, Fantry, & Vopat, 2015; Lentz et al., 2015; Sonesson, Kvist, Ardern, Osterberg, & Silbernagel, 2017).

Andrade, Pereira, van Cingel, Staal, and Espregueira-Mendes (2019) carried out a systematic review and claim that immediate knee mobilisation and strength/neuromuscular training should be used during ACLR postoperative rehabilitation, such as early full weightbearing exercises, open and closed kinetic chain exercises, cryotherapy and neuromuscular electrostimulation, based on the patient’s individual circumstances; however, most guidelines recommend not performing continuous passive motion or functional bracing.

Rehabilitation can support the successful return to preinjury sporting activities, and clinicians usually follow specific progression rehabilitation criteria involving a series of steps, and rely on clinical and impairment-based criteria before giving patients the go-ahead to RTS (Burgi et al., 2019; Grindem et al., 2016; Kyritsis et al., 2016; Rambaud et al., 2018). However, it has been shown in a prospective study of 158 professional male football players, that those players who failed to meet the RTS criteria in place, were four times more likely to suffer a second ACLR when compared to those athletes who met all of the criteria (Kyritsis et al., 2016): 12 out of 26 players with a second ACLR met the RTS criteria, while 28 out of 132 players with no second ACL injury did not pass the RTS criteria.

2.2.3.1 Targeting Strength and Functional Performance

The main aim of rehabilitation for patients wanting to RTS is the restoration to pre-injury knee function, along with reducing the risk of re-injury through meeting key milestones for strength and functional performance. Thus, as well as the minimal RTS timeframe, strength and performance test criteria should be used to decide when a patient can RTS, and rehabilitation must involve strength and performance deficits effectively by providing an appropriate amount and intensity of training according to personal requirements in order to maximise performance. van Melick et al. (2016) have set out guidance on postoperative exercises and timeframes for progression, including key elements such as quadriceps strengthening and functional performance testing. In addition, adding structured agility and jump-landing to resistance training and graded activity, and improving strength and hop test performance will help to fully ensure the individual is prepared to RTS (Ebert et al., 2018), as this will address the biomechanical deficits linked to ACL injury (Hewett et al., 2005; Pappas, Shiyko, Ford, Myer, & Hewett, 2016). However, the route for rehabilitation following ACLR is still unclear, and the protocols available vary in intensity and duration, whether aimed at improving function, quality of life or RTS participation (Beynnon et al., 2011). Thus, rehabilitation is in the main informed by guidelines and the particular preferences of the treatment provider (van Melick et al., 2016).

Research into the relationship between risk of injury and a chronic training load may provide useful guidance on the safe progression of exercises during rehabilitation (Blanch & Gabbett, 2016), especially as weekly training loads that are much greater than the patient's average training load over the preceding four weeks will increase the risk of injury (Blanch & Gabbett, 2016). Therefore, monitoring training loads should be useful for rehabilitation, especially for patients as it will increase their enthusiasm for training if they are able to meet milestones along the way. The rehabilitation programme should avoid rapid increases in training load, and it should be well planned and use a pre-agreed RTS timeframe. For young people, educating patients on the relationship between injury risk and training load should lead to greater independence in rehabilitation and may reduce the risk of patients progressing through the rehabilitation process too quickly.

To summarise, postoperative rehabilitation programs should target strength and functional performance, and it is recommended to follow an RTS timeframe agreed on with the patient, as long as RTS is no earlier than nine months and rapid increases in training load are avoided. If the patient decides to do activities involving a lower risk of injury (e.g. running, cycling, swimming), the rehabilitation process will be more straightforward and can simply involve educating the person on how to increase their training load safely. For example, if a patient was previously playing a pivoting or cutting sport, for example as football, and undergoes ACLR, if they then decide to do long-distance running rather than returning to football, there will be less emphasis on pivoting, cutting, jumping and other activities required for football, and so minimal intervention will be required, although this could include educating them about how to sensibly increase their running mileage (Zadro & Pappas, 2018).

2.2.3.2 Supervised Rehabilitation

Physiotherapists are in the ideal position to assist patients in optimising their outcomes after an ACL injury, because they can advise and arrange effective rehabilitation programs and provide the knowledge required. Even so, it is essential that physiotherapists consider the patient's RTS goals and their preferred type of rehabilitation, as well as the logistics involved, such as costs and access to physiotherapy.

Ebert et al. (2018) recently conducted an observational study which showed a positive correlation between the amount of supervised rehabilitation patients received following ACLR and performance measures, and they claim that many patients do not receive adequate supervised rehabilitation (Ebert et al., 2018). Grindem, Arundale, and Ardern (2018) also claim that rehabilitation is lacking based on the aforementioned paper, although it should be noted that the design of the above-mentioned study did not appropriately evaluate effectiveness and several factors may have impacted on its findings (Ebert et al., 2018); for example, patients who experience positive outcomes early on in their rehabilitation could be more motivated to continue, whereas patients initially experiencing poor outcomes could have dropped out if they felt that the cost of supervised rehabilitation outweighed the benefits.

Randomised control trials have been examined to discover whether supervised rehabilitation is better than home-based programs, and it has been found that supervised rehabilitation following ACLR is rarely better than home-based rehabilitation (Beard & Dodd, 1998; Grant & Mohtadi, 2010). For example, Hohmann, Tetsworth, and Bryant (2011) found that a physiotherapist led exercise program that involved strengthening, neuromuscular training, aerobic exercise and a graded RTS during 20 sessions over a nine month period provided similar outcomes for function, strength, hop test performance and sports participation to an identical home-based program guided simply by an exercise sheet (Hohmann et al., 2011). It was also found that 17 sessions of physiotherapist-led exercise had no advantage over four sessions with regard to improving quality of life, range of motion, and strength and knee laxity, at four years follow up (Grant & Mohtadi, 2010; Grant, Mohtadi, Maitland, & Zernicke, 2005).

Even so, if a patient wants more supervision and guidance, that should be their choice. However, patients should be told that home exercise is just as good as supervised rehabilitation, as this will support shared decision making and may even reduce the risk of over-treatment.

2.2.3.3 Timing of RTS

There are benefits to delaying RTS and rehabilitation programs no longer tend to aim for an early RTS, whereas in the past RTS has sometimes been as early as six months (van Grinsven, van Cingel, Holla, & van Loon, 2010), because for every month that RTS is delayed (up to 9 months), the risk of re-injury halves (Grindem et al., 2016); in addition, patients are given more time to pass the RTS criteria, which also reduces the risk of re-injury. In fact, the risk of re-injury increases by 400% if the patient fails knee strength and hop performance tests, as well as not completing a sports-specific rehabilitation program (Kyritsis et al., 2016). It is essential to consider this point when dealing with patients wishing to return to sports involving pivoting and cutting, as the risk of re-injury is four times as high (Grindem et al., 2016).

Time has a strong correlation with passing RTS criteria after ACLR (Grindem et al., 2016), and some patient outcomes require longer than nine months to be achieved (Nagelli & Hewett, 2017). In a prospective study, Welling et al. (2018) discovered that 50% patients achieved LSI scores for knee extension strength of > 90% at nine months following ACLR. Furthermore, a systematic review of 88 studies (n = 4927) states a major difference in the proportion of patients passing RTS criteria for quadriceps and hamstring strength at between six months and 12 months, as most studies have reported that the average LSI scores for quadriceps strength are < 80% at six months (Abrams et al., 2014). Considering that patients do not usually pass RTS criteria before nine months post ACLR is essential for clinicians who do not have equipment available to accurately measure strength and functional performance (Zadro & Pappas, 2018). Moreover, these results suggest that a minimum RTS timeframe of at least nine months should be introduced for patients returning to high-risk sports.

RTS should be delayed for up to two years for those involved in high-risk sports, based on the ongoing biological restoration (bone mineral density, proprioception and graft maturation); the time required for recovery to pre-injury strength and functional performance (Nagelli & Hewett, 2017). However, this is likely to cause a problem with regard to the patient's athletic career, which is therefore a deciding factor when considering the best postoperative rehabilitation approach to take, and its association with success after ACLR. Thus, defining success after ACLR is essential and will now be discovered.

2.3 Defining Success after ACLR

While there have been significant developments and the validation of a range of outcome measures regarding the ACL injured population that include the three main essential issues of structure and function (the body), activity and participation, as set out by the World Health Organisation international classification of functioning disability and health (WHO ICF), Lynch et al. (2015b) claim that there is no gold standard definition for success following ACLR surgery. The literature has defined success mainly according to three criteria: symptoms (Dunn & Spindler, 2010); functional stability (Barenius, Forssblad, Engstrom, & Eriksson, 2013), and return to pre-injury participation (Czuppon, Racette, Klein, & Harris-Hayes, 2014; Dunn & Spindler, 2010; Fitzgerald, Lephart, Hwang, & Wainner, 2001). As well as the short term outcomes, longer term outcomes are now increasingly being considered, such as preventing further injury to the meniscus and cartilage, and limiting early onset osteoarthritis (Barenius et al., 2013; Culvenor, Cook, Collins, & Crossley, 2013). Furthermore, a statement has been issued by the Delaware-Oslo research group as a way towards resolving this issue (Lynch et al., 2015b). The criteria attained from a literature review, along with expert opinion, have been piloted with a group of 40 specialists, followed by the conducting of an international survey with 1779 professionals from every continent and different relevant professions; however, the majority of surveys returned from North America and Europe are from physiotherapists, which has implications for interpretation of the data. The respondents were asked to consider whether the points were of primary or secondary importance, rather than "not important" or "do not use", to enable a consensus to be reached. Six of the criteria led to a consensus: the absence of giving way; quadriceps and hamstring strength LSI >90%; no more than mild knee effusion; return to sport, and patient reported outcome measures (PROM). However, no consensus was reached on which PROM is best. This suggests that the inclusion of PROMs by clinicians requires more work in order for validated tools to be introduced for measuring success following ACLR surgery. There was no consensus on functional testing either, which had a summed importance of 75%, which reveals that most respondents view activity measures as being important.

A number of studies (Heijne et al., 2008; Kocher et al., 2002; Mancuso et al., 2001; Swirtun, Eriksson, & Renstrom, 2006) have examined issues around ACLR from the patient's perspective. For example, Heijne et al. (2008) carried out a small scale but good quality qualitative study that utilised semi-structured interviews. They found that patients saw ACLR as an opportunity to return to being "a completely restored functional human being", and they viewed ACLR as the only option if they wanted to return to previous levels of activity. Similarly, Mancuso et al. (2001) carried out research with a larger sample of ACLR patients, and these reported that they expected the knee to "be back to the way it was" and be able to return to pre-injury sports. Swirtun et al. (2006) carried out research with 72 participants who had suffered an ACL injury. They assessed function using the KOOS, and participation using Tegner; importantly, they questioned the participants about the choice to undergo surgery, whether early on, or later, after a period of rehabilitation. The most frequent reason given for early surgery (9 from 20) was the belief that pre-injury activity could not be returned to without surgery. For the late reconstruction group, recurrent instability (7 of 16) and the inability to do pre-injury activities (5 of 16) were the most common reasons given for having the surgery. Combining this data strongly suggests that patients view success as being normality and preinjury participation.

The above studies reveal that clinicians and patients both view restoration to pre-injury levels, and healthy knee functioning and participation as defining short term success following ACLR. This also emphasises the importance of healthy pre-injury status being clearly defined to provide an effective primary comparator, as well as including all of the issues affected. It is possible to align these points with the WHO ICF model for health, which is discussed below.

2.3.1 Success in Relation to the WHO ICF

A conceptual framework has been laid out by the WHO ICF (2001) that can be used to define and measure health. This framework led to a major shift in the way health is conceptualised. It takes a traditional medical model that focuses on the causes of ill health and combines it with a social model that takes into account the effect of ill health and the ability to function in society, which led to the production of a biopsychosocial holistic approach to health. The WHO ICF model looks at human functioning according to the following three levels: the body, both structure and function; the person and their level of activity, and society with regard to participation in it, which therefore addresses personal and environmental factors. The body structure means the anatomical parts of the body, whereas function refers to the physiological functioning of the body's systems, and any difficulties are referred to as impairments. The definition of activity is defined as the individual's ability to perform a task, and any difficulties are labelled limitations. Participation refers to the ability of the individual to engage in a life situation (WHO ICF, 2001), and any difficulties are labelled restrictions. To calculate the impact of the environment, capacity and performance qualifiers are used; capacity considers the person's capabilities according to a standardised environment, and performance is according to the person's own environment.

A number of studies have used the ICF to assess the outcomes after an ACL injury and after ACLR (Button, Roos, & van Deursen, 2014; Irrgang, 2008; Zelle, Herzka, Harner, & Irrgang, 2005). However, there is no consensus on in the literature concerning exactly which ICF domain is being measured when using common outcome instruments and this is further complicated by some studies addressing several domains at the same time. To address this issues, Irrgang and Anderson (2002) introduced a scheme for differentiating between domains. They describe impairments as pain, swelling, instability, muscle weakness and fatigue; activity limitations as problems that happen during activities such as walking, running, jumping, landing and cutting, and participation restrictions as occurring during in work, sports or recreational activities (Irrgang and Anderson (2002). A way of utilising these descriptors with an ACL injured individual is set out in (Table 2.4), which makes it possible to select outcomes from each domain of the ICF in order to come up with a definition of success. Another important issue is the use of appropriate comparators for healthy and pre-injury status, and this will be discussed in the following section.

Table 2.4: Domains of the WHO ICF, items and measurement tools for the ACLD / ACLR population

Domain		Measurement tool
Structure	Instability Swelling Range of motion	KT 2000 Sweep test Goniometer
Function	Muscle weakness Symptoms such as pain, swelling, instability	Isokinetic, Isometrics Patient reported outcome measures
Activity	Walking Hopping Squatting Running Jumping	Performance measures Strategy measures Biomechanics
Participation	Work Recreational activity Sport	Patient reported outcome measures Fear of re-injury Psychological readiness

2.3.2 Appropriate Comparators when Assessing Success after ACLR

Success following ACLR has been defined as a return to pre-injury or healthy levels of function and activity (Heijne et al., 2008; Lynch et al., 2015b). Therefore, outcomes should be assessed according to this standard, and this is addressed in the majority of studies, as differences between cohorts, pre and post analysis of longitudinal data, and comparing outcomes according to specific categories are usually described. These methods are discussed in more detail below, followed by looking at their clinical significance and healthy comparators that can be utilised to assess outcomes according to the above definition of success.

There are some discrepancies between statistical significance and clinical significance in the literature with regard to activity measures and functional performance tests, which is mainly because the contralateral limb is usually used as the comparator, mostly through hop tests, muscle strength and outcomes stated according to a limb symmetry index (LSI). In addition, the categories applied to performance indices vary. Although symmetrical performance is important, it does not provide a full picture of normal performance.

The LSI (limb symmetry index) is used to assess the performance of the injured limb compared the non-injured limb as a percentage score according to the performance. This is because it is assumed that symmetry will help to prevent overuse of the affected limb and therefor reduce the risk of injury when returning to activities that present a risk of injury (Thomeé et al., 2011). The validity of LSI is based on the following two assumptions: symmetry as representing the individual's pre-injury functional state, and secondly that the non-injured limb is representative of healthy normality and has not been affected by the injury (Bent, Wright, Rushton, & Batt, 2009; English, Brannock, Chik, Eastwood, & Uhl, 2006; Fitzgerald et al., 2001; Herrington, 2013). However, the literature on this issue is split between those who recommend using the LSI (Haillotte, Hardy, Granger, Noailles, & Khiami, 2017; Logerstedt et al., 2012; Logerstedt et al., 2013; Petschnig, Baron, & Albrecht, 1998) and those warning against its use (Ageberg, 2002; Chmielewski et al., 2011; Fitzgerald et al., 2001; Gokeler et al., 2017; Thomeé et al., 2012; Welling et al., 2018; Wellsandt, Failla, & Snyder-Mackler, 2017) and preferring comparisons to healthy control values (Ageberg, Zatterstrom, Friden, & Moritz, 2001; Ageberg, Zatterstrom, & Moritz, 1998; English et al., 2006; Fitzgerald et al., 2001; Tegner, Lysholm, Lysholm, & Gillquist, 1986; Zwolski, Schmitt, Thomas, Hewett, & Paterno, 2016) or using absolute measures to provide context to the symmetry values (Gokeler et al., 2017; Reid et al., 2007).

Logerstedt et al., (2013) supports the use of the LSI, as they claim that the non-injured limb represents the healthy state of the individual, although out of the papers reviewed, it is only Petschnig et al. (1998) and O'Donnell, Thomas, and Marks (2006) that provide data that seems to confirm this in comparison to using a healthy group as the comparator. However, there are doubts around the way that matching was carried out in both of these studies, as the control groups were sedentary compared the participants who had suffered an ACL injury, and low activity levels would have lowered the standard of performance for the healthy leg. Therefore, van der Harst, Gokeler, and Hof (2007) claim that this evidence does not provide adequate support for using the LSI and the uninjured leg as the comparison. Moreover, the assumption is made that the uninjured limb of Anterior Cruciate Ligament Deficit (ACLD) subjects is unaffected, which may not necessarily be the case.

A number of studies have revealed that impairments to the function of the contralateral limb often occur following an ACL injury (Nagai, Schilaty, Laskowski, & Hewett, 2019; Wellsandt et al., 2017; Wren et al., 2018; Xergia et al., 2013; Zwolski et al., 2016), in particular, a weakening of muscle strength (Chung et al., 2015; Hiemstra, Webber, MacDonald, & Kriellaars, 2007; Kuenze, Hertel, Weltman, et al., 2015; Larsen, Farup, Lind, & Dalgas, 2015; Lisee, Lepley, Birchmeier, O’Hagan, & Kuenze, 2019; Neeter et al., 2006; Nyberg, Granhed, Peterson, Piros, & Svantesson, 2006; Thomeé et al., 2012; Zwolski et al., 2016); reduced muscle recruitment (Chmielewski, Stackhouse, Axe, & Snyder-Mackler, 2004; Hart, Ko, Konold, & Pietrosimone, 2010; Pfeifer & Banzer, 1999; Urbach, Nebelung, Becker, & Awiszus, 2001); proprioceptive awareness (Friden, Roberts, Ageberg, Walden, & Zatterstrom, 2001; Roberts, Friden, Stomberg, Lindstrand, & Moritz, 2000; Solomonow & Krogsgaard, 2001; Trulsson, 2018); weakened reflex responses (Konishi et al., 2007; Konishi, Suzuki, Hirose, & Fukubayashi, 2003); incorrect balance reactions (Friden, Zatterstrom, Lindstrand, & Moritz, 1989; Zatterstrom et al., 1994), and problems with the central processing of sensorimotor function (Ageberg, 2002; Ageberg, Björkman, Rosén, Lundborg, & Roos, 2009; Courtney, Rine, & Kroll, 2005; Kapreli et al., 2009; Valeriani et al., 1996) in the contralateral limb of ACL injured subjects. Therefore reduced performance as well as altered strategies are likely in the uninjured limb (Ingersoll, Grindstaff, Pietrosimone, & Hart, 2008).

In the event that the performance of the non-injured limb has been affected, this would create similarities, and the LSI would overestimate performance (Nagai et al., 2019; Thomeé et al., 2012; Wellsandt et al., 2017), and those assumed to have acceptable symmetry could have reduced performance that is not properly acknowledged. However, the number of studies that have looked at the performance of the non-injured limb in relation to healthy values is limited, although some data suggests that performance is in fact usually affected. For example, Button, van Deursen, and Price (2005) found reduced hop performance in the non-injured limb in the early stages after ACL injury. In addition, although no other studies have made direct comparisons between the non-injured limb of ACLR and healthy subjects, some data is available that supports this notion. Baltaci et al. (2012) discovered no statistically significant differences (P=0.05) between healthy (92%) and ACLR (95%) subjects using the LSI, and they conclude that function is similar to that of healthy subjects. However, an examination of the raw data reveals that the injured leg for the ACLD had a single-hop for distance mean distance of 133cm (+/-25), and for the non-injured leg had a mean distance of 151cm +/- 25; whereas the healthy sample, which was matched well, had a hop distance of 177 +/-12. This shows that the mean deficit for hop distance is around 25% and the mean for the ACLR group below 2 standard deviation (SD) of the healthy mean, which is a meaningful deficit and has clinical significance. The small sample size (n= 15) may have added to a lack of power for detecting differences, but using distance or symmetry appears to be a significant factor.

Some longitudinal studies have revealed improved performance in both limbs following ACLR (Keays et al., 2000; Logerstedt et al., 2013; Reid et al., 2007) and when ACLR is compared to ACLD (Gustavsson et al., 2006), which suggests that there is often a bilateral deficit at baseline; moreover, this bilateral improvement suggests that bilateral performance gains may not be noted if LSI is the only outcome measure used. Reid et al. (2007) examined a rehabilitation intervention and found significant changes in hop distance not apparent in the LSI values because of similar improvements in the performance of the contralateral limb. Keays et al. (2000) noted an increase of 5% in hop distance for the reconstructed limb, yet LSI values stayed the same (83%) because of the contralateral limb displaying a statistically significant increase of 6% in hop distance. Logerstedt et al. (2013) found similar findings in their study on the LSI, and it is evident that using the LSI changes is likely to lead to an underestimation of recovery outcomes.

Other researchers recommend using the LSI and claim that a standard of 90% indicates recovery (Thomeé et al., 2011). Barber et al. (1990) were the first to suggest a cut off for acceptable performance based on 90% of healthy participants scoring an LSI of > 85%. A range of evidence suggests that healthy subjects are much more symmetrical than previously thought, and they have much higher LSI values for single-hop for distance; the following figures have been reported: 94% (Ageberg et al., 1998), 95% by (Petschnig et al., 1998), and 95.5% (Gokeler et al., 2010), which has led to calls for LSI standards being increased for competitive athletes. Thomeé et al. (2012) have shown the importance of standardising levels for LSI, with their data for success ranging from 80% to 100%, which highlights how an increase in the LSI cut off level has a major impact on the number of individuals classed as being recovered. Thomeé et al. (2011) have also called for the success rates for each level of limb symmetry to be published to further illustrate this point. However, questions remain around what is a safe or appropriate LSI for defining recovery or recommending rehabilitation interventions.

The LSI clearly requires further research and testing on its use as an outcome for rehabilitation (English et al., 2006; Thomeé et al., 2012; Wellsandt et al., 2017). The European Board of Sports Rehabilitation (EBSR) has recommends that the LSI should be presented along with absolute values, including at the group level, as well as reporting the proportion of individuals that achieve each standard (Thomeé et al., 2011). Logerstedt et al. (2013) claim that symmetry is an important goal for post-operative rehabilitation, and this remains valid, but it should also be considered alongside absolute performance. In order to provide accurate context to LSI measures, and to make further recommendations about its validity, a greater understanding of the performance of the non-injured limb in relation to healthy subjects is required. Comparisons with healthy subjects/limbs is essential to measuring success among the ACL injured population, and the use of hop testing was examined early on by Tegner et al. (1986) who looked at clinical significance criteria; moreover, a similar form of analysis could be useful for assessing the usefulness of the LSI. The next section will move on to the ways in which success following ACLR can be predicted.

2.3.3 Predicting Success Following ACLR

Predicting outcomes is a crucial point when developing orthopaedic solutions and interventions. Spindler and Dunn (2010) suggest carrying out longitudinal research in order to best identify the outcomes that are most important to patients, prior to developing and testing practical solutions, and they differentiate between modifiable and non-modifiable predictors. They describe non-modifiable predictors as affecting choices about intervention pathways, such as conservative or surgical treatment for ACL injury, and modifiable predictors as being useful in the development of new types of intervention, such as new rehabilitation practices. Therefore, identifying predictors that can be modified should help to inform rehabilitation programmes and inform practice, and developing new interventions may improve outcomes (Logerstedt et al., 2012; Thomee et al., 2008). Adams et al. (2012) recommend that rehabilitation follows well established specific criteria to ensure progression based on functional testing. However specific performance measures used as rehabilitation signifiers have not been well researched with regard to their appropriateness or the ability to modify them. de Valk et al. (2013) carried out a systematic review using meta-analysis in order to summarise current awareness around predictors of outcomes following ACLR. They found evidence that operating less than three months after an injury on younger (<30) males with a lower BMI and high pre-injury activity levels, leads to the optimum result. Furthermore, meniscal injury, a high BMI, and reduced ROM and quadriceps strength, were found to be predictors of poor outcomes (Hamrin Senorski, Svantesson, Beischer, et al., 2018).

2.3.4 Return to Sport after ACLR

Most patients who have suffered an ACL injury or gone through ACLR want to go back to their normal activities and RTS as quickly as possible (Bauer et al., 2014). It is possible to achieve a satisfactory level of activity without ACLR, although activity levels are likely to decrease, as well as there being physical and psychological factors involved (Osterberg, Kvist, & Dahlgren, 2013). In fact, the rate of return to pre-injury activity levels is much the same whether surgery is carried out or not (Frobell et al., 2015), and this can include return to elite professional football is possible after an ACL injury is treated non-surgically, although it is not common (Weiler, Monte-Colombo, Mitchell, & Haddad, 2015).

An important clinical outcome after ACLR is RTS. Ardern, Taylor, et al. (2014) carried out a meta-analysis, which showed that 81% of patients returned to some sort of sport, and 65% regained their preinjury level in a 40 month follow-up after unilateral ACLR, yet only 55% returned to competitive sport even though they had good physical function (Ardern, Taylor, et al., 2014). Long term participation in sport following an ACLR has not been thoroughly investigated, although Frobell et al. (2015) found that five years later, one out of five subjects was still active, but regardless of whether they had undergone ACLR or not. Roos, Ornell, Gardsell, Lohmander, and Lindstrand (1995) carried out a study with 1012 patients in Sweden and found that only 30% of football players who had suffered an ACL injury were still playing three years after the injury compared to 80% of a control population that had not suffered this injury. In addition, Walden, Hagglund, Magnusson, and Ekstrand (2016) found that 86% of elite male football players were still playing football three years after an ACLR, and 65% were at the same level as prior to the injury.

Ardern, Taylor, et al. (2014) found that young athletes under twenty-five years old are 1.5 times more likely to RTS following ACLR, and elite athletes are >2 times more likely to RTS. For female athletes, the percentage that RTS is lower than for males (Tan, Lau, Khin, & Lingaraj, 2016), and female athletes also RTS later than males following ACLR (Ardern et al., 2011b). Following RTS, Ardern et al. (2012a) report that two to seven years after ACLR, females were more concerned than males about environmental conditions and the risk of re-injury. In addition, Walden, Hagglund, Magnusson, and Ekstrand (2011) examined two cohorts of female and male elite ACLR football players and found that 86% and 100% respectively returned to football training within 12 months after surgery. Moreover, younger age and being male are factors associated with RTS among football players after ACLR (Brophy et al., 2012; Sandon, Werner, & Forssblad, 2015). Factors linked to RTS include greater quadriceps strength; less pain and less effusion, although the evidence supporting this is weak (Czuppon et al., 2014).

Creighton, Shrier, Shultz, Meeuwisse, and Matheson (2010) explained that the recommendations that should be followed are that strength and ROM need to be close to pre-injury level or the same as the uninjured side, with no instability, tenderness, inflammation or effusion when RTS. In addition, a gradual build up to training is essential, along with monitoring the quality of movement prior to RTS (Myer, Paterno, Ford, & Hewett, 2008). In order to assess whether a patient is ready to RTS, functional performance tests are usual carried out, along with an evaluation of PROMs. Testing usually involves functional performance, including muscle strength; knee stability; limb symmetry; posture control; agility and technique, and PROMs (Ellman et al., 2015; Myer et al., 2006). The decision to RTS should involve the coach, the physiotherapist, the surgeon and the patient.

Functional performance has formed the focus of previous research into testing and evaluating patients who have undergone an ACLR and whether they should RTS. However, recent research has also looked at psychological factors, such as readiness to return to RTS; fear of new injury, and confidence in the knee (Langford et al., 2009; Tjong, Murnaghan, Nyhof-Young, & Ogilvie-Harris, 2014). Carrying out an assessment of the athlete's psychological profile has been shown to be useful for identifying individuals more likely to return to preinjury activity levels (Gobbi & Francisco, 2006), as low fear of re-injury, a positive outlook, along with self-motivation and confidence, suggest readiness to RTS. The most important factors is fear of re-injury (Ardern et al., 2012a)., and it is notable that subjects that have undergone ACLR within three months after the injury occurred showed a lower fear of re-injury than those who were operated on later.

Considering motivation to RTS is important (Tjong et al., 2014), as individuals with high levels of motivation to RTS before ACLR (Gobbi & Francisco, 2006) and one year post ACLR (Ardern, Taylor, Feller, Whitehead, & Webster, 2015) have been found to be more likely to successfully RTS. At around 35 months after ACLR, psychological readiness to RTS is the main factor associated with returning to preinjury levels of activity (Ardern, Osterberg, et al., 2014).

Therefore, it is apparent that personality influences RTS following ACLR; however, this has not been properly studied. Personality traits such as cautiousness, pessimism, and lack of self-confidence and self-motivation have been linked to failing to RTS (Everhart et al., 2015). The next section will discuss the main outcome measures after ACLR.

2.4 Outcome Measures after ACL Injury

2.4.1 Self-reported Outcome Measures

Patients usually set out to gain treatment due to symptoms and functional disabilities, and so subjective patient-oriented outcomes should be used when assessing patients' attitudes towards surgery, physical therapy, outcomes and treatment (Frobell et al., 2013). There has been a paradigm shift, resulting in greater expectations that healthcare providers and researchers will focus outcome assessments more on patient derived subjective assessments of symptoms and function (Hambly & Griva, 2010).

Clearly, the patient is a key stakeholder within healthcare, and patient satisfaction is now seen to have greater clinical and economic implications (Hambly & Griva, 2010). Self-reported knee function measures have been designed to assess patient derived symptoms and function effectively (Frobell et al., 2013), and the selection of these measures is based on the needs of the target population and their appropriateness. Overall, selected patient-reported measures are chosen that best reflect the patient's most important concerns (Hambly & Griva, 2010).

Copay, Subach, Glassman, Polly, and Schuler (2007) noted three main reasons why self-reported outcomes are utilised in the research, which are: Firstly, the patient is the source of the information and person judging the intervention, and pain or fear, for example, do not have adequate or objective forms of measurement. Secondly, there is a lack of correlation between objective and subjective data. Thirdly, there is no third-party evidence involved. The following sections set out the most relevant subjective assessment methods that have been utilised to assess ACL injury (Collins, Misra, Felson, Crossley, & Roos, 2011).

2.4.1.1 International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form

The International Knee Documentation Committee (IKDC) subjective score form is made up of 18 questions scored in the range of 1 to 100, and a score of 100 is optimal (Lentz et al., 2012). The IKDC is aimed at patients with anterior knee pain; knee ligament problems; meniscal, chondral injury or pathology, and as long as normative data can be obtained. The IKDC has three domains, which are symptoms, sports and daily activities, although the third domain is not included in the overall score. It takes around five minutes to complete the IKDC form and five minutes to administer it. Moreover, no training is required to use the score form (Collins et al., 2011; Irrgang, 2012).

The International Knee Documentation Committee developed the score form in 1987 to create a knee-specific and standardised method of measuring improvement or deterioration in symptoms, function and the sporting activities carried out by orthopaedic patients (Irrgang et al., 2001). The American Orthopaedic Society for Sports Medicine (AOSSM) board revised the form in 1997 having evaluated it for reliability and validity. It was found that the IKDC test-retest reliability ranged from 0.92 - 0.95, making the IKDC a reliable and valid knee-specific measure for mixed sex groups suffering from a number of knee conditions. In addition, further minor revisions have been made since them, and the IKDC (2000) subjective knee evaluation form is the current version in use (Collins et al., 2011) (Appendix 8.1).

An AOSSM task force has summarised the outcome measures for sports-related knee injuries, which includes the IKDC subjective knee evaluation score form (Irrgang, 2012), as they discovered that the IKDC is related to other similar measures, as well as to measures of general physical and emotional function. Collins et al. (2011) came to the same conclusion in their review, and they claim that the construct validity of the IKDC has been proven through strong correlations with other subjective score forms, for example the Rand-36; the Cincinnati Knee Rating System; the visual analogue for pain; the Oxford 12 item questionnaire; the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and the Lysholm score. Even so, Collins et al. (2011) point out that there is a lack of item contribution by patients, and the minor revisions that have been made means that its content validity should not be assumed. The IKDC's internal consistency is reported to be $\alpha = 0.77 – 0.97$, with interclass correlation coefficient test-retest reliability ranging from 0.87 – 0.98 (Irrgang, 2012). Effect sizes over time due to the response rate of the inventory range from 0.76 – 2.11 (Irrgang, 2012). The larger effect sizes are mainly seen from six months post-surgery in ACL populations (Collins et al., 2011), and minimum detectable changes have been shown to range from 6.7 to 20.5, with a small important difference covering a wide range from 3.19 to 16.7 (Collins et al., 2011; Irrgang, 2012). However, in (Collins et al., 2011) psychometric testing is lacking for patients with knee osteoarthritis as well as responsiveness following non- surgical management.

Overall, the IKDC focuses on issues that are important to the patient, and it has enough internal consistency for use with mixed groups suffering from a range of knee pathologies. Importantly, little administrative time is needed to utilise it. Despite these advantages, its validity cannot be assumed, and the fairly long recall period could be a problem for some patients. In addition, the IKDC may not be reliable for assessing individual patients (Collins et al., 2011). Moreover, differ concerning both gender and age (Anderson, Irrgang, Kocher, Mann, & Harrast, 2006; Frobell, Svensson, Gothrick, & Roos, 2008; Hamrin Senorski, Svantesson, Baldari, et al., 2018), as self-reported outcome measures are affected by the age and gender of the subject (Haillotte et al., 2017; Thomeé, Petersen, Carlsson, & Karlsson, 2013). This means that outcomes may need to be adjusted to account for the impact of age and gender. In addition, Logerstedt et al. (2014) state that the IKDC should not be relied on as the only indicator of normal knee function, and the ability to pass RTS criteria is questionable. They found patients who scored poorly on the IKDC were four times more likely to fail RTS tests, for athletes did well on the IKDC, almost 50% overestimated their level of recovery.

2.4.1.2 Knee Injury and Osteoarthritis Outcome Score (KOOS)

The Knee Injury and Osteoarthritis Outcome Score (KOOS) was originally developed as an add on to the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) in order to assess additional issues due to arthritis knee injuries (Collins et al., 2011; Lohmander et al., 2004; Roos, Roos, Ekdahl, & Lohmander, 1998). The KOOS is therefore important to the ACL population due to the high risk of patients suffering an ACL rupture going on to develop osteoarthritis (Lohmander et al., 2004).

The KOOS inventory can be used to evaluate knee function and symptoms in the short term (over weeks) or in the long term (decades) (Collins et al., 2011; Lohmander et al., 2004; Roos et al., 1998). Since it was introduced in 1995 by Roos and colleagues, the KOOS has not been altered (Roos & Lohmander, 2003), and it still has 42 items that are divided into five domains, which are: pain, symptoms, activities of daily living (ADL), sport, and knee related quality of life (QOL). Each domain is scored individually before being transformed into a 0 – 100 score; 100 suggests there are no problems with the knee. The KOOS takes around ten minutes to administer and 10 minutes to complete, and it has a recall time period of one week.

Patients were directly involved in the development of the KOOS score, which ensured content validity. Strong correlations were found by Collins et al. (2011) between the KOOS, Rand-36 and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), which reveals construct validity. In addition, internal consistency, test-retest reliability, effect size, and minimal detectable change have been found for all five domains of the KOOS (Irrgang, 2012), as shown in (Table 2.5). (Roos & Lohmander, 2003) suggest 10 points as the cut-off to show clinically significant differences, however, this approach has been criticised (Irrgang, 2012).

Table 2.5: Demonstrating the internal consistency, test-retest reliability, effect size, and minimal detectable change for each of the 5 dimensions within the KOOS score (Irrgang et al. 2012).

	Symptoms	Pain	ADL	Sports	QOL
Internal consistency	α = 0.25 – 0.83	α = 0.65 – 0.94	α = 0.78 – 0.97	α = 0.84 – 0.98	α = 0.64 – 0.90
Test-retest reliability	0.74 – 0.95	0.80 – 0.92	0.73 – 0.94	0.45 – 0.89	0.60 – 0.95
Effect Size	0.72 – 1.63	0.82 – 2.59	0.67 – 2.25	0.90 – 1.31	1.15 – 2.8
Minimal Detectable Change	9.9 – 24.3	11.8 – 29.0	11.9 – 31.5	12.2 70.0	14.2 – 34.0

The QOL subscale, and then Pain, present the most responsive scores, as they have the greatest effect size; however, this is in regard to total knee replacements and not ACL injuries (Roos & Lohmander, 2003). In addition, a randomised control trial that compared two types of ACL reconstruction, revealed significant between-group differences with regard to ADL, Sport and QOL at a range of time points after surgery (Roos & Lohmander, 2003). According to Roos and Lohmander (2003), the test-retest reliability for most of the subscales is enough reveal a subject’s change in performance over time.

Comins, Brodersen, Krogsgaard, and Beyer (2008) carried out a Rach analysis, which suggests using caution if using the KOOS with ACLR patients earlier than 20 weeks after surgery, because the score form is designed mainly to recognise arthritic symptoms. On the other hand, an ACLR athletic population was assessed by Salavati, Akhbari, Mohammadi, Mazaheri, and Khorrami (2011) at 7.6 ±2.2 months post-surgery, and they found the KOOS to provide reliable and valid scores. Moreover, the KOOS is recommended for use post ACLR by the National Knee Ligament Registries (Hill & O'Leary, 2013). Agarwalla et al. (2018) conducted a systematic review of 30 studies that included 2253 ACLR patients, and they report that clinically significant improvements were apparent in the KOOS and IKDC up to 12 and six months respectively following ACLR, although no clinical significance was noted beyond that time. However, only one study out of 30 included studies reported outcomes after 12 months.

In conclusion, The IKDC and KOOS are specifically designed to capture symptoms and disabilities experienced by ACLR patients (Hambly & Griva, 2010). However, many KOOS items did not experienced by ACLR, and the long-time needed to be completed. Therefore, the IKDC is more suitable than KOOS for ACLR patients due its overall performance (Hambly & Griva, 2010).

Higher scores suggest a more knee function and less disability, and RTS score within 15th percentile of healthy gender–age-matched subjects (Logerstedt et al., 2014). While subjective variables of function and symptoms are important, they are not representative by objective variables. Therefore, it is important that rehabilitation and outcome measurements should include subjective outcome measurements (Hambly & Griva, 2010).

2.4.2 Objective Clinical Measures

Strength Tests

The most important clinical measure of function following an ACL reconstruction is strength, and an assessment of the maximum strength of the quadriceps and hamstrings is essential as part of monitoring a patient's recovery after an ACLR (Moisala et al., 2007). Strength is routinely used as a benchmark to determine and develop the most appropriate type of treatment plan for individual patients (Felson et al., 2000).

At six months post-surgery, patients with ACLR have been shown to have strength deficits ranging from as low as 3% to as high as 40% in comparison to the non-injured limb (Burks, Crim, Fink, Boylan, & Greis, 2005; Cardone, Menegassi, & Emygdio, 2004; Gobbi, Tuy, Mahajan, & Panuncialman, 2003a; Gokeler, Schmalz, Knopf, Freiwald, & Blumentritt, 2003; HB, G, D, & H., 2011; Knezevic, Mirkov, Kadija, Nedeljkovic, & Jaric, 2014a; Kobayashi et al., 2004; Krych et al., 2015). The research also tends towards the view that higher quadriceps strength is linked to more positive self-reporting and function performance measures following ACL reconstruction (Knezevic, Mirkov, et al., 2014a; Lepley & Palmieri-Smith, 2016; Schmitt et al., 2012).

Knee stability and healthy cartilage is improved by muscle strength (Sharma et al., 2003). This is because the muscles around the knee joint work to protect the joint structures by controlling motion and reducing joint forces (Schmitt et al., 2012). This means that quadriceps and hamstring strength are important to protecting joint motion, and assist with shock absorption, proprioception and joint stability (Becker, Berth, Nehring, & Awiszus, 2004). Any impairment in neuromuscular protection will raise the mechanical stress loading of the joint, causing earlier than normal degeneration (Becker et al., 2004). It is claimed by (Schmitt et al., 2012) that if strength is compromised, excessive forces could be transferred to the joint surface directly, resulting in cartilage damage. This means that a loss in muscle strength can change knee kinematics, even leading to the development of osteoarthritis (Mendias et al., 2013).

A traumatic injury, or increasing biomechanical abnormalities due to age usually cause the progression of osteoarthritis, and neuromuscular dysfunction is often apparent in patients with osteoarthritis, for example reduced quadriceps strength (Becker et al., 2004). It is generally noted by researchers and clinicians that there is a relationship between knee osteoarthritis and quadriceps muscle strength, for example Slemenda, Brandt, Heilman, and et al. (1997) carried out a study which showed that in individuals with osteoarthritis, quadriceps muscle weakness is a predictor of knee pain and function. A link between quadriceps muscle weakness and an increase in disability was also found by Steultjens, Dekker, and Bijlsma (2001). Other studies have reported ongoing muscle weakness of over 20% in the quadriceps following ACLR, and this is linked to the progression of osteoarthritis later on (Mendias et al., 2013). On the other hand, greater strength is associated with better physical performance and less susceptibility to repeat injuries (Mendias et al., 2013). The findings of strength deficits at RTS suggests a widespread issue with assessing ACLR patients post operatively. However, it has not been determined whether such deficits are a result of ineffective strength training set out in standard rehabilitation protocols, or due to limitations in the muscular structures' ability to recover and strengthen within standard rehabilitation timeframes.

The majority of the previous studies used isokinetic dynamometry to assess muscle strength following ACLR, though regarded as the gold standard in terms of construct validity, it is expensive and time consuming to use reducing the number of patients that it is possible to screen, which affects the clinical application of screening. In addition to its learning effects so the subject needs a practical session of two maximal strength which may lead to fatigue and effect the overall performance during the test (Van Cingel et al., 2001). Therefore, it is important to be able to screen large numbers of patients quickly and easily, perhaps using portable devices. This type of screening would be useful within injury prevention and rehabilitation programmes.

Isometric Strength Testing

Fixed laboratory-based dynamometry provides the criterion-reference assessment for muscle strength and power; however, one of the limitations of laboratory-based dynamometers is their expense. In addition, they are cumbersome and therefore not suitable for routine patient assessment (Stark, Walker, Phillips, Fejer, & Beck, 2011). Alternative devices for assessing dynamic muscle power are: linear position transducers (Villadsen, Roos, Overgaard, & Holsgaard-Larsen, 2012); the Nottingham power rig (Villadsen et al., 2012), and force plates

(McMaster, Gill, Cronin, & McGuigan, 2014). Even so, the cost is still an issue, along with problems related to availability, difficulty utilising them, and the time required to do so, which limits their use in clinical settings. However, clinic-based assessment of muscle strength is important, as well as results that can be easily interpreted.

Hand-held dynamometers (HHDs) are used to measure isometric lower limb muscle strength. HHDs are portable devices, which are low-cost and provide a convenient way of assessing muscle strength in a clinical setting. Moreover, they have strong reliability and validity in comparison to expensive laboratory based dynamometers (Bohannon, 2012). To use a HHD, the joint position must be fixed in a specific angle. Then, the patient is requested to attempt to contract their muscle as much as possible and maintain that contraction, typically for five seconds (Kues, Rothstein, & Lamb, 1994). The most common angles used in testing the knee extensor and flexor are 30, 45, 60 and 90 degrees (Wessel, 1996). The reliability and validity of HHDs in assessing knee flexor and extensor isometric muscle strength ranges from 0.89 to 0.98 for knee flexor and extensor strength measurements (Mentiplay BF et al., 2015). However, the literature on HHDs and assessing isometric lower limb strength has mainly been on measuring the knee extensors LSI, and little research has been conducted to assess the validity of assessing the strength of the knee flexors (Bohannon, 2012). Moreover, it has been shown that using LSI alone does not provide an entirely accurate assessment of the level of impairment that persists in the ACLR population. A more thorough indicator of quadriceps and hamstring strength may require comparing strength and performance values with the normative values of healthy control participants.

2.4.3 Functional Performance Tests

Rehabilitation programmes are put in place to help the athlete to return to sport and back to full participation as soon as possible, in an appropriate and safe way. There are a number of assessing an athlete's performance and their ability to do so, although the only accurate way of doing so is through a full functional trial.

Reliable measures of functional outcome are essential when examining the usefulness of surgical interventions and rehabilitation (Brosky, Nitz, Malone, Caborn, & Rayens, 1999). Functional testing is described by Bandy and McLaughlin (1993) as: "the performance of one maximal effort of a functional activity, or a series of activities in an attempt to quantify function". It should be borne in mind that function is rather subjective, and the patient’s perception of their condition and their functional limitations around sports and activities of daily living must be considered. In short, functional performance tests provide a way of quantifying muscle function (Barber-Westin, Noyes, & McCloskey, 1999).

Choosing the most useful functional performance test partly depends on the population being tested, for example, hop tests are usually used to assess ACL reconstructed patients (Thomeé et al., 2011). Hop tests are useful because they do not need much space or complicated equipment. In addition, while hop tests are not specific to any particular sport, they mimic the forces endured during most sports and can be performed under controlled conditions (Clark, 2001).

The clinician should consider the reliability and validity of a functional performance test when deciding whether or not to use it, in order for the results to be meaningful. Clark (2001) carried out an in-depth literature review to examine functional performance tests for athletes suffering from knee ligament injuries and found intra-class correlation coefficients, as did several other researchers (Hopper et al., 2002; Reid et al., 2007). Therefore, the literature suggests that hop for distance is most applicable to the ACLR population (Figure 2.1).

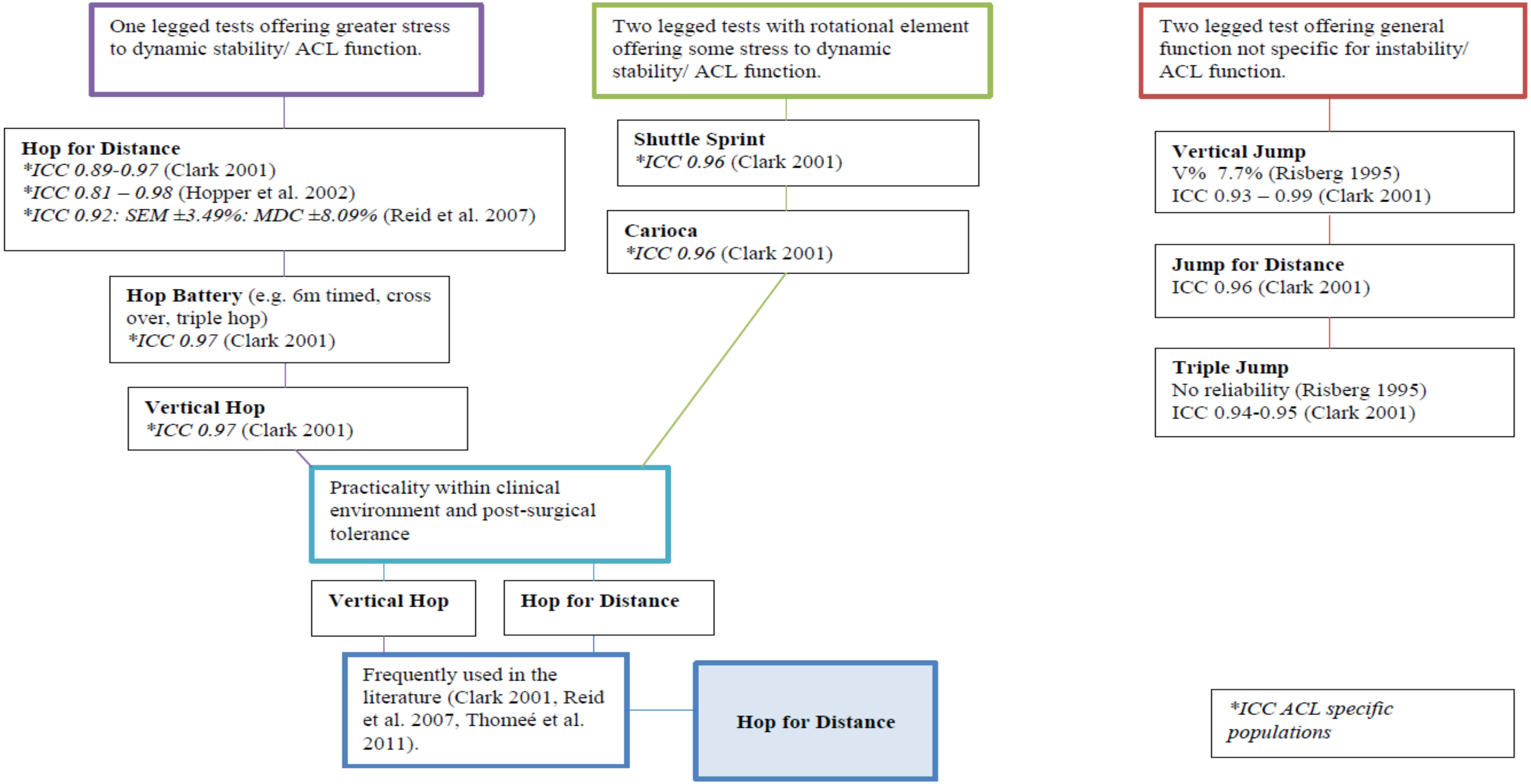


Figure 2.1: Flowchart highlighting the decision process used to identify the objective measure of function used in this thesis; single- leg hop for distance.

Single-Leg Hop for Distance

Hop tests present the most popular and useful assessment tools that can be implemented to assess whether an ACLR patient is ready to return to sport (Rudolph, Axe, & Snyder-Mackler, 2000). Hop tests provide a useful way of monitoring progress and measuring functional performance following an injury or surgical procedure, including assessing whether a RTS or normal activities should be recommended or not (Barber et al., 1990; Lephart & Henry, 1995; Noyes et al., 1991). The most reliable and valid hop tests when it comes to ACLR patients are the single hop for distance and crossover hop tests (Clark, 2001; Logerstedt et al., 2012).

The individual must have sufficient flexibility, strength, power, rate of force development, proprioception, neuromuscular control, dynamic balance, agility, joint laxity, as well as confidence, in order to perform a hop, and any or all of these factors may be affected following an injury (Clark, 2001; Hopper et al., 2002). Research has shown the usefulness of hopping tasks in predicting whether individuals are likely to face problems in the future (Fitzgerald et al., 2001), as well as to evaluate the recovery process (Gotlin & Huie, 2000; Heckman, Noyes, & Barber-Westin, 2000). To check athletes' levels of stability and performance, single-leg hop tests are often used, as they are seen as being challenging enough and a useful measure of athletic performance (Brown, Ross, Mynark, & Guskiewicz, 2004; Colby, Hintermeister, Torry, & Steadman, 1999; Munro & Herrington, 2011; Ross, Langford, & Whelan, 2002; Ross & Guskiewicz, 2003; Wikstrom, Powers, & Tillman, 2004).

The muscle strength of the lower extremities will be reflected in hop test scores, and the literature shows this link between muscle strength and performance during single-leg hop tests (Baltaci et al., 2012; Barber et al., 1990; Noyes et al., 1991; Sharma et al., 2003; Thomeé et al., 2012; Wilk et al., 1994; Xergia et al., 2013). This is useful, as muscular strength is an essential requirement of dynamic athletic performance, especially sports that require high force generation in a short time period (Newton & Kraemer, 1994). In addition, hop tests can be used as a performance indicator, and they have been proven to correlate with self-reported knee function scores (Logerstedt et al., 2012; Reinke et al., 2011a; Serrão et al., 2012).

According to (Noyes et al., 1991), a single-leg hop for distance is one of the four hop tests that can be used as an outcome measure for evaluating patients' performance during rehabilitation following ACL reconstruction. Quickly hopping horizontally in an accurate manner is important in many sports, therefore many athletes have training programs that are specifically designed to improve their capabilities at moving and hopping horizontally (Ross et al., 2002), and single-leg hop tests may be used to evaluate the progress of training. In addition, they can be used to assess the level of recovery following an injury or surgical intervention, whether in the field or in a clinical setting (Noyes et al., 1991).

Hop tests have been shown to reveal differences between the limbs in injured participants in several studies (Goh & Boyle, 1997; Petschnig et al., 1998; Reid et al., 2007), and such tests are usually implemented with injured participants to assess the patient's function. Hop tests can also be used with healthy people to check limb symmetry or the overall strength and power of the lower limbs (Hamilton et al., 2008). However, symmetry, assessed through comparison to the contralateral leg, with regard to hop test does not necessarily mean that adequate recovery has taken place or confirm that the patient is ready to return to sport.

Two personal factors that affect ICF's dimensions are age and gender, and these lead to a number of outcome variables; however, no scores or tests have so far been designed to date that are age or gender specific, even though hop performance is affected by the age and gender of the subject (Ageberg et al., 2001). This means that outcomes may need to be adjusted to account for the impact of age and gender, including when comparing groups that have undergone ACLR and their recovery.

2.4.4 Psychological Factors and Fear of Re-Injury

Despite the extensive discussions related to the medical and physical components of ACL reconstruction, little attention has focused on the psychological aspect of the rehabilitation process, even though the way that an athlete copes with such an injury will have a major impact on their subsequent return to sport, including competition. During the past decade, studies into the psychological impact of injuries have mainly examined specific psychosocial factors that could affect the rehabilitation process.

2.4.4.1 ACL-Return to Sport Index (ACL-RSI)

A tool used to measure the psychological impact of returning to sport after ACLR is the Anterior Cruciate Ligament Return to Sport Index (ACL-RSI) (Appendix 8.3). This is a condition-specific scale that uses a 12 item scale to measure three psychological constructs: emotions, confidence in performance, and risk appraisal, on a scale of zero to 100 (Webster et al., 2008) . Higher scores suggest a more positive attitude towards returning to sport, with 56 or over indicating the ability to return to play (Ardern et al., 2013), and a score of 76 suggesting the individual has the ability to return to full competition (Webster et al., 2008).

2.4.4.2 Tampa Scale for Kinesiophobia-17 (TSK-17)

The Tampa Scale of Kinesiophobia (TSK) (Appendix 8.4) is a 17 item self-report checklist that utilises a four-point Likert scale. It was introduced to measure patients' fear of movement or re-injury. Total scores range between 17 and 68, with a high value revealing a high degree of kinesiophobia. In addition, the cut-off score was developed by (Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995), and for this, a score over 37 is seen to be a high score and indicating high fear of movement, and scores below that considered to be low.

An important post injury psychological variable is the fear of re-injury, as it has the potential to prevent RTS following an ACLR (Kvist et al., 2005). A high fear of re-injury has been shown to correlate with poor self-reporting with regard to function and physical impairment (Kvist et al., 2005; Lentz et al., 2014; White et al., 2014). (Ardern, Taylor, et al., 2014; Kvist et al., 2005) studied the relationship between kinesiophobia and sports with ACLR patients using TSK and found that higher TSK scores correlated with lower activity levels in comparison to those who had returned to pre-injury levels of sporting activities. Moreover, the ACL-RSI is now often used as a measure to assess the psychological impact of returning to sporting activities post ACLR surgery (Webster et al., 2008). However, in the study by (Ardern, Taylor, et al., 2014) 36% of included studies did not report the pre-injury levels of sporting activities. the pre-injury levels of sporting activities may assist to provide an indication of the most appropriate return to the pre-injury level outcomes.

(McPherson, Feller, Hewett, & Webster, 2019) carried out a study into whether psychological readiness to return to sport is associated with suffering a second ACL injury. They discovered that out of 329 patients who returned to sport after ACLR, 52 (16%) suffered a second ACL injury, and these patients displayed lower psychological readiness at 12 months in comparison to their non-injured counterparts (60.9 vs 67.2 points; P = .11). However, their finding cannot be generalised to other population as their study was conducted in a single, private clinic. These findings highlight the importance of psychological counselling along with physical recovery in order to increase the chance of successful RTS, and to reduce the risk of a second ACL injury.

There has been a lack of research conducted with athletes into the psychological factors related to rehabilitation and little has been done with regard to ACL rehabilitation. Andersen (2001) explains that professional athletes are extremely dedicated to their sports, which means that their experience of injury can be very different to that of recreational athletes. Most of the studies which have examined the psychological factors of injury rehabilitation have not been carried out at the time of the occurrence of the injury, rehabilitation or return to competition but often a number of months or years later; therefore, their retrospective design limits the results.

The relationship between knee impairment, kinesiophobia and function was studied by Lentz, Tillman, Indelicato, and Chmielewski (2009), and they discovered 45% of patients who had not returned to sport stated fear of re-injury and a lack of confidence as the reasons for this. Their findings also revealed that pain, quadriceps strength, kinesiophobia and knee flexion restriction correlated with self-reports concerning function only. In a study by Devgan, Magu, Siwach, Rohilla, and Sangwan (2011), it was discovered that five years post-operatively, for the group that had not returned to sport 25% reported fear of re-injury as being the main factor in not doing so.

Similarly, the most frequently cited reason for reduced sports participation among those who did not return to their previous level of sport after ACLR, in a meta-analysis by (Ardern et al., 2011b), was fear of re-injury. Therefore, the impact of kinesiophobia as a factor in the return to sporting activities following ACLR requires further investigation and correlation with functional performance and objective outcomes before rehabilitation ends.

2.5 Conclusion

This chapter has discussed the clinical features and risk factors of ACL injuries, along with treatment options for ACL injuries include ACLR surgery, as well as conservative approaches and physiotherapy rehabilitation. ACL injuries are a common type of injury, particularly among the young and athletic; therefore, the importance of managing the patient following a diagnosis of ACL injury has been highlighted. In addition, postoperative rehabilitation is important in order to ensure the ligament repair process takes place successfully, with the aim of achieving normal knee functionality. Physiotherapy rehabilitation provides an alternative to ACLR surgery for some patients, and it has been shown to be useful in helping to restore pre-injury levels of function and performance. The benefits of ACLR vary and the methods currently being utilised make the assessment of recovery difficult. Therefore, future research should be conducted with healthy control groups in order to provide a strategy for measuring success. Thus, the aim of this thesis is to investigate the functional recovery at discharge from rehabilitation following ACLR.

Chapter 3

3 Methods

Before investigating the thesis's main goal, it is essential to conduct the study using proper measurement procedures that give reliable values with small measurement errors. In addition, a process of cross-cultural adaptation and validation is needed in order for any questionnaire to be implemented with Arabic-speakers. Moreover, it is important to have an adequate reference value for the outcome measures from a healthy matched gender, age and level of activity for an appropriate comparison with ACLR patients. This chapter will describe how the methods used in the study were developed to meet these requirements. This chapter is split into three sections to make understanding the processes involved easier. The first section investigates the reliability and validity of using two different measurement techniques to measure isometric muscle strength. Then, the second section discusses the adaptation of Arabic version of IKDC and ACL-RSI for Arabic people with ACLR. Finally, the last section, gives details of normative values for subject reported knee function, muscle strength and functional performance in a healthy active population. The aim and objectives with the procedures applied for data collection, also, details of the statistical analysis, results and discussion are presented for each of the three sections. The methodology used in the last section is the same as those methods used for the main study, which investigates the functional recovery at discharge from rehabilitation following ACLR.

3.1 Reliability and validity of isometric strength measurement of quadriceps and hamstring muscles by using two different measurement techniques Biodex System 4 PRO dynamometer and hand-held dynamometer (HHD) in healthy active population.

(Question one): Is there an agreement between repeated measurement scores for knee extensors and flexors muscles, using the HHD?

3.1.1 Introduction

Anterior cruciate ligament (ACL) injury inevitably leads to a significant deficit in strength (Thomeé et al., 2012), which may then have a relationship to over 50% of suffers developing knee osteoarthritis within 10 years following injury (Lohmander et al., 2007). Evaluating the maximum strength of the quadriceps and hamstrings is of major importance when monitoring the patient's recovery after an ACL reconstruction (ACLR) (Moisala et al., 2007). Several methods have been used for the assessment and monitoring of muscle strength following an ACLR, including the standard isometric test, which assesses the maximum voluntary contraction of the muscle being tested (Hartigan, Zeni, Di Stasi, Axe, & Snyder-Mackler, 2012). To ensure effective rehabilitation, it is essential to use accurate muscle testing methods which are both reliable and valid (Meyer et al., 2013). When measuring strength certain potential technique-based limitations should be considered (Boling et al., 2009; Meyer et al., 2010). The first limitation is the time it takes to collect the data, another is the expense of the equipment, the suitability to be used for large scale screening and finally the reliability and validity of the measurement. Using technology such as isokinetic dynamometry, though regarded as the gold standard in terms of construct validity, it is expensive and time consuming to use reducing the number of patients that it is possible to screen, which affects the clinical application of screening. Therefore, it is important to be able to screen large numbers of patients quickly and easily, perhaps using portable devices. This type of screening would be useful within injury prevention and rehabilitation programmes. Recent evidence suggests that the Hand Held Dynamometer (HHD) could have the potential to assess patients strength following ACL injury (Katoh & Yamasaki, 2009; Willson, Ireland, & Davis, 2006), and so the study undertaken will evaluate the reliability and validity of testing the strength of the knee extensors and flexors muscles to discover the reliability and validity of the Hand Held Dynamometer within this context.

3.1.2 Aim and Objectives

1- To investigate the reliability of isometric strength testing of the knee flexors and extensors (quadriceps and hamstring muscles), within-day and between-days using hand-held dynamometry (HHD)

2- To assess the relationship between HHD and isokinetic dynamometry (Biodex System 4 PRO dynamometer), knee flexors and extensors strength scores to understand whether HHD is accurate enough and suitable for screening knee muscles strength.

3.1.3 Hypothesis

1. There will be agreement between repeated measurement scores, obtained both within-day and between-days tests for knee extensors and flexors muscles, using the HHD and Biodex System 4 PRO dynamometer.
2. There will be a relationship between the HHD and Biodex System 4 PRO dynamometer for knee extensors and flexors muscles strength scores.

3.1.4 Ethical Considerations and Risk Assessment

This study had been ethically approved by the Research, Innovation and Academic Engagement Ethical Approval Panel at University of Salford HSCR 16-75 (Appendix 8.5). Every participant in this study had been given a written information sheet providing details about the study. This also described the purpose and procedures of the study, the length of time required, the physical risks involved, and advised of their right to withdraw (Appendix 8.10). Participants were informed that they could ask questions before, during and after the study. After the participants decided to take part, they were checked to see if they met the inclusion criteria, then they were asked to complete and sign a consent form (see Appendix 8.8). All data collected from patients were held on a secure password protected computer. Each subject was given a reference number so that no individual details could be identified from the data (Data Protection Act, 1998). A risk assessment was conducted according to the study protocol and based on the risk assessment policy and risk control procedures.

3.1.5 Participants:

According to the recommendations of Walter, Eliasziw, and Donner (1998) on sample size of reliability study, twenty healthy male active participants volunteered to take part (age 32.8±4.5 years; mass 71.8±10.4 kg; height 1.7±0.06 m; leg length 0.91±0.05 m). All of them Saudi students play football in a regular basis. The requirement reported that they were active in accordance with American College of Sports Medicine guidelines (exercised at least 3–5 times a week at a moderate intensity for no less than 30 min) (Garber et al., 2011). In addition, the participants should not have experienced any lower extremity injuries during the six months prior to testing, and they must have had no lower extremity surgery at any time in the past. Injury referred to any musculoskeletal complaints that prevented the participant from performing their usual exercise routine.

3.1.6 Study Procedure:

The data on isometric muscle strength levels in both legs was obtained using two different tests for the knee extensor and flexors muscles: a Biodex System 4 PRO dynamometer, and a hand-held dynamometer. The participants were asked to wear sports clothing and the tests were carried out at two separate times on the same day that they attended, and this was repeated a week later, at the same time of day. Participants were instructed to keep their regular activities during the experimental period and not to involve in any strong physical activity for 2 days prior to their test date. To minimize body movements during the measurement, straps were applied across the chest, pelvis and mid-thigh. Also, the investigator provided standardized (verbal) encouragement and the participants were asked to put their arms across the chest throughout the testing procedure. (Maffiuletti, Bizzini, Desbrosses, Babault, & Munzinger, 2007).

3.1.7 Tests

3.1.7.1 Biodex System 4 PRO dynamometer procedure

Prior to the Biodex procedure, the system was calibrated. The participant was asked to sit on the chair of the Biodex with the knee and hip joints positioned at 90º in preparation for the knee extensors and knee flexors tests. Isometric testing was selected, and the lever arm was adjusted to ensure that the pad of the dynamometer was attached 2-3 cm proximal to the ankle joint in the opposite direction of the action of the muscle being tested. The axis of rotation of the arm was placed at the level of the rotational axis of the knee joint (lateral femoral epicondyle). The time of contraction was adjusted for 5 s contraction repeated three times, and 60 s rests were taken in between (Douma, Soer, Krijnen, Reneman, & van der Schans, 2014).

3.1.7.2 Validity of HHD to Biodex System 4 PRO dynamometer procedure

Maximum peak force in Newton/torque in (Newton meter) (N, Nm) was measured using the Biodex System 4 PRO dynamometer and the HHD (MicroFet F1) during five seconds of muscle contraction at the same time during a single session. To measure the quadriceps muscles, participants were asked to sit on the chair of the Biodex with their knees and hips at 90 degrees flexion and with both feet not in contact with the ground. The participants were then requested to apply maximum force in extending the knee joint against the Biodex lever arm and the immovable HHD device, which was fixed with a belt and placed in front of the leg proximal to the ankle joint (Figure 3.1). They were asked to do so for 5 seconds and repeated the assessment three times with 60 seconds rest in between. For the hamstring muscles, the participants were requested to sit on chair of the Biodex knee and hip joints flexion 90 degrees, and then they were asked to apply maximum force in flexing the knee joint against the Biodex lever arm and the immovable HHD device which was fixed using a belt and placed at back of the leg proximal to the ankle joint (Figure 3.2). This was performed for 5 seconds and repeated three times with 60 seconds rests taken in between each. The maximum peak force obtained by HHD (N) was calculated in (Nm) by multiplying the peak force produced (N) by the Biodex lever arm (m). To make sure that the measurements obtained from the Biodex System 4 PRO dynamometer was not affected by the distance between the Biodex System 4 PRO dynamometer lever arm and the participant’s leg because of the position of the HHD, a pilot study has been done to compare the peak torque obtained from the Biodex System 4 PRO dynamometer alone and the peak torque obtained from the Biodex System 4 PRO dynamometer plus HHD at the same time during a single session. There were no differences between the measurements obtained from Biodex System 4 PRO dynamometer measurements alone and Biodex System 4 PRO dynamometer plus HHD measurements (Appendix 8.11).

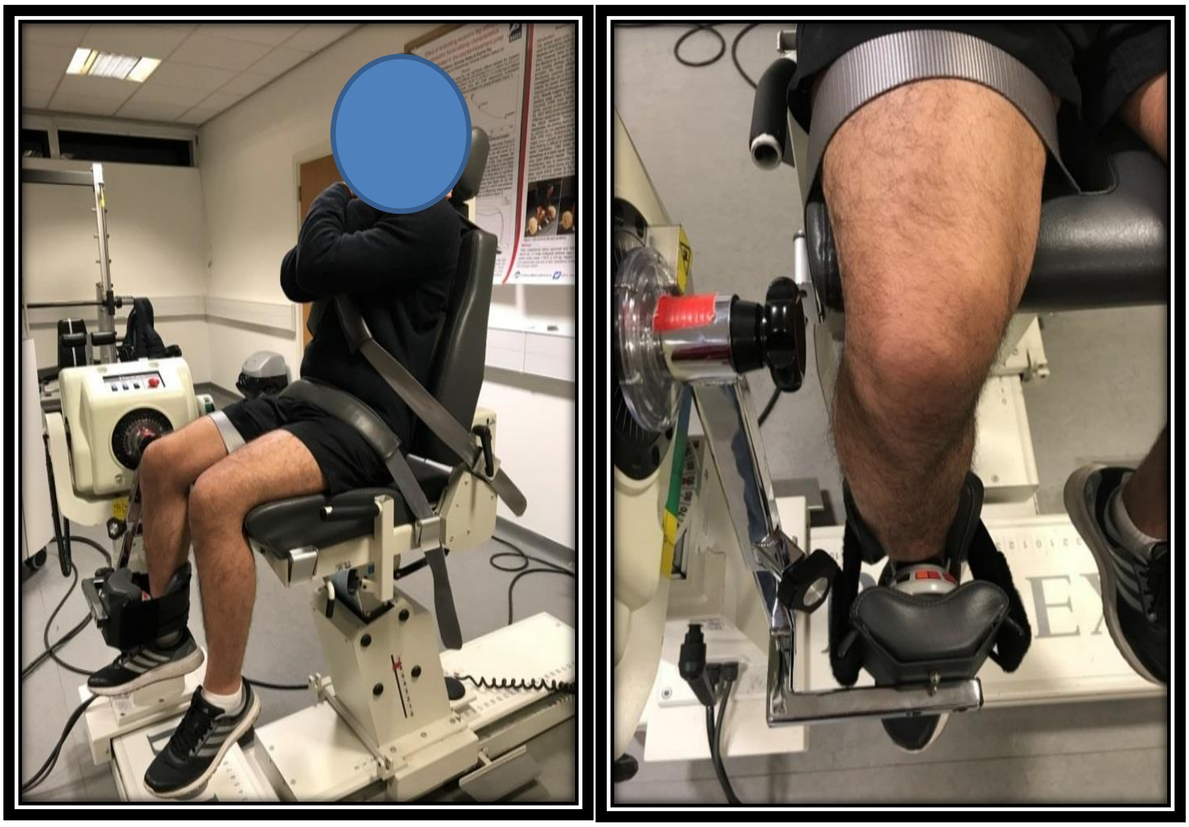


Figure 3.1: Validity of HHD to Biodex System 4 PRO dynamometer when measuring quadriceps muscle

Figure 3.2: Validity of HHD to Biodex System 4 PRO dynamometer when measuring hamstring muscle.

3.1.7.3 Reliability of HHD

Next, peak force was measured only by using the HHD (MicroFet F1) for five seconds of muscle contraction on the same day and repeated the test three times with 60 seconds rest in between, and this test was repeated a week later. Participants had a 15 minute rest between tests during both sessions to reduce any fatigue experienced (Martin et al., 2006). The participants were requested to sit on the quadriceps chair with their knees and hips at 90 degrees flexion and both feet not in contact with the ground; the lever arm of the quadriceps chair was the same length as the Biodex lever arm used in the previous test (Figure 3.1). To measure quadriceps muscles, participants were instructed to sit on the quadriceps chair with 90 degrees' flexion in the knee and hip joints with both feet off the ground. Then, participants were instructed to apply maximum force to extend knee joint against the immovable (HHD) device that fixed with belt and placed in front of the leg proximal to the ankle joint, for 5 seconds and repeat it for 3 times with 60 seconds rest in-between. Maximum peak force was recorded during the three trails. To measure hamstring muscles, participants were instructed to sit on the quadriceps chair with 90 degrees' flexion in the knee and hip joints with both feet off the ground. Then, participants were instructed to apply maximum force to flex knee joint against the immovable HHD device that fixed with belt and placed in back of the leg proximal to the ankle joint, for 5 seconds and repeat it for 3 times with 60 seconds rest in-between. Maximum peak force was recorded during the three trails. After completing the test, the participants were asked to repeat the procedure with the other leg, see (Figure 3.3) and appendix (8.12).

Figure 3.3: Using HHD when measuring quadriceps and hamstring muscles strength

As per recommendation of the European Board of Sports Rehabilitation (EBSR) muscle strength was expressed as an LSI as well in absolute values (Thomeé et al., 2011). The participant's body mass was used during data analysis to normalise muscle strength. The muscle strength data was normalised to body mass by dividing the peak force produced by the participant's mass (N/kg). Maximum peak torque (Nm) was measured using the HHD by multiplying the peak force produced (N) by the lever arm of the quadriceps chair in meter (m).

3.1.8 Statistical analysis

To compare all the muscle forces (N) that were measured using the HHD with the peak torque (Nm), which was measured using the Biodex System 4 PRO dynamometer, the peak torque (Nm) was divided by the arm length (m) between the knee joint and the ankle, in order to calculate the muscle force (N).

All statistical analyses were performed using SPSS software (v. 24, SPSS Inc., Chicago, IL). Descriptive analysis (mean and standard deviation) for each dependent variable was carried out. All data was tested for normality using a Shapiro-Wilk test; values were normally distributed because they are more than 0.05 (*p*-value was set at 0.05), and descriptive analysis (means and standard deviations) were calculated (Batterham & George, 2003).

Intra-Class Correlation Coefficients (ICCs) and standard error of measurement (SEM) were used to determine the reliability and the level of agreement, and the ICC values were measured as follows: Poor <.40, Fair .40 to 70, Good 70 to 90, Excellent >.90 (Coppieters, Stappaerts, Janssens, & Jull, 2002). Any ICC scores lower than 0.70 result in the hypothesis being rejected (Terwee et al., 2007). The reason for selecting the ICC is because of its stringent and uniform criteria, as well as its coefficient reliability relative the other elements from the same classification or category. Yaffee (1998) has described how the 'ICC compares the covariance of the scores' with total variance. The decision on the two-way mixed effect, absolute agreement, ICC model (3.1) chosen was made after examining the recommended guidelines put forward by Koo and Li (2016). While the ICC appears straight forward with regard to obtaining data, it cannot depict reliability properly if it is used on its own because no error margin is set out between two measurements; essentially it measures relative not absolute reliability. Therefore in order to measure absolute reliability, it is useful to utilise the Standard Error Measurement (SEM), which described by Rankin and Stokes (1998) as 'an important tool that will provide the error interval between two measurements', this makes it possible to confirm an approximation of the real change, as well as providing an error interval, by using the formula: SEM = SD (pooled) x √(1-ICC) (Thomas, Silverman, & Nelson, 2015) and smallest detectable difference (SDD) with 95% confidence intervals defined by Kropmans, Dijkstra, Stegenga, Stewart, and de Bont (1999) as 1.96 * √ (2) * SEM. Munro, Herrington, and Carolan (2012) point out that for 'practitioners who require a way to discern individual improvements, calculation of the SEM is incredibly valuable'. The SEM gives a value that can present absolute reliability, and lower values are more reliable. According to Baumgartner (1989), this makes it possible to confirm an approximation of the real change. Calculation of the SEM can help greatly in discerning the actual change in outcomes, instead of a measurement error. Having a high ICC and a low SEM, SDD is considered reliable.

In the past, assessment of the reliability of two different tools designed to measure the same variable often relied on ICC and a correlation coefficient. These methods can however be misleading. Bland and Altman (1986) explained the reasons why these methods are not appropriate for comparison studies. Thus, these authors proposed a new method for assessing the agreement between two different instruments of clinical measurement.

In a Bland and Altman plot, systemic bias can be characterised by spreading of all the data in both a positive or negative direction, and random error can be characterised by the magnitude of the spread around the mean difference (Batterham & George, 2003). Bland and Altman plots have two advantages in comparison to ICC: their powerful visual representation of the degree of agreement, and the easy identification of bias, outliers and any relationship between the variance in measures and the size of the mean (Rankin and Stokes, 1998). Therefore, Bland and Altman plots with 95% Limits of Agreement (LOA) were used in conjunction with ICCs to investigate the extent of agreement between tests. 95% LOA was calculated using this formula, mean ± SD of the difference x 1.96, to show the agreement in calculated muscle strength between two measurement tools (Bland & Altman, 1986; Portney & Watkins, 2009). In order to assess the disagreement between measurements of this study, Biodex system dynamometer and the first test of hand-held dynamometer (HHD1) were chosen to have Bland and Altman plots because the maximum peak force was measured using the Biodex System 4 PRO dynamometer and the HHD1 at the same time during a single session.

Validity analysis carried on both limbs. Relationships, including parametric variables, were tested using Pearson's rank correlation (r), to explore the relationships between Biodex System 4 PRO dynamometer and HHD. measurement differences were determined using a paired-sample t-test with effect sizes determined where significant differences were found. (Table 3.1) illustrates the interpretation of the strength of correlation coefficients used in this study (Cohen, 1988).

Table 3.1: Correlation coefficient scores and levels of association (Cohen, 1988)

Correlation coefficient score	Level of association
(0.10–0.29)	Small
(0.30–0.49)	Medium
(0.50–1)	Large

3.1.9 Results

3.1.9.1 HHD reliability

The results for internal consistency; test–retest within-day and between-days reliability, and measurement error, are set out in (Table 3.2 and Table 3.3). Internal consistency was shown to be excellent for all tests, both within and between-days. Same-day reliability was calculated using two repeat tests carried out on day one, and all measurements came back as highly reliable (ICCs = 0.91 - 0.94). Test-retest reliability for seven days later was also high (ICC = 0.94 - 0.96). Therefore, significantly high reliability was revealed for both tests, although between days reliability values were higher than the within-day reliability values. The SEM ranged from 2.1 to 2.77 N and the SDD between 5.82 N and 7.68 N for all of the tests, as shown in (Table 3.2 and Table 3.3).

Table 3.2: Mean HHD scores, ICC and SEM at test and retest within day, test-retest reliability and internal consistency [α].

	ICC (95% CI)	Session 1 (SD)	Session 2 (SD)	SEM	SDD
Right Flexors	0.93 (0.85-0.98)	210.9 (9.51)	207.65 (9.23)	2.5 N	6.87 N
Right Extensors	0.94 (0.86-0.98)	382.9 (11.03)	379.75 (10.39)	2.62 N	7.27 N
Left Flexors	0.91 (0.86-0.97)	203.25 (9.11)	197.95 (9.35)	2.77 N	7.68 N
Left Extensors	0.93 (0.84-0.97)	385.2 (10.16)	383.5 (11.12)	2.77 N	7.67 N

[α] ICC, intraclass correlation coefficients; SEM, Standard error of measurement; SDD, smallest detectable difference

Table 3.3: Mean HHD scores, ICC and SEM at test and retest administrations one week apart, test-retest reliability and internal consistency [α].

	ICC (95% CI)	Session 1 (SD)	Session 3 (SD)	SEM	SDD
Right Flexor	0.95 (0.94-0.99)	210.9 (9.51)	208.9 (9.27)	2.10 N	5.82 N
Right Extensor	0.96 (0.90-0.98)	382.9 (11.03)	379.5 (10.05)	2.11 N	5.84 N
Left Flexor	0.94 (0.87-0.97)	203.25 (9.11)	200.3 (9.34)	2.26 N	6.27 N
Left Extensor	0.95 (0.85-0.99)	385.2 (10.16)	381.9 (10.28)	2.29 N	6.33 N

[α] ICC, intraclass correlation coefficients; SEM, Standard error of measurement; SDD, smallest detectable difference

3.1.9.2 Bland and Altman test

3.1.9.2.1 Right Knee Flexors

The mean difference was 6.9 N and standard deviation was 5.5. The lower limit of 95% of limit of agreement (LOA) was -3.95 and the upper limit of 95% LOA was 17.75. The difference between the means of the two tests was plotted on the Y-axis against their average on the X-axis. The plot revealed that the points were distributed more on the positive side of the plot and two points fall on the line of agreement. However, there was no systematic pattern between the two tests and minimal random error (see figure 3.4). This means that 95% of the scores obtained by Biodex system dynamometer and hand-held dynamometer for right knee flexor muscles fell between -3.95 and 17.75. The difference between the upper and lower limits of 95% LOA was 21.7 N.

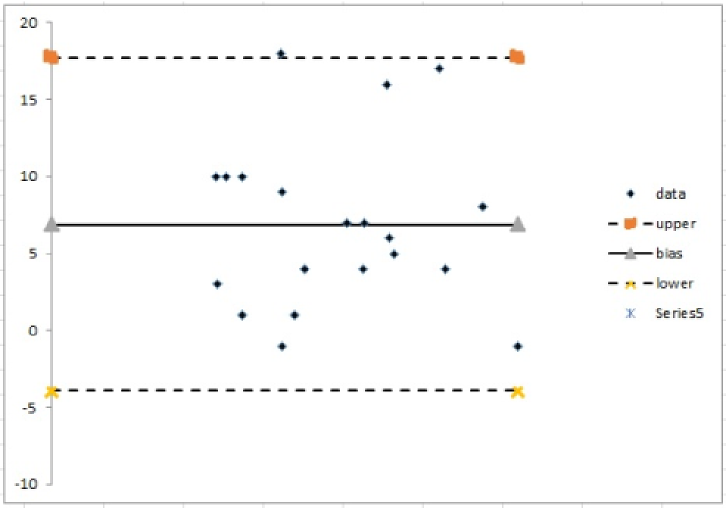


Figure 3.4: Bland and Altman plot for right knee flexor muscles

3.1.9.2.2 Right Knee Extensors

The mean difference was 6.8 N and standard deviation was 4.8. The lower limit of 95% of limit of agreement (LOA) was -2.75 and the upper limit of 95% LOA was 16.35. The difference between the means of the two tests was plotted on the Y-axis against their average on the X-axis. The plot revealed that the points were distributed more on the positive side of the plot and two points fall on the line of agreement. However, there was no systematic pattern between the two tests and minimal random error (see figure 3.5). This means that 95% of the scores obtained by Biodex system dynamometer and hand-held dynamometer for right knee flexor muscles fell between -2.75 and 16.35. The difference between the upper and lower limits of 95% LOA was 19.1 N.

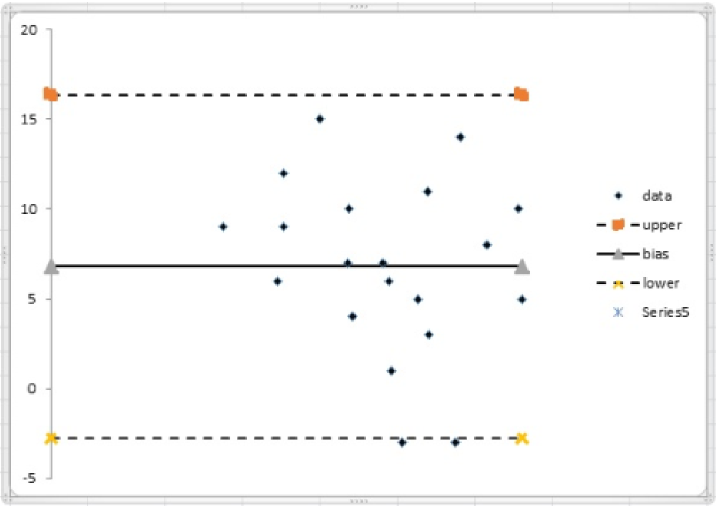


Figure 3.5: Bland and Altman plot for right knee extensor muscles

3.1.9.2.3 Left Knee Flexors

The mean difference was 8.95 N and standard deviation was 5.59. The lower limit of 95% of limit of agreement (LOA) was -1.99 and the upper limit of 95% LOA was 19.9. The difference between the means of the two tests was plotted on the Y-axis against their average on the X-axis. The plot revealed that the points were distributed more on the positive side of the plot and one-point fall on the line of agreement. However, there was no systematic pattern between the two tests and minimal random error (see figure 3.6). This means that 95% of the scores obtained by Biodex system dynamometer and hand-held dynamometer for left knee flexors muscles fell between -1.99 and 19.9. The difference between the upper and lower limits of 95% LOA was 21.89 N. There were two clear outliners, indicating that all the measurements fell between 95% of LOA except one score fell below the lower limit and one score fell above the upper limit.

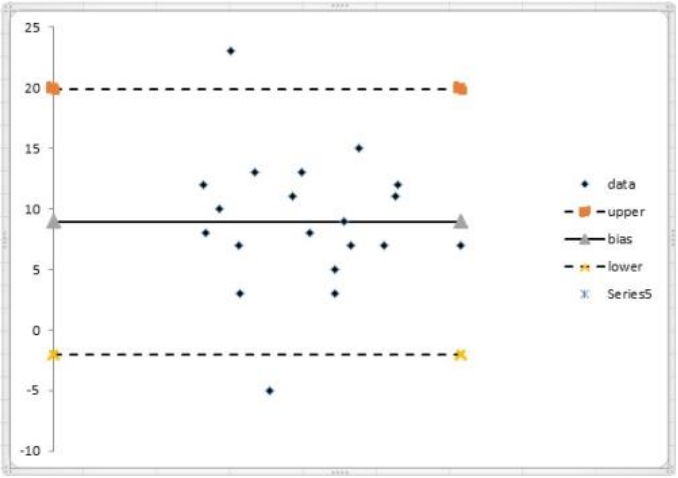


Figure 3.6: Bland and Altman plot for left knee flexor muscles

3.1.9.2.4 Left Knee Extensors

The mean difference was 4.6 N and standard deviation was 8.93. The lower limit of 95% of limit of agreement (LOA) was -12.90 and the upper limit of 95% LOA was 22.10. The difference between the means of the two tests was plotted on the Y-axis against their average on the X-axis. The plot revealed that the points were distributed more on the positive side of the plot. However, there was no systematic pattern between the two tests and minimal random error (see figure 3.7). This means that 95% of the scores obtained by Biodex system dynamometer and hand-held dynamometer for left knee extensors muscles fell between -12.90 and 22.10. The difference between the upper and lower limits of 95% LOA was 35 N.

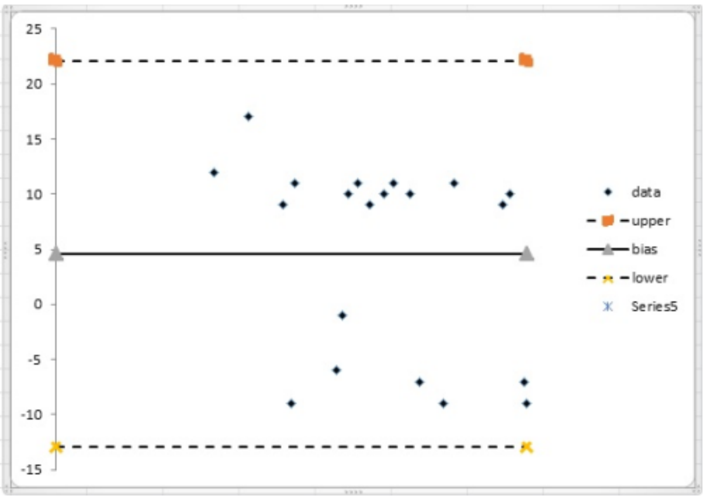


Figure 3.7: Bland and Altman plot for left knee extensor muscles

Table 3.4: Bland and Altman for Knee flexors and extensors muscle strength (N).

	Mean difference	Standard deviation	Lower limit of 95% LOA	Upper limit of 95% LOA
Right Knee Flexor	6.9	5.5	-3.95	17.75
Right Knee Extensor	6.8	4.8	-2.75	16.35
Left Knee Flexor	8.95	5.59	-1.99	19.9
Left Knee Extensor	4.6	8.93	-12.90	22.10

3.1.9.3 HHD Validity

Compared to the Biodex System 4 PRO dynamometer, the mean peak force values attained from the HHD were lower, but for the paired samples t-test, there was no statistically significant difference found between the HHD and the Biodex System 4 PRO dynamometer although the effect sizes were minimum, as shown in (Table 3.5). A Pearson correlation analysis showed that the correlation coefficients of the HHD extensor muscles measurements were: $r = 0.98$ (right) and $r = 0.93$ (left). This reveals a high correlation with the Biodex System 4 PRO dynamometer measurements ($p=0.05$). The correlation coefficients for the HHD flexors muscles measurements were $r = 0.99$ (right) and $r = 0.97$ (left), revealing a high correlation with the measurements from the Biodex System 4 PRO dynamometer ($p=0.05$), as shown in (Table 3.6).

Table 3.5: Mean (SD) and p-value, Comparison of Significant ($P = 0.05$) between the HHD and the Biodex System 4 PRO dynamometer

	HDD 1 (SD)	Biodex Pro (SD)	p-value	Effect size
Right Knee Flexors	210.9 (9.5)	213.4 (61.1)	0.48	0.16 N
Right Knee Extensors	382.9 (11.1)	384.4 (87.1)	0.52	0.15 N
Left Knee Flexors	203.25 (9.1)	205.2 (51.2)	0.55	0.14 N
Left Knee Extensors	385.2 (10.2)	386.7 (101.2)	0.58	0.13 N

Table 3.6: Pearson Correlation Coefficient of HHDs and the Biodex System 4 PRO dynamometer for peak force.

Hand-held dynamometer	Biodex System 4 PRO dynamometer
Right Knee Flexors	0.99
Right Knee Extensors	0.98
Left Knee Flexors	0.97
Left Knee Extensors	0.93

3.1.10 Discussion

A convenient and cheap way of measuring muscles strength is with the use of a HHD, although a number of factors can affect the test results, which has a negative impact on its reliability. Studies that have been carried out using a HHD to measure strength have revealed the importance of the position of the patient, and the impact of the relative strength of the assessor (Bohannon, 2012; Kim, Kim, Seo, & Kang, 2014). It was discovered by Kim et al. (2014) that fixing the HHD onto the leg using a specially designed band led to higher validity and reliability than when it was held by the rater in one hand. Alternatively, the make-test method involves the subject applying force to the HHD while the rater attempts not to move it; in addition, the break-test requires the subject to work against the force applied by the rater to his/her leg using the HHD. As the make-test's reliability has been found to be higher than the break-test (Stratford & Balsor, 1994), this study has measured muscle strength was measured using the make-test method. If the rater is stronger than the subject, the reliability of the HHD test is greater (Deones, Wiley, & Worrell, 1994). Therefore, in this study, the HHD was fixed to the leg to mitigate the factors that could arise from the impact of the strength of the rater or the subject. In addition, some of the other factors that could have affected the reliability of the HHD test results have been addressed and attempts made to control them.

In order to confirm the reliability of HHD in this study, test-retest reliability coefficients within and between-days were found to be high for all of the tests performed in the current study, at (ICCs = 0.91 - 0.96). This is similar to the findings from other studies that examined the reliability of the HHD, such as Kim et al. (2014) who had ICCs ranging from 0.94 to 0.98; Mentiplay BF et al. (2015) who attained 0.91 to 0.92, Toonstra, Mattacola, and Lattermann (2012) at 0.90 to 0.93.

It is not possible to make a clinical assessment by relying only on the ICC because it only demonstrates the relative reliability of the test and does not provide a clear picture of the real extent of the difference between the measurements. It is important to ensure that the measurements used have absolute reliability indicators; therefore, in the current study, the SEM and SDD have been calculated. The SEM scores were very low for all of the muscle measurements ranging from (2.1 to 2.77) N, and this is lower than the findings by Kim et al. (2014) who found SEM ranging from (2.9 to 3.88); furthermore, it is lower than the findings found by (Mentiplay BF et al., 2015), which were SEM ranging from (5.29 to 8.98). In the current study, low results were found on analysing the SDD, which suggests low measurement error, ranging from (5.82 to 7.68) N; this is lower than the results of (Mentiplay BF et al., 2015), which were (14.66 to 24.88) (see Table 3.2 and Table 3.3). Analysing the SDD for HHD measurements of muscle strength and power could be more useful if conducted with clinical populations rather than the current study's examination of healthy participants. However, no comparison values for SDD have been found in the literature, apart from (Mentiplay BF et al., 2015), suggesting that for some dimensions of the HHD, it is necessary to achieve changes of up to 7.68 N in order to measure true change rather than measurement error.

Bland and Altman plots have been used in the current study to discover the amount of agreement between all of the muscle's measurements obtained by the Biodex 4 PRO dynamometer and HHD. Furthermore, Bland and Altman plots drawn to reach solid conclusions about the absolute reproducibility of the method (Rankin and Stokes, 1998).The Bland and Altman plot for all of the muscle measurements obtained using the Biodex 4 PRO dynamometer and HHD reveals minimal bias between the Biodex 4 PRO dynamometer and the HHD; in addition, there was very little random error, and the difference between both arms of the LOA was minimal (see Table 3.4). However, no acceptable value has been found for variability within the LOA in the context of clinical practice, and this value would not be considered of minimal clinical difference. The variation found could be due to the variation between the tools utilised to measure the muscle strength of the knee flexor and extensor. However, no comparison values have been found in the literature.

Finding the specific link between the HHD and the biodex System 4 PRO dynamometer has been attempted in order to check its validity (Arnold, Warkentin, Chilibeck, & Magnus, 2010; Kim et al., 2014; Mentiplay BF et al., 2015). Thus, in this study, validity has been checked through an analysis of the relationship between the HHD and the Biodex System 4 PRO, and the results reveal a high correlation (r = 0.93 to r = 0.99, p = 0.05). This result is similar to the findings of previous studies that tested the validity of the HHD and have found high correlation between HHD and Biodex System 4 PRO dynamometer (Arnold et al., 2010; Kim et al., 2014; Mentiplay BF et al., 2015). Moreover, the sample size used in this study is bigger than the sample size used in other similar studies, for example (Arnold et al., 2010); (Lan & Jessica, 2012) and (Toonstra et al., 2012), thereby suggesting ecological validity has been attained.

A comparison between the knee extensors and flexors strength values in HHD tests and Biodex System 4 PRO tests has revealed no statistically significant differences observed between them although the effect sizes were minimum, which may be because of the use of fixed methods, as this could have prevented systemic errors (Taylor, 1999). A systemic error means a bias that continuously happens in a specific direction, highlighting a link between the value being measured and the true value. As the rater resists the force of the subject's leg to sustain their measurement position, if the rater's strength is not enough, the chance of a systemic error occurring increases, equally, if the rater's force against the subject is very strong a systemic error can also occur. To mitigate this, the HHD was fixed to the subject's leg with a band, and so the systemic error decreased, and the validity improved.

A limitation of the current study is the sample used, as these were young, healthy, and physically active. Even so, to check the reliability and validity of the HHD test, the subjects were active only, which helped to control the variables and to simplify the structure of the main study. Thus, the results of this study cannot be generalised, and further research is required with a sample that includes people with lower limb injuries to carry out clinical measurements of their leg muscle strength.

The knee extensors and flexors strength were measured with an HHD, and this measurement was confirmed to improve the reliability and validity of the instrument for measuring quadriceps and hamstring strength. As the HHD method is both cheaper and more convenient to use in comparison to the biodex System 4 PRO method, it could be used to replace the biodex System 4 PRO method in some clinical or research settings. In conclusion, the HHD has been found to be a reliable and valid tool for measuring muscle strength with regard to the knee musculature.

3.2 Cross-cultural adaptation, Reliability, Internal Consistency and validation of the Arabic version of the International Knee Documentation Committee subjective knee form (IKDC), the ACL Return to Sports after Injury (ACL-RSI) scale and the Tampa Scale of Kinesiophobia (TSK) for Arabic people with ACLR

(Question two): Is there an agreement between repeated measurement scores for Arabic versions of IKDC, ACL-RSI and TSK questionnaires?

3.2.1 Introduction

Evaluating the benefits and cost effectiveness of surgical interventions; types of diagnostics, and rehabilitation, forms a key discussion with regard to clinical outcome research in the management of knee injuries (Irrgang & Anderson, 2002). Measuring the outcomes of clinical interventions for the knee usually involves physical and complementary examinations; however, such measurements do not always correlate with the function and well-being experienced by the patient (Dawson, Clader, & Bassett, 1985). Therefore, quality of life and the patient's perception of improvement needs to be focused more on when the status of their general health and function, in order to gain the information necessary for evaluating the effectiveness of various types of treatment (Sugarbaker, Barofsky, Rosenberg, & Gianola, 1982).

A number of health-related quality of life instruments have been introduced, some of which are disease specific, whereas others are joint specific and focus on musculoskeletal issues. With regard to the knee, the Knee injury and Osteoarthritis Outcome Score (KOOS) is the only instrument that has been translated into the Arabic language with reported validity (Almangoush et al., 2013), even though there is evidence that the International Knee Documentation Committee (IKDC) could be more suitable than the KOOS for assessing patients in the short term (Roos & Toksvig-Larsen, 2003).

The joint committee of the American Orthopaedic Society for Sports Medicine (AOSSM) and the European Society of Sports Traumatology, Knee Surgery and Arthroscopy designed the (IKDC) Subjective Knee Form in 2001; it facilitates knee-specific subjective outcome measurements in relation to the status of the patient's general health. The IKDC measures symptoms and limitations in function, including sporting activities, from the patient's perspective, as result of knee impairment for all types of knee related problems- not just arthritis, but ligament injuries as well. The reliability and validity of the IKDC has been thoroughly checked as part of the evaluation of the instrument (Irrgang et al., 2001). Furthermore, the original English version of the IKDC Subjective Knee Form has been translated into many languages in a number of different cultural settings (Haverkamp et al., 2006; Lertwanich, Praphruetkit, Keyurapan, Lamsam, & Kulthanan, 2008; Padua et al., 2004), but despite this, no Arabic version is currently available.

Following ACLR, a number of factors are involved in the decision to RTS, in particular, physical, psychological and demographical factors (Lentz et al., 2012). With regard to readiness to RTS, physical performance tests were used in the past to assess side-to-side asymmetries, with the main clinical focus on whether the patient was able to achieve a score of 85 percent or over in the limb symmetry index (Barber-Westin & Noyes, 2011). This is despite a meta-analysis revealing that just 64 percent of patients were given permission to RTS following ACLR, even though around 90 percent of them were successful in their physical performance assessments (Barber-Westin & Noyes, 2011). This discrepancy between RTS and physical performance outcomes following ACLR may be due to psychological factors.

A link between psychological factors and RTS rates following ACL injury was found by Ardern et al. (2013). With fear of re-injury being shown to be a very challenging and present psychological factor following an ACL injury (Everhart et al., 2015). In one study, almost 24 percent of ACLR patients did not RTS as a result of being afraid of re-injury (Kvist et al., 2005). Webster et al. (2008) developed and validated the ACL Return to Sports after Injury (ACL-RSI) scale for athletes, which contains 12 factors or domains that evaluate emotions, confidence in performance, and risk appraisal in relation to RTS after ACL injury and/or surgery. This scale was originally written in English and has been translated and validated in Swedish, French and Dutch populations with ACLR patients (Bohu, Klouche, Lefevre, Webster, & Herman, 2015; Kvist et al., 2013; Slagers, Reininga, & van den Akker-Scheek, 2017).

In addition, the ACL-RSI has been shown to have an ability to identify which patients RTS, and those who do not RTS, following ACLR (Webster et al., 2008). Muller, Kruger-Franke, Schmidt, and Rosemeyer (2015) found the ACL-RSI scale to be the best predictive parameter for RTS at six months post ACLR. Therefore, it is assumed that an Arabic version of the ACL-RSI would be highly beneficial for evaluating the impact of psychological factors on RTS among Arabic-speaking patients undergoing ACL reconstruction.

Pain beliefs are an important concept, and according to fear-avoidance theory (Waddell, Newton, Henderson, Somerville, & Main, 1993), painful experiences easily lead to fear and avoidance behaviours that alter people's everyday lives, including work and recreational activities. According to this theory, pain-related fear; fear of re-injury; fear avoidance beliefs, and a fear of movement, are all predictive of pain occurring (Swinkels-Meewisse et al., 2006), as well as on-going disability (Vlaeyen & Linton, 2000). Identifying pain related behaviours early on is important, because it helps clinicians to introduce appropriate strategies to reduce pain, such as cognitive-behavioural reconditioning and managing chronic pain (Swinkels-Meewisse et al., 2006). In order to evaluate pain related fear, Kori, Miller, and Todd (1990) developed the original Tampa Scale for Kinesiophobia (TSK). The TSK is a self-report questionnaire containing 17 items, with each question scored using a four-point Likert scale ranging from 1 (strongly disagree) to 4 (strongly agree); four of the items on the TSK (4, 8, 12, and 16) are negatively worded and reverse scored. The result totals range from 17 to 68, with higher scores representing stronger fear-avoidance beliefs. The TSK has demonstrated good internal consistency, test-retest reliability and validity concerning its psychometric properties. In addition, it has been shown to be positively correlated with measures of fear-avoidance beliefs and pain-related disability (French, France, Vigneau, French, & Evans, 2007), as well as being validated in several languages (Askary-Ashtiani, Ebrahimi-Takamejani, Torkaman, Amiri, & Mousavi, 2014; Gomez-Perez, Lopez-Martinez, & Ruiz-Parraga, 2011; Haugen, Grøvle, Keller, & Grotle, 2008). A cross-cultural adaptation of the TSK has been developed in the Arabic language and psychometrically assessed for patients with low back pain by (Malik et al., 2017). However, Arabic researchers and health providers appear to be coming across limitations when utilising the TSK to evaluate the outcomes among patients with knee injuries, as its reliability and validity have not been tested among patients with knee injuries and so further testing of the validity and reliability of the Arabic version of the TSK for patients with knee injuries is required.

A thorough process of cross-cultural adaptation and validation is needed in order for any questionnaire to be implemented with Arabic-speakers so that equivalence between the original publication and the target version of the questionnaire can be achieved (Beaton, Bombardier, Guillemin, & Ferraz, 2000). An important consideration while doing so, is the process of evaluation of such instruments across cultures, because even if items are translated well, they need to be made culturally suitable (Beaton et al., 2000).

3.2.2 Aim and Objectives

1- The main aim of the current study is to translate and culturally adapt the IKDC and ACL-RSI to make them suitable for Arabic speaking patients with ACL injuries.
2- The secondary aim is to assess the Arabic versions of the IKDC, ACL-RSI and TSK in order to test their psychometric characteristics (reliability, validity and dimensionality) among Arabic patients with ACL injuries.

3.2.3 Hypothesis

1- There will be agreement between repeated measurement scores, obtained between-days tests for IKDC, ACL-RSI and TSK questionnaires.

2- There will be a relationship between IKDC, ACL-RSI, TSK questionnaires and KOOS RAND-36, VAS.

3.2.4 Ethical Considerations and Risk Assessment

This study had been ethically approved by the Research, Innovation and Academic Engagement Ethical Approval Panel at University of Salford HSCR 16-75 (Appendix 8.6) and Medical Rehabilitation Hospital in Saudi Arabia (Ethical Application 13/03/17) (Appendix 8.7). Every participant in this study had been given a written information sheet providing details about the study. This also described the purpose and procedures of the study, the length of time required, the physical risks involved, and advised of their right to withdraw (Appendix 8.10). Participants were informed that they could ask questions before, during and after the study. After the participants decided to take part, they were checked to see if they met the inclusion criteria, then they were asked to complete and sign a consent form (see Appendix 8.8). All data collected from patients were held on a secure password protected computer. Each subject was given a reference number so that no individual details could be identified from the data (Data Protection Act, 1998). A risk assessment was conducted according to the study protocol and based on the risk assessment policy and risk control procedures.

3.2.5 Translation and Cross-cultural adaptation

The translation and cross-cultural adaptation process has been carried out according to previously established guidelines (Beaton et al., 2000). The English IKDC and ACL-RSI have been translated into Arabic by three Arabic native speakers (a physical therapist with experience of knee rehabilitation; an orthopaedic surgeon specialising in knee surgery, and a professional translator). The Arabic translations have been back translated to English by three native English speakers: two English teachers and one professional English translator; none of them had prior knowledge of the original version. A multidisciplinary committee was involved, which included two orthopaedic surgeons, one physiotherapist, one psychologist and one professional translator, all of whom are bilingual and checked and discussed the translated questionnaires.

The translations were reviewed by the committee who reached a consensus on any discrepancies, leading to the development of a pre-final version of the questionnaire for field testing, with translations produced that are suitable for use with most people in language that can be understood by a 12 year old child (Beaton et al., 2000). Presenting all of the translations to the committee meant that any discrepancies could be addressed, and problem items rejected, and new items could be written up and included straight away. Issues related to the items, instructions, response options and scoring were all examined by the committee.

3.2.6 Pilot study of the pre-final version

The pre-final version of the questionnaire was tested on 15 Arabic speaking patients at the Medical Rehabilitation Hospital in Saudi Arabia who had undergone ACL reconstruction. This was to make sure that they fully understood all parts of the questionnaire and completed this satisfactory. An attempt was made to note any problems that arose during the administration of the questionnaire, and at the end of the interview, each patient was requested to make comments on the questionnaire and point out any words that they had difficulty understanding. This ensured that the questionnaire could easily be understood. The subjects stated that could understand all of the questions and response options; therefore, this version did not undergo any further modifications and was taken to be the final version.

A committee meeting was arranged to develop the final version of the Arabic IKDC, and ACL-RSI questionnaires based on the findings from the pilot. The cross-cultural adaptation of the IKDC and ACL-RSI involved not only translation, but also the adjustment of cultural words, idioms, and colloquialism. Thus, some minor changes were required for some items in order to clarify and maintain the meaning of the original concept, and so some easily understandable, simple formal Arabic words with colloquial idioms were utilised to make the questionnaire clearer (Beaton et al., 2000).

3.2.7 Participant

A convenience sample of 35 Saudi patients who had undergone ACL reconstruction (ACLR) was obtained from the Medical Rehabilitation Hospital in Saudi Arabia. The inclusion criteria were patients aged 18 to 44 years, with a unilateral ACL injury, and who had undergone ACL reconstruction, with an average period of 5.4 months after surgery. All of the patients are native Arabic speakers with a good level of education to ensure they understood and could answer the questionnaire accurately, and all of them were required to give their consent prior to participating. The exclusion criteria were: patients with cardiovascular, pulmonary or neurological conditions that limit physical activity; problems with other joints affecting the lower extremity; pelvic or lower back problems, and psychiatric disorders. Each patient was given a self-report instrument package that included the patient's characteristics, the KOOS, Rand-36, IKDC, ACL-RSI, and TSK with VAS numeric pain scale after agreeing to participate in the study, which they completed independently during a visit to the rehabilitation department.

3.2.8 Instruments

The Arabic version of the KOOS is a questionnaire made up of 42-items with five subscales: Pain, Symptoms, Activities of Daily Living (ADL), Sport and Recreation (Sport/Rec) and Knee-related Quality of Life (QoL) (Almangoush et al., 2013). To score each item, a five-point Likert scale ranging from 0 (extreme problems) to 4 (no problems) was used, and the scores for each subscale were individually transformed into a 0 to 100 scale (0 = extreme knee problems, 100 = no knee problems) (Roos et al., 1998).

The Arabic version of RAND-36 generic self-administered instrument of health status is made up of eight subscales: Physical Functioning, Role limitations due to physical problems, Role limitation due to emotional problems, Vitality, Emotional well-being, Social Functioning, Pain and General health (Coons, Alabdulmohsin, Draugalis, & Hays, 1998). These subscales are scored from 0 to 100; the higher the scores, the better the health status.

The VAS numeric distress scale ranges from 0 (no problem) to 10 (extreme problem), and this was used to assess the average intensity of overall knee pain felt during the last week. The VAS has been found to be reliable and valid for evaluating patients with knee-specific conditions (Flandry, Hunt, Terry, & Hughston, 1991).

The IKDC is made up of three categories: symptoms, sports activities, and function. It includes ten questions: one sporting activities question on the effect of the knee joint on daily activity, and nine specific performance questions. The overall score for individual questions was transformed into a final IKDC score, which ranges from 0 to 100, with a higher score indicating better health status.

The ACL-RSI is a condition-specific scale with a 12-item scale for measuring three psychological constructs: emotions, confidence in performance, and risk appraisal, on a scale of zero to 100. A higher score suggests a more positive attitude towards RTS.

The Tampa Scale of Kinesiophobia (TSK) is a 17 item self-report checklist that utilises a four-point Likert scale. It was introduced to measure patients' fear of movement or re-injury. Total scores on the checklist range from between 17 to 68, with a high value suggesting a high degree of kinesiophobia.

The scales described above have been used to establish the validity of the IKDC, ACL-RSI and TSK.

3.2.9 Psychometric scale properties and data analysis

3.2.9.1 Acceptability:

In order to assess this**,** the percentage of refusals; completed questionnaires, and missing items were taken into account, along with the time taken to complete the questionnaire. In addition, the acceptability of the questionnaire has been considered, by noting the percentage of items, items that were hard to understand or confusing, and the willingness of the subjects to complete the questionnaire a second time.

3.2.9.2 Reliability:

Cronbach's alpha was used to calculate internal consistency for the first administration, and it has been considered acceptable if the value is 0.70 or over (Mokkink et al., 2018; Souza, Alexandre, & Guirardello, 2017). The KOOS, RAND-36, IKDC, ACL-RSI, TSK and VAS were administered to the patients in the clinic; they were given the second round of questionnaires during the follow up appointment on the fourteenth day to complete it. To reduce the chance of memorisation, the questionnaires were made into one document as a single questionnaire. The time interval has to be long enough to avoid memorisation bias, and short enough to make sure those subjects have not significantly changed during that period. A time wait of 2 weeks is frequently considered suitable for the assessment of PROMs (Mokkink et al., 2018). All of the participants (n=35) completed questionnaires within the allotted time period. Test-retest stability was assessed using intra-class coefficient correlation (ICC), and equal or greater than 0.7 was considered acceptable (Mokkink et al., 2018; Souza et al., 2017; Terwee et al., 2007).

Measurement error concerns the systematic and random error of a patient's score that is not as a result of true changes in the construct being measured. Standard error of measurement (SEM) for absolute agreement was calculated based on the sample standard deviation (SD) and the calculated intraclass correlation coefficient. It was collected from the study sample using the following formula: SEM = SD √(1-ICC) (Baumgartner, 1989).

3.2.9.3 Validity:

Construct validity has been confirmed by using Spearman correlation coefficient (r), which addressed the ability of the questionnaire to measure what it was intended to measure (Terwee et al., 2007). A priori hypothesised patterns of associations with other related and validated instruments are required as evidence of construct validity (Terwee et al., 2007). Thus, construct validity was assessed by comparing the IKDC and ACL-RSI with the KOOS subscales, VAS and the RAND-36 subscales. It was hypothesised that:

1. High correlations between the IKDC and KOOS ADL, KOOS Sport/Rec would be found;
2. The correlations between the IKDC and the RAND-36 subscales of Physical Health (physical functioning, role limitations because of physical problems, and pain) would be higher than between the IKDC and the Rand-36 subscales of Mental Health (role limitation because of emotional problems, vitality, emotional well-being, social functioning and general health);
3. High negative correlations would be found between the IKDC and VAS;
4. High correlations between ACL-RSI and KOOS QoL would be found;
5. Higher correlations would be found between the ACL-RSI and Rand-36 subscales of Mental Health (role limitation due to emotional problems, vitality, emotional well-being, social functioning and general health) than between the ACL-RSI and the Rand-36 subscales of Physical Health (physical functioning, role limitations because of physical problems, and pain);

6. The negative correlations between ACL-RSI and VAS will be moderate to high;
7. The negative correlations between the TSK and KOOS will be moderate to high;
8. The negative correlations between the TSK and Rand-36 will be moderate to high
9. The correlations between TSK and VAS subscales would be moderate to high.

Spearman correlations: $r < 0.30$ = low; $0.30 < r < 0.60$ = moderate; $r > 0.60$ = high have been used to assess construct validity (Streiner, Norman, & Cairney, 2015), with the construct validity of the IKDC and ACL-RSI deemed to be good if 75% of the hypotheses were confirmed (Terwee et al., 2007).

3.2.9.4 Floor/ceiling effects:

The presence of floor or ceiling effects suggests that extreme items are missing at the lower or upper end of the scale, which indicates limited content validity according to (Terwee et al., 2007). Floor/ceiling effects are the limitations faced when measuring health status scores. Being aware of such limitations is important due to the problems that can arise when interpreting the results obtained, no matter the domain being measured, or the instrument being used. Floor/ceiling effects have been considered to be present if over 15% of the participants achieved the lowest-possible or the highest-possible score on the scale (Terwee et al., 2007). The analyses were carried out using SPSS 24.0 software.

3.2.10 Statistical analysis

All statistical analyses were performed using SPSS software (v. 24, SPSS Inc., Chicago, IL). Descriptive analysis (mean and standard deviation) for each dependent variable was carried out. All data was tested for normality using a Shapiro-Wilk test to check whether the data were normally distributed or not (parametric or non-parametric); values were not normally distributed if they are equal to or less than 0.05 (*p*-value was set at 0.05), and descriptive analysis (means and standard deviations) were calculated (Batterham & George, 2003).

Intra-Class Correlation Coefficients (ICCs) and standard error of measurement (SEM) were used to determine the reliability and the level of agreement, and the ICC values were measured as follows: Poor <.40, Fair .40 to 70, Good 70 to 90, Excellent >.90 (Coppieters et al., 2002). Any ICC scores lower than 0.70 result in the hypothesis being rejected (Terwee et al., 2007). The reason for selecting the ICC is because of its stringent and uniform criteria, as well as its coefficient reliability relative the other elements from the same classification or category.

Yaffee (1998) has described how the 'ICC compares the covariance of the scores' with total variance. The decision on the two-way mixed effect, absolute reliability, ICC model (3.1) chosen was made after examining the recommended guidelines put forward by Koo and Li (2016); Shrout and Fleiss (1979). While the ICC appears straight forward with regard to obtaining data, it cannot depict reliability properly if it is used on its own because no error margin is set out between two measurements. Therefore, it is useful to utilise the Standard Error Measurement (SEM), which described by Rankin and Stokes (1998) as 'an important tool that will provide the error interval between two measurements'. Munro et al. (2012) point out that for 'practitioners who require a way to discern individual improvements, calculation of the SEM is incredibly valuable'. The SEM gives a value that can present absolute reliability, and lower values are more reliable. According to Baumgartner (1989), this makes it possible to confirm an approximation of the real change, as well as providing an error interval, by using the formula: SEM = SD (pooled) x $\sqrt{(1\text{-ICC})}$. Calculation of the SEM can help greatly in discerning the actual change in outcomes, instead of a measurement error. Having a high ICC and a low SEM is considered reliable.

Validity analysis was carried on all questionnaires. Relationships, including nonparametric variables, were tested using Spearman's rank correlation (p), to explore the relationships between IKDC, ACL-RSI, TSK and KOOS, RAND-36, VAS. Bonferroni correction was applied in instances where significant differences were found for all comparisons. The Bonferroni correction is a modification made to P values when numerous statistical tests are being performed concurrently on a single data set (Napierala, 2012). The Bonferroni correction is used to reduce the chances of obtaining false-positive results (type I errors) when multiple pair wise tests are performed on a single set of data (Napierala, 2012). To perform a Bonferroni correction, we divided the critical P value (α) by the number of comparisons being made. The statistical power of the study is then calculated based on this modified P value.

3.2.11 Results

3.2.11.1 Subjects

The study included 35 ACLR male patients with a mean (SD) age of 30.34 years (5.9); and a mass of 78.08 kg (16.42). All of the subjects (100%) engaged in sport regularly. 22 (62.9%) have suffered injury to the right knee, and 13 (37.1%) to the left knee. 25 (71.4%) have had hamstring tendon graft reconstruction for the ACL, and 10 (28.6%) have had patellar tendon grafts. 19 (54.3%) of the ACL injuries occurred without physical contact; 16 (46%) were contact injuries, and 32 (91.4%) of ACL ruptures occurred while playing football. The average waiting time of the ACL patients before their operations was 7.2 months, and this ranged from one to 24 months. The average period for post-operative rehabilitation was 5.4 months, which ranged from five to six months, for rehabilitation.

3.2.11.2 Acceptability of the Arabic IKDC and Arabic ACL-RSI:

All of the subjects (100%) completed the questionnaires, and there was no (0%) missing data as all items were answered, which shows that the questionnaire had a very good acceptance rate. Completion of the questionnaire usually took 20-25 minutes, and none of the items were said to be confusing, and no multiple answers were given. All of the subjects agreed to complete the questionnaire a second time, and they all (100%) returned the questionnaires a second time.

3.2.11.3 Reliability

(Table 3.7) illustrates the Cronbach's alpha of IKDC, ACL-RSI and TSK questionnaires. This was between 0.90 and 0.93 and suggests excellent internal consistency for each of the questionnaires. ICCs ranged from 0.93 to 0.95, which reveals a strong correlation between the data collected on both occasions for all of the questionnaires. No differences were found between the means of the test-retest values. The SEM for all questionnaires ranged between 2.0 and 5.61 points.

[α]Table 3.7: [α]Mean IKDC, ACL-RSI and TSK scores at test and retest administrations two week apart, test-retest reliability and internal consistency [α].

	Mean (SD)	Range	Median	% Floor effect	% Ceiling alpha	Cronbach's alpha (α)	ICC (95% CI)	SEM Pt	SDD Pt
IKDC	78.3 (15.1)	46 - 100	82.4	0	2.9	0.91	0.95 (0.93 –0.97)	3.38	9.36
ACL-RSI	67 (21.2)	25 - 100	69.9	0	5.7	0.93	0.93 (0.91 –0.95)	5.61	15.54
TSK	37.5 (7.5)	24 - 54	36.5	0	0%	0.90	0.93 (0.87 –0.96)	2.0	5.50

[α] ICC, Intraclass correlation coefficient; SEM, Standard error of measurement; SDD, Smallest detectable change; Pt, point.

3.2.11.4 Construct validity

The normality tests found that all questionnaires' results were not normally distributed. The correlations between the scores of IKDC, ACL-RSI, TSK and the KOOS subscales, Rand-36, VAS are shown in (Table 3.8) and (See Appendix 8.18) for more detail. The a priori hypotheses have been confirmed, as there is a high correlation between IKDC and KOOS (*p* = 0.76); high correlation between IKDC and Rand-36 subscales of Physical Health; high negative correlations between the IKDC and the VAS (*p* = -0.64); moderate correlations between ACL-RSI and KOOS subscales (*p* = 0.39), and moderate correlations between the ACL-RSI and VAS (*p* = -0.41). In addition, moderate correlations have been found between the TSK, KOOS subscales and VAS (*p* = 0.48 and 0.41)

Table 3.8: [α]Validity: Spearman's correlation between Arabic IKDC, ACL-RSI, TSK and KOOS, VAS, RAND-36 subscales. Bonferroni corrected *p*-value (α = 0.001).

Outcome measure		IKDC	ACL-RSI	TSK
KOOS	KOOS Pain	**0.69**	0.29	-0.39
	KOOS Symptoms	0.28	0.14	-0.18
	KOOS ADL	**0.74**	0.30	-0.49
	KOOS Sport/Rec	**0.74**	0.28	-0.49
	KOOS QoL	**0.62**	**0.55**	-0.37
	KOOS Total	**0.76**	0.39	-0.48
Rand-36	Physical functioning	**0.80**	**0.65**	-0.27
	Role limitations due to physical health	**0.62**	**0.54**	-0.42
	Role limitations due to emotional problems	0.34	**0.66**	-0.34
	Vitality	0.29	**0.75**	-0.25
	Emotional well being	0.46	**0.62**	-0.35
	Social functioning	0.46	0.47	-0.39
	Bodily pain	**0.78**	**0.53**	-0.29
	General health	0.48	0.47	-0.31
VAS		**-0.64**	-0.41	0.41

3.2.11.5 Floor/ceiling:

As only one subject (2.86%) and two subjects (5.71%) scored the highest value on the IKDC and ACL-RSI respectively, floor or ceiling effects are considered not to be present in the Arabic version of the IKDC, ACL-RSI and TSK, as these values are lower than 15% (Terwee et al., 2007).

3.2.12 Discussion

A reliable and valid version of the measurement instruments the IKDC and ACL-RSI questionnaires are required in Arabic, which can be utilised in research that involves measuring outcome in people with knee and ACL injuries in Arabic countries. Currently, no valid and tested version of IKDC and ACL-RSI exists for use in Arabic speaking countries; therefore, the aim was to adapt and translate the English American version of the IKDC and ACL-RSI questionnaires cross-culturally into Arabic. The psychometric properties of the translated version have been evaluated and shown to be satisfactory. Thorough testing for reliability and validity has been carried out in this study, which has revealed that the questionnaire should be useful for other research studies and ensure reliable results. The subjects in this research study had undergone ACLR, and the number of ACLR patients is similar to those in the sample of research by Almangoush et al. (2013). Furthermore, the sample is larger than in other similar studies, such as (Kim et al., 2013) and (Metsavaht, Leporace, Riberto, Sposito, & Batista, 2010), which suggests the potential for strong ecological validity.

The acceptability of the Arabic versions of IKDC, ACL-RSI and TSK was excellent, as there were no disturbing questions or confusing items; no missing data for either items or scales, and the time the subjects took to complete the questionnaire was fairly short. This all confirms that there is no issue with regards to the translation, and that the Arabic version is a reliable and valid measure for Arabic patients with ACLR and meniscal injuries. A markedly higher correlation of the IKDC, KOOS sport/rec and KOOS ADL subscales was found compared to the scores of other KOOS subscales; although this may be due to the age of the patients (mean age 30.3 years), and because all (100%) of them engage in sport on a regular basis.

The Bonferroni correction is used to reduce the chances of obtaining false-positive results (type I errors) when multiple pair wise tests are performed on a single set of data (Napierala, 2012). However, although the Bonferroni correction can become very conservative as the number of tests increases. This, in turn, increases the risk of generating false negatives results (type II errors), the risk of making erroneous false-positive conclusions is increased when testing multiple hypotheses on a single set of data. To discover the risk of generating false negatives results (type II errors) in our findings, we compared the significant differences were found for all comparisons before and after Bonferroni correction and we found that all the significant strong correlation before Bonferroni correction remained, significant with no changes. Thus, there was no risk of increasing false negatives by using Bonferroni correction in this study see (Appendix 8.18).

For IKDC, ACL-RSI and TSK in the present study, the test-retest reliability coefficients were high, illustrating the satisfactory stability of IKDC, ACL-RSI and TSK over time among the current subjects.

3.2.12.1 IKDC

The Arabic IKDC Subjective Knee Form revealed excellent test-retest reliability between repeated measures, as the ICC was (0.95), which is similar to the findings of other studies carried out in different languages under similar conditions; for example, Korean (0.94) by Kim et al. (2013); Dutch (0.96) by Haverkamp et al. (2006), and Brazilian (0.98) by Metsavaht et al. (2010). Internal consistency was also strong, as Cronbach’s alpha revealed values of (0.91), which is comparable to the Cronbach’s alpha of the Brazilian IKDC (0.94) and the Dutch (0.92) and Korean versions (0.91) (Haverkamp et al., 2006; Kim et al., 2013; Metsavaht et al., 2010).

The construct validity of the Arabic IKDC is supported by the higher correlations between the IKDC, KOOS subscales and the RAND-36 subscales, which measure similar constructs (convergent construct validity); as well as the moderate and lower correlations between the IKDC, KOOS subscales and the RAND-36 subscales, which measure dissimilar constructs (divergent construct validity). These findings are in line with the findings of previous cross-cultural adaptation studies (Haverkamp et al., 2006; Kim et al., 2013; Metsavaht et al., 2010). In addition, it can be seen that the IKDC correlated moderately with RAND-36 with regard to role limitations because of emotional problems, which has also been noted in other adapted versions. In comparison to other previous studies, the current study shows a higher correlation between the IKDC and the Rand-36 with regard to role limitations, as a result of the physical problems sub-scale. This may be due to the younger age range of the subjects in the current study compared to other studies. Furthermore, the subjects in the current study had ACLR for a relatively short period since injury, as opposed to OA subjects, which means that they had not yet been affected by secondary disability. The VAS scores were correlated highly negatively with the IKDC scores, and these results are compatible with the Dutch and Brazilian versions that used WOMAC (pain) (Haverkamp et al., 2006; Metsavaht et al., 2010).

One of the limitations with regard to the cross-cultural adaptation, internal consistency, and validity and reliability of the Arabic version of the (IKDC) study, is that the IKDC questionnaire was only completed by male subjects with ACLR. In addition, the age range was young and so the questionnaire should be tested with older patients, including those with osteoarthritis. Even though the questionnaire has been translated into Arabic in order to be easily understood by all Arabic speakers from different urban and rural subcultures, the results should be interpreted with care. As mentioned previously, the subjects that took part are not representative of all patients with knee problems, including women, older age groups, and those with different knee problems. Therefore, there is a need to carry out research with a wider range of subjects, and future research is proposed in order to assess the usefulness and accuracy the questionnaire as a valid instrument for the evaluation of the impact of surgical and rehabilitative interventions.

3.2.12.2 ACL-RSI

The Arabic ACL-RSI has shown strong consistency. The Cronbach's alpha (0.93) was show to be on par with the Cronbach's alpha of the Chinese ACL-RSI (0.96); the French (0.96), and the Dutch versions (0.94) (Bohu et al., 2015; Chen et al., 2017; Slagers et al., 2017). Furthermore, the test-retest reliability of the Arabic ACL-RSI in this study was high (ICC = 0.93), and this is similar to the Turkish (ICC = 0.92); the French (ICC = 0.90), and the Dutch (ICC = 0.93) versions (Bohu et al., 2015; Harput et al., 2017; Slagers et al., 2017).

Determining the specific relationship of the ACL-RSI scale with the KOOS subscales has been examined to check its validity (Bohu et al., 2015; Chen et al., 2017; Harput et al., 2017; Slagers et al., 2017). In the current study, construct validity has been assessed by analysing the relationship between the Arabic ACL-RSI, KOOS subscales and Rand-36. The results show that the correlation between the Arabic ACL-RSI and Rand-36 subscales of Mental Health (role limitation due to emotional problems, vitality, emotional well-being) was high (r = 0.66, r = 0.75, r = 0.62, $p < 0.001$). This was expected, as the ACL-RSI considers emotions, confidence in performance, and risk appraisal among athletes. Previous studies have also reported high correlations between ACL-RSI and the KOOS quality of life subscale that are similar to the present study (r = 0.55), for example the French version (r = 0.64); the Chinese version (r = 0.66), and the Turkish versions (r = 0.58) (Bohu et al., 2015; Chen et al., 2017; Harput et al., 2017). On the other hand, other KOOS subscales (pain, symptoms, ADL and sport & recreation) showed lower correlations with the Arabic ACL-RSI than in previous studies. These differences could be because of the time elapsed (TE) following ACL surgery. TE after ACLR was 5.4 months in the current study, whereas it was 13.6 months in the Turkish version; 9.5

months in the Dutch version, and around 42 months in the Swedish version. The KOOS is intended for use with patients suffering from knee injuries that could result in post-traumatic osteoarthritis (Roos et al., 1998). Due to the TE being longer in the previous studies, the patients' knee function and return to sports readiness could have been better, which may have led to a higher correlation between the KOOS subscales and the ACL-RSI score. In normal every day clinical practice, the Arabic ACL-RSI could assist Arabic clinicians by providing them with standardised and reliable instrument for identifying ACL reconstructed individuals who may it difficult to return to sport due to psychological factors. The evaluation of psychological factors is a key to supporting patients and spotting who require psychological interventions in conjunction with physical therapy.

The ACL Return to Sports after Injury (ACL-RSI) scale study has some limitations with regards to cross-cultural adaptation, internal consistency, and the reliability and validity of the Arabic version. As mentioned previously, the participants were all male, and so the findings of may not be representative of female patients, although there is no evidence in the literature that suggests that females display different psychological responses to men with regard to RTS following an ACL injury. Also, only patients that have undergone ACL reconstruction were included in the current study. Therefore, further studies are needed in order to test the generalisability of the Arabic ACL-RSI scale to patients with ACL deficiency.

3.2.12.3 TSK

The Arabic version of the TSK revealed high test-retest reliability between repeated measures. It showed (ICC = 0.93) and strong internal consistency, with Cronbach's alpha values of (0.90). Previous studies have revealed similar test-retest reliability for the Brazilian-Portuguese TSK (ICC = 0.93) (de Souza, Marinho Cda, Siqueira, Maher, & Costa, 2008), as well as internal consistency with the Cronbach's alpha of the Italian TSK (0.96) (Monticone et al., 2010), although not for patients with ACLR. No previous research has been found in English that has evaluated the test-retest reliability and internal consistency in patients with ACLR, and so it has not been possible to carry out any comparisons between this study's findings and studies published in English.

The lack of validated outcome measures in Arabic meant it was impossible to test the convergent validity of the Arabic TSK, for example with the Fear Avoidance Belief Questionnaire (Waddell et al., 1993); Pain Catastrophizing Scale (Sullivan, Bishop, & Pivik, 1996); Pain Anxiety Symptom Scale (McCracken, Zayfert, & Gross, 1992); Hopkins'

Symptom Checklist (Derogatis, Lipman, Rickels, Uhlenhuth, & Covi, 1974), or the State-trait Anxiety Inventory (Spielberger CD, Goruch RL, & RE, 1970). However, Arabic TSK was validated for patients with low back pain by (Malik et al., 2017). It is important to note this, therefore an attempt was made to validate the new measure for improving ACLR patients' assessment in Arabic countries by testing the discriminant validity of the Arabic TSK through a comparison with the Rand-36, VAS and KOOS subscales (Haugen et al., 2008).

A moderate negative correlation between the Arabic TSK and VAS was found in the current study (r = - 0.41), which may be explained by fear of movement not being directly related to actual pain levels. In addition, moderate to low level correlations were found with Rand-36 that are similar to the findings with the Norwegian version (Haugen et al., 2008), and the highest correlation found with KOOS sport and recreational subscale (r = 49); however, the Norwegian study did not compare the TSK with KOOS subscales. French et al. (2007) discovered low correlation for the original version of TSK with a VAS (r = 0.23), and the Italian (r = 35) and Portuguese versions (r = 0.43) (de Souza et al., 2008; Monticone et al., 2010).

The low correlations of many of the discriminant validity results highlight the ability of the Arabic TSK to distinguish the fear of movement domain from other conceptual domains, such as pain and function. It is predicted that convergent validity will be discovered if further research compares the Arabic TSK with other questionnaires for measuring fear of movement, for example the FABQ (Waddell et al., 1993) once these are translated into Arabic and validated.

This study was limited to Arabic male patients with ACLR; therefore, further research is required to examine other knee conditions, such as patellofemoral joint syndrome, ACL deficit and osteoarthritis, in female as well as male patients. It is likely that introducing an Arabic version of the TSK would enable wider application.

3.2.13 Conclusion

The current study has shown that the Arabic-versions of the IKDC, ACL-RSI and TSK are valid and reliable instruments for Arabic patients with ACLR, although further research is required with a more varied sample, in order to enable generalisation to the wider population.

3.3 Normative values for self-reported knee function, muscle strength and functional performance in a healthy active population

(Question three): Are there differences between Right and Left leg in a healthy active population, in the outcome measures?

3.3.1 Introduction

Functional symmetry between injured and uninjured limbs has been examined in the literature (Ardern et al., 2011b; Borsa, Lephart, & Irrgang, 1998; Clark, 2001; Thomeé et al., 2011), and patients displaying an acceptable level of symmetry of 85 to 100% are seen as being more likely to return to sporting activities. However, a problem has arisen, as several studies have revealed that, actually, the uninjured limb is sometimes much weaker than injured matched control limb (Mattacola et al., 2002; Schmitt et al., 2012), Therefore, any assumptions concerning normality need to be tentatively formed, because the amount of time required for pre-operative and post-operative rehabilitation can result in weakness and atrophy in the uninjured limb and so a disparity to both its pre injury status and to appropriate controls. This shows the importance of normative data being available, and outcomes being compared to normative values from a matched age group. Normative data is useful for carrying out comparisons with the patient population, in addition to comparing side-to-side differences in an individual. Normative data can be used to better inform standard hop distance, strength assessment and self-reported knee function key outcome measured used clinical in the ACLR patient (Herrington, 2013). The main goal following injury to the knee is the return to previous activity levels, and accurate outcome measures will help clinicians in deciding the best time for the patient to return to activities safely (De Carlo & Sell, 1997).

Functional performance tests are useful techniques for assessing more "real world" performance (Jones & Bampouras, 2010), but there are questions around which types of functional tests are most appropriate. There are important points that need to be considered when implementing functional tests, for example the uninvolved side may compensate for the affected limb (Paterno, Ford, Myer, Heyl, & Hewett, 2007; Paterno et al., 2011). In addition, bipedal tasks can hide impairments and the functional deficits that occur after unilateral lower extremity injuries (Pappas & Carpes, 2012). The single-leg hop for distance is an important unilateral functional performance test that has a great deal of support in the literature with regard to its reliability and validity (Clark, 2001). A limb symmetry index (LSI) is usually used to compute scores for single-leg hop for distance, by comparing the affected lower extremity with one that is not affected. Even so, there are concerns around the use of the unaffected limb as the only standard used for the affected limb, as the unaffected limb's ability may decline during rehabilitation, and it could have been affected by a previous injury or surgery. Also, an athlete could have perfect limb symmetry, but not be ready to compete because both limbs are much weaker than usual compared to the average individual (Reid et al., 2007). Apart from studies by (Carlo & Sell, 1997; Munro & Herrington, 2011; Myers, Jenkins, Killian, & Rundquist, 2014), there is no normative data available for hop test performance.

Morris, Dawes, Howells, Scott, and Cramp (2008) explain that one of the most important determinants of physical performance is muscle strength, as it is essential to support performance during activities of daily living and sporting performance. A number of processes, including aging, the development of pathological symptoms, and injury, can result in reduced muscle strength. A range of instruments can be used to measure muscle strength, for example HHD can produce precise measurements, and these allow muscle force to be measured according to a continuous scale. Several studies have shown that HHD is suitable for various settings, and the data has been shown to be reliable and valid in quantifying muscle strength. Despite this, it must be borne in mind that accurate measurement outcomes are useful only if a comparison can be made with unaffected muscle groups or, better still, normative values. ACLR patients, for example, may show a decrease in non-injured leg strength (Herrington, 2013) moreover, recent studies have shown that the matched controls is significantly stronger than non-injured leg (Chung et al., 2015; Hannon, Wang-Price, Goto, Garrison, & Bothwell, 2017; Schmitt et al., 2012) this suggests that the extent of the decline in a particular patient can only be properly assessed through a comparison with normative reference values. This highlights the importance of the use of normative values to compare the outcomes of such measurements (Bohannon, 1997a). Values are usually presented in form of means and standard deviations of maximum voluntary forces carried out by seemingly asymptomatic subjects. However, the majority of published normative values for muscle force are for measurements obtained using isokinetic dynamometers, with limited research into normative values for measurements obtained using hand-held dynamometers (Andrews, Thomas, & Bohannon, 1996; Bohannon, 1997b; Douma et al., 2014).

The International Knee Documentation Committee subjective knee form (IKDC) is a knee-specific outcome measure which is useful for assessing symptoms, as well as function and level of sporting activity (Irrgang et al., 2001). Another option is the Knee injury and Osteoarthritis

Outcome Score (KOOS), which enables the collection of patient reports with regard to their symptoms, pain levels, and the functional limitations due to knee injuries and osteoarthritis (Irrgang, Snyder-Mackler, Wainner, Fu, & Harner, 1998). Normative comparison assists interpreting the data from the results of the IKDC and KOOS, and this can be used to make patient management decisions. It also allows the comparison of different groups of patients so that the closeness of patients to the normal range of functioning can be easily noted, and this is helpful for clinicians when making decisions on readiness to return to normal activities and sports. Few articles have set out the normative values for IKDC (Anderson et al., 2006; Slobogean, Mulpuri, & Reilly, 2008; Xergia et al., 2013) and KOOS (Cameron et al., 2013; Paradowski, Bergman, Sundén-Lundius, Lohmander, & Roos, 2006; Williamson, Sikka, Tompkins, & Nelson, 2016); however, the usefulness of the values produced is reduced due to several factors, including gender, age, the types of subjects involved, and the methods used.

The main aim of this study is to describe normative data scores, as well as scores of different ages, and place them within the context of normal population values. This will be useful for both clinicians who are dealing directly patients, as well as researchers.

3.3.2 Aim and Objectives

- To establish normative scores for single-leg hop for distance in a healthy active population according to age groups.
- To establish normative scores for isometric muscle strength in a healthy active population according to age groups.
- To establish normative scores for self-reported knee function in a healthy active population according to age groups.

3.3.3 Hypothesis

1- To investigate the normative score of single-leg hop for distance in healthy active population.

Hypothesis:

1-a There are no differences between Right and Left leg of healthy active population, in single-hop for distance test.

1-b LSI will be ≥ 90%.

1-c There are differences between healthy age groups, in single-hop for distance test.

2- To investigate the normative score of isometric quadriceps muscle strength in healthy active population.

Hypothesis:

2-a There are no differences between Right and Left leg of healthy active population, in isometric quadriceps muscle strength test

2-b LSI will be ≥ 90%.

2-c There are differences between healthy age groups, in isometric quadriceps muscle strength test.

3- To investigate the normative score of isometric hamstring muscle strength and hamstring muscle strength to quadriceps muscle strength ratio H/Q in healthy active population.

Hypothesis:

3-a There are no differences between Right and Left leg of healthy active population, in isometric hamstring muscle strength tests and H/Q ratio.

3-b LSI will be ≥ 60%.

3-c There are differences between healthy age groups, in isometric hamstring muscle strength tests and H/Q ratio.

4- To investigate normative score of self-reported knee function in heathy active population.

Hypothesis:

4-a (KOOS) score will be ≥ 85%.

4-b (IKDC) score will be ≥ 85%.

4-c There are differences between healthy age groups, in (KOOS).

4-d There are differences between healthy age groups, in (IKDC).

3.3.4 Ethical Considerations and Risk Assessment

This study had been ethically approved by the Research, Innovation and Academic Engagement Ethical Approval Panel at University of Salford HSCR 1617-43 (Appendix 8.6). Every participant in this study had been given a written information sheet providing details about the study. This also described the purpose and procedures of the study, the length of time required, the physical risks involved, and advised of their right to withdraw (Appendix 8.10). Participants were informed that they could ask questions before, during and after the study. After the participants decided to take part, they were checked to see if they met the inclusion criteria, then they were asked to complete and sign a consent form (see Appendix 8.8). All data collected from subjects were held on a secure password protected computer. Each subject was given a reference number so that no individual details could be identified from the data (Data Protection Act, 1998). A risk assessment was conducted according to the study protocol and based on the risk assessment policy and risk control procedures.

3.3.5 Methods

3.3.5.1 Participants

The demographic profile of all participants involved in this study was aged between 18-44 and were divided into three groups:

1- (18-24) years old
2- (25-34) years old
3- (35-44) years old

3.3.5.2 Inclusion Criteria and Exclusion Criteria

The subjects requirements were that they must be healthy active in accordance with American College of Sports Medicine guidelines (exercised at least 3–5 times a week at a moderate intensity for no less than 30 min) (Garber et al., 2011). In addition, the participants should not have experienced any lower extremity injuries during the six months prior to testing, and they must have had no lower extremity surgery at any time. Injury referred to any musculoskeletal complaints that prevented the participant from performing their usual exercise routine.

3.3.5.3 Exclusion criteria

1- Unable to give informed consent or comply with the study procedures.
2. Subjects with cardiovascular, pulmonary or neurological conditions that limited physical activity.
3. Subjects with any lower limb, pelvic or spinal pathology that limits the ability to hop comfortably.
4. Subjects with any lower limb surgery.

3.3.5.4 Recruitment

Healthy active Saudi participants were recruited to take part in the study, all males within three different age categories (18-24; 25-34 and 35-44). The participants that volunteered for the study were physically active individuals who perform a minimum of 30 minutes of physical activity 3-5 times a week, and they were required to have done so for the previous six months. It was also ensured that they had not suffered a lower extremity injury that prevented them from their usual exercise routine during the past six months and had no lower extremity surgery.

3.3.5.5 Sample size and population demographics

3.3.5.5.1 Self-reported knee function

The KOOS and IKDC was administered to 150 healthy males, within three different age categories (18-24; 25-34 and 35-44 years). The number of respondents according to age group is shown in (Table 3.9).

Table 3.9: Number of Respondents by Age

Group age		
	n	**%**
18-24 years	23	15
25-34 years	72	48
35-44 years	55	37
Total	150	100

3.3.5.5.2 Single-leg hop and isometric muscle strength

105 healthy active male participants recruited to take part in the study, 35 in each age categories (18-24; 25-34 and 35-44 years), Characteristics of the population stratified by age group shown in (Table 3.10). The participants who volunteered for the study were physically active individuals. It was also ensured that they had not suffered a lower extremity injury that prevented them from their usual exercise routine during the past six months.

Table 3.10: Characteristics of the subjects stratified by age group

Group age	n	Age (years) (SD)	Height (m) (SD)	Mass (kg) (SD)
18-24 years	35	20.5 (2.2)	172.9 (5.4)	66.1 (14.4)
25-34 years	35	29.6 (2.6)	170.3 (5.6)	70.5 (8.8)
35-44 years	35	36.3 (1.25)	171.3 (3.7)	72.7 (9.8)

3.3.5.6 Procedures

Once subjects have demonstrated that they are interested in the study, they were briefed on the study and have all of the equipment and procedures explained to them. Any questions were answered in full, and if happy, they were asked to sign the consent form (Appendix 8.8). Each subject was given a reference number and his age, height, mass and legs length were noted on the data collection sheet (see Appendix 8.9).

Each participant was asked to:

1. Complete the International Knee Documentation Committee (IKDC) (see Appendix 8.1)
2. Complete the Knee injury and Osteoarthritis Outcome Score (KOOS) (see Appendix 8.2)
3. Measure isometric muscle strength for both legs for knee extensors and knee flexors muscles, using a hand-held dynamometer (HHD).
4. Perform a single-leg hop for distance on both legs.

3.3.5.7 Tests

3.3.5.7.1 Self-reported knee function

Participants were asked to complete the Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire (Appendix 8.2) which is measuring subjective outcomes (Symptoms, stiffness, pain, function daily living, function sport sand recreational activities and quality of life) and The International Knee Documentation Committee subjective knee form (IKDC) questionnaire (Appendix 8.1) which is a knee-specific outcome measure for assessing symptoms, function, and sports activity.

3.3.5.7.2 Isometric muscle strength

In order to collect isometric muscle strength data, for each participant, the data of isometric muscle strength in both legs was taken during the execution of two different tests which are knee extensors and knee flexors muscles using hand-held dynamometer (HHD). For more details see method chapter (section 3.1.7.3)

3.3.5.7.3 Hop Test

In order to collect hop test, participants were asked to perform single leg hop to measure distance, and this was checked by using a normal metric tape measure (Figure 3.8). A 3m strip of tape was placed on the floor, with the start line labelled using a 0.3m strip of tape placed perpendicular to it. The participants performed three practice trials, after which the three test trials were performed to measure single leg hop distance, as described by (Bolgla & Keskula, 1997). An attempt was deemed successful if the participant hops and lands on one leg with complete stability for three seconds. To prevent experimenter bias, subjects were not given any special instructions with regards to their hop strategy. Participants' arm movements were not restricted during the hop tests. The participants were required to achieve three maximum hop attempts with complete stabilisation after landing for three seconds. Attempts were deemed unsuccessful if the participant hops and touches the ground with their other leg during landing, or if they fail to hop within the limited marked distance; any failed hops were counted and noted, but not processed. The participant's leg length was measured while they are lying in a supine position before the first test using a standard tape measure to measure from the anterior superior iliac spine (ASIS) to the distal tip of the medial malleolus. Leg length was used during data analysis to normalise excursion distances (Munro et al., 2012).

The participants began with their toe on the starting line, standing on one leg, before hopping as far as they can horizontally and landing on the same leg, and the distance hopped was recorded. The hop data was normalised to limb length by dividing the distance covered by the participant's leg length and then multiplying by 100, resulting in a percentage value. After completing the test, the participants were asked to repeat the procedure with the other leg (Munro et al., 2012).

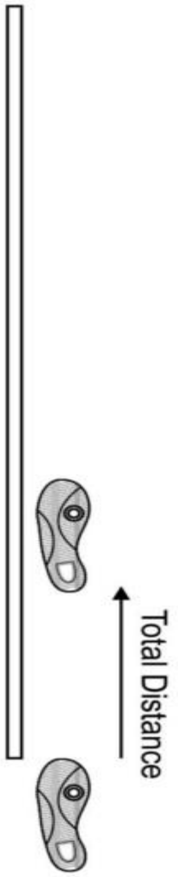


Figure 3.8: Single-leg hop for distance procedure (Munro and Herrington, 2011)

3.3.6 Statistical analysis:

The statistical analyses were carried out using Statistical Package for Social Sciences software (version 24, SPSS Statistics 24. Ink). Descriptive statistics (mean, range of scores and standard deviations) and scatter graphs were presented the data descriptively. Data were tested for normal distribution using Shapiro-Wilk test. Limb differences were determined to evaluate the differences between right and left leg using a Paired-sample t-test with effect sizes determined where significant differences were found. Effect sizes were determined using the Cohen δ method (Thomas et al., 2015), which defines 0.2, 0.5 and 0.8 as small, medium and large respectively.. A *P* value =0.05 was defined as statistically significant. The mean value of the three measures (trials) for each test was calculated.

Scores were stratified by the age range groups: 18 to 24, 25 to 34 and 35 to 44. Variations in questionnaires, single-hop test and isometric strength between age groups were compared using one-way ANOVA with turkey post-hoc analysis used for pairwise comparisons if the data are normally distributed, Kruskal-Wallis test was used if not.

3.3.7 Results

3.3.7.1 Self-reported knee function

A total of 270 subjects responded to the questionnaires. 50 participants reported a history of lower limbs injuries in the past and 40 participants were over 44 years old and were excluded. 30 submitted forms were excluded because they were incomplete. Scores could thus be calculated for 150 subjects included in this study. The highest response rate (48%) was observed among those aged 25-34. The normality tests were assessed using the Shapiro-Wilk test.

Normative mean scores for IKDC scores were determined in each of 3 age categories. However, the mean score for all participants was 91.42 (SD, 8.19; 95%CI, 90.1 - 92.7; range, 68 -100). The oldest groups reported more knee related complaints than younger groups. The 18-24 male reported the highest score (92.9) (Table 3.11).

Normative mean scores for 5 subscales of the KOOS (Pain, Symptoms, Functional ADL, Sports and Recreation Function and Knee-Related QOL) were measured in each of 3 age categories. However, mean scores for all subscales were (92.57), the KOOS subscale with the lowest score was Sport and recreation, except the 18- 24 group symptoms was lowest subscale (Table 3.12).

Table 3.11: [a]IKDC Subjective Knee Evaluation Form Percentiles and Descriptive Statistics by Age group[a]

	Age Group, Men		
Percentage	18-24 y	25-34 y	35-44 y
100			
95			
90	100	100	100
75	99.00	98.75	99.00
50	97.00	91.00	93.00
25	85.00	84.00	84.00
10	81.00	74.30	71.00
5	77.80	70.25	65.60
Mean	92.78	89.53	89.31
95% CI	89.50	87.23	86.29
	96.06	91.83	92.33
SD	7.59	9.78	11.18
Median	97.00	91.00	93
Minimum	77	63	58
Maximum	100	100	100
No. of subjects	23	72	55

[a]IKDC, International Knee Documentation Committee; 95% CI, 95% confidence interval; SD; SD, standard deviation; y, years old.

Table 3.12: [a] KOOS Outcomes by Age Cohort, Stratified by sex

Age / group	Mean ± SD	95%CI	Median	Percentile								
				5	10	25	50	75	90	100	Min.	Max.
18-24 y												
Symptoms	89.8 ± 6.5	87.0 – 92.6	89.0	76.4	82.0	86.0	89.0	96.0	98.4	100.0	75	100
Pain	94.4 ± 5.5	92.0 – 96.7	94.0	82.0	86.0	92.0	94.0	100.0	100.0	100.0	81	100
ADL	95.2 ± 8.3	91.6 – 98.8	99.0	67.8	82.6	93.0	99.0	100.0	100.0	100.0	65	100
Sport/Rec	93.5 ± 8.5	89.8 – 97.1	100	75.0	77.0	90.0	100.0	100.0	100.0	100.0	75	100
QOL	93.3 ± 11.1	88.5 – 98.2	100	58.6	73.8	94.0	100.0	100.0	100.0	100.0	56	100
25-34 y												
Symptoms	89.6 ± 9.4	87.4 – 91.8	93.0	68.6	76.2	83.0	93.0	96.0	100.0	100.0	64	100
Pain	93.5 ± 7.3	91.7 – 95.2	97	78.0	83.0	89.0	97.0	100.0	100.0	100.0	72	100
ADL	94.3 ± 7.6	92.5 – 96.1	97.0	75.7	84.0	91.5	97.0	100.0	100.0	100.0	65	100
Sport/Rec	87.7 ± 15.2	84.1 – 91.3	95.0	53.3	70.0	80.0	95.0	100.0	100.0	100.0	30	100
QOL	90.0 ± 11.1	87.4 – 92.7	94.0	68.7	70.8	81.0	94.0	100.0	100.0	100.0	63	100
35-44 y												
Symptoms	92.0 ± 7.8	89.9 – 94.1	93.0	74.2	79.0	86.0	93.0	96.0	100.0	100.0	71	100
Pain	93.2 ± 8.5	90.9 – 95.5	97.0	77.4	97.8	89.0	97.0	100.0	100.0	100.0	72	100
ADL	92.9 ± 9.5	90.3 – 95.4	96.0	75.0	76.0	91.0	96.0	100.0	100.0	100.0	53	100
Sport/Rec	89.9 ± 14.0	85.3 – 92.9	95.0	54.0	71.0	80.0	95.0	100.0	100.0	100.0	45	100
QOL	92.0 ± 12.4	88.7 – 95.4	100	67.80	75.0	88.0	100.0	100.0	100.0	100.0	38	100

[a]KOOS, Knee Injury and Osteoarthritis Outcome Score; 95% CI, 95% confidence interval; SD; SD, standard deviation; y, years old; QOL, quality of life; ADL, activities of daily living; y, years old

Kruskal-Wallis test was conducted to explore the impact of age on self-reported knee function scores, as measured by the Life Orientation Test (LOT). Participants were divided into three groups according to their age (Group 1: 18-24yrs; Group 2: 25-34yrs; Group three 35-44yrs). There were a statistically significant differences for IKDC and KOOS (p = 0.02 and p = 0.0001) respectively at the p = 0.05 level in LOT scores for group (18-24), (25-34) and (35-44). Post-hoc analysis for pairwise comparisons shown in (Table 3.13).

Table 3.13: [a] Comparison of significant (P = 0.05) between age groups

Task	Age Group	(18-24)	(25-34)	(35-44)
IKDC	(18-24)	-----	**0.03***	**0.01***
	(25-34)	-----	-----	0.78
KOOS Symptoms	(18-24)	-----	0.79	0.92
	(25-34)	-----	-----	0.34
KOOS Pain	(18-24)	-----	0.47	0.23
	(25-34)	-----	-----	0.77
KOOS ADL	(18-24)	-----	0.43	**0.05***
	(25-34)	-----	-----	0.26
KOOS Sport/Rec	(18-24)	-----	**0.05***	**0.03***
	(25-34)	-----	-----	0.94
KOOS QOL	(18-24)	-----	0.09	0.47
	(25-34)	-----	-----	0.45

(*) Statistically significant
[a] IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; 95% CI, 95% confidence interval; SD; SD, standard deviation; y, years old; QOL, quality of life; ADL, activities of daily living.

3.3.7.2 Single-leg hop for distance

Normality checking findings for all tests in all age groups were performed using Shapiro-Wilk test. (Table 3.14) below shows the descriptive statistics for single-hop test scores both right and left leg. Furthermore, it provides a summary of reference values for all age groups in healthy population, including the mean and standard deviation for the hop normalisation to leg length, normalisation to leg length by dividing the distance reached by leg length, then multiplying by 100 and LSI which calculated by dividing the normalised distance hopped on the right leg by the normalised distance hopped on the left leg, and multiplying the result by 100, giving a percentage value. Detail results of single-hop test including the mean and standard deviation, p-value, effect size and LSI for the hop distance (cm) in (Appendix 8.13). There were statically significant differences in single hop distance (%) between right and left leg apart from in age group 25-34. see (Table 3.14).

Table 3.14: Mean (SD) and p-value, Comparison of significant (P = 0.05) between right and left leg single-hop test in men age groups

Test	Right leg (SD)	Left leg (SD)	p-value	Effect size	Single hop LSI (%)
Men (18-24) n=35					
Single hop (%)	170.16 ± 12.13	165.80 ± 15.64	0.03*	0.38	103.05 ± 6.9
Men (25-34) n=35					
Single hop (%)	148.06 ± 21.88	147.74 ± 16.78	0.85	0.03	100.02 ± 6.85
Men (35-44) n=35					
Single hop (%)	137.85 ± 32.05	133.14 ± 37.93	0.002*	0.40	107.02 ± 8.70

(*) Statistically significant

(Table 3.15) below shows the percentage of participants achieving LSI values for single-leg hop test. It seems that the majority of the participants achieved 85% of LSI.

Table 3.15 Percentage of participants achieving LSI values for single-leg hop test

LSI	≥ 85	≥ 90	≥ 95	≥ 100
Men (18-24) n=35				
Single leg hop	35 (100%)	32 (91%)	31 (89%)	28 (80%)
Men (25-34) n=35				
Single leg hop	35 (100%)	34 (97%)	32 (91%)	28 (80%)
Men (35-44) n=35				
Single leg hop	35 (100%)	34 (97%)	33 (94%)	29 (83%)

one-way ANOVA test was conducted to explore the impact of age on single hop performance, as measured by the Life Orientation Test (LOT). Participants were divided into three groups according to their age (Group 1: 18-24yrs; Group 2: 25-34yrs; Group three 35-44yrs). There was a statistically significant difference in right single leg hop (p = 0.02) and left single leg hop (p = 0.01) at the p = 0.05 level in LOT scores for group (18-24), (25-34) and (35-44). Post-hoc analysis for pairwise comparisons shown in (Table 3.16).

Table 3.16: Comparison of significant (P = 0.05) between age groups in hop test

Task		(18-24)	(25-34)	(35-44)
Right Single leg hop (%)	(18-24)	-----	**0.0001***	**0.01***
	(25-34)	-----	-----	0.19
Left Single leg hop (%)	(18-24)	-----	**0.0001***	**0.0001***
	(25-34)	-----	-----	**0.04***
Hop LSI	(18-24)	-----	0.26	
	(25-34)	-----		

(*) Statistically significant

3.3.7.3 Isometric muscle strength

Normality checking findings for all tests in all age groups were performed using Shapiro-Wilk test. (Table 3.17) below shows the descriptive statistics for isometric muscle strength test scores both right and left leg. Furthermore, it provides a summary of reference values for all age groups in healthy population, including the mean and standard deviation for the peak force in (Nm) normalized to body mass (Nm/Kg), normalisation to body mass in by dividing the peak force by body mass, then multiplying by 100, hamstring/quadriceps ratio by dividing the hamstring peak force by quadriceps peak force and multiplying the result by 100, and LSI which calculated by dividing the normalised peak force on the right leg by the normalised peak force on the left leg, and multiplying the result by 100, giving a percentage value. Detailed results of the peak force in N, N/kg and Nm including the mean and standard deviation, p-value, effect size and LSI for the quad recipes and hamstring muscle strength in (Appendix 8.13).

There were no statically significant differences in quadriceps and hamstring peak force in (N. Nm), no differences in peak force normalisation to body mass in (N/kg, Nm/kg) and no differences in quadriceps/ hamstring ratio between right and left leg (p=0.05), see (Table 3.17).

Table 3.17: Mean (SD) and p-value, Comparison of significant (P = 0.05) between right and left leg peak force test in men age groups

Test	Right leg (SD)	Left leg (SD)	p-value	Effect size	LSI (%) (SD)
Men (18-24) n=35					
Quadriceps peak force (Nm/kg)	2.84 ± 0.57	2.83 ± 0.71	0.97	0.01	101.74 ± 21.23
Hamstring peak force (Nm/kg)	1.50 ± 0.35	1.55 ± 0.37	0.08	0.30	97.60 ± 11.95
Hamstring / Quadriceps ratio (%)	54.87 ± 10.38	56.66 ± 12.53	0.46	0.12	
Men (25-34) n=35					
Quadriceps peak force (Nm/kg)	2.39 ± 0.43	2.41 ± 0.60	0.60	0.10	100.51 ± 7.42
Hamstring peak force (Nm/kg)	1.28 ± 0.27	1.30 ± 0.30	0.54	0.11	99.96 ± 11.42
Hamstring / Quadriceps ratio (%)	53.97 ± 8.93	54.85 ± 10.98	0.47	0.12	
Men (35-44) n=35					
Quadriceps peak force (Nm/kg)	2.26 ± 0.28	2.26 ± 0.30	0.98	0.01	101.60 ± 15.74
Hamstring peak force (Nm/kg)	1.17 ± 0.18	1.20 ± 0.26	0.44	0.13	100.15 ± 17.03
Hamstring / Quadriceps ratio (%)	52.01 ± 7.98	52.66 ± 6.47	0.66	0.07	

(Table 3.18) below shows the percentage of participants achieving LSI values for isometric muscle test. It seems that the majority of the participants achieved 85% of LSI.

Table 3.18: Number and percentage of participants achieving LSI values for isometric muscle tests.

LSI	≥ 85	≥ 90	≥ 95	≥ 100
Men (18-24) n=35				
Quadriceps muscle peak force	35 (100%)	33 (94%)	30 (86%)	25 (71%)
Hamstring muscle peak force	35 (100%)	32 (91%)	31 (89%)	24 (69%)
Men (25-34) n=35				
Quadriceps muscle peak force	35 (100%)	34 (97%)	32 (91%)	23 (66%)
Hamstring muscle peak force	35 (100%)	32 (91%)	31 (89%)	27 (77%)
Men (35-44) n=35				
Quadriceps muscle peak force	34 [a] (97%)	31 (89%)	29 (83%)	22 (63%)
Hamstring muscle peak force	34 [a] (97%)	34 (97%)	28 (80%)	20 (57%)

[a] One subject scored < 85

one-way ANOVA was conducted to explore the impact of age on isometric muscle strength, as measured by the Life Orientation Test (LOT). Participants were divided into three groups according to their age (Group 1: 18-24yrs; Group 2: 25-34yrs; Group three 35-44yrs). There were a statistically significant differences in right and left quadriceps muscle strength (p = 0.02 and 0.01) respectively, and there were a statistically significant differences in right and left hamstring muscle strength (p = 0.02 and 0.01) respectively at the p = 0.05 level in LOT scores for group (18-24), (25-34) and (35-44) age groups in Quadriceps and hamstring muscle strength / body mass. Post-hoc analysis for pairwise comparisons shown in (Table 3.19).

Table 3.19: Comparison of significant (P = 0.05) between age groups in isometric muscle test.

Test	**Age Group**	(18-24)	(25-34)	(35-44)
Right Quadriceps muscle / body mass	(18-24)	-----	**0.0001***	**0.0001***
	(25-34)	-----	-----	1
Left Quadriceps muscle / body mass	(18-24)	-----	**0.01***	**0.0001***
	(25-34)	-----	-----	1
Right hamstring muscle / body mass	(18-24)	-----	**0.01***	**0.0001***
	(25-34)	-----	-----	0.29
Left hamstring muscle / body mass	(18-24)	-----	**0.02***	**0.0001***
	(25-34)	-----	-----	0.52
Right Hamstring / Quadriceps ratio	(18-24)	-----	0.41	
	(25-34)	-----		
Left Hamstring / Quadriceps ratio	(18-24)	-----	0.33	
	(25-34)	-----		
Quadriceps muscle LSI	(18-24)	-----	0.37	
	(25-34)	-----		
Hamstring muscle LSI	(18-24)	-----	0.59	
	(25-34)	-----		

(*) Statistically significant

3.3.8 Discussion

3.3.8.1 Self-reported knee function

The main aim of this study, as described previously, is to discover and set out normative data for scores using the KOOS and IKDC using a representative sample. Previous normative data scores for the KOOS and IKDC are limited, as they have compared narrow age ranges, for example preadolescents, or have included only those patients with a history of hard physical activity, such as military personnel. Others have included a wide age range but have not taken into consideration the participants' history of knee-related injuries, which is a confounding factor for normative scores. The data shown in (Table 3.11 and 3.12) sets out baseline data, which can be used by researchers and clinicians to compare with a point of reference. It is useful for evaluating treatment options according to the characteristics of the patient attending a clinic with a knee-related problem, such as age; the data enables a comparison between patients who are a similar age and so on. Moreover, the sample size used in this study is bigger than the sample size used in other similar studies investigated normative values for self-reported knee function, for example (Slobogean et al., 2008; Xergia et al., 2013), thereby suggesting an adequate sample size has been attained.

As an example of using (Table 3.11), a 40 year old scoring 93 has a percentile ranking of 50, which shows that his score is 50% greater than most men between the age of 35 and 44. Also, this normative data can be used for converting the patient's score on a Subjective Knee Form into a standard score (z), which compares the patient's results with the average for a healthy population, as well as the standard deviation for the patient's age and gender. Anderson et al. (2006) show that the standard score for a patient can be calculated as follows:

$$z = \frac{\text{patient's score} - \text{mean score for age, group}}{\text{standard deviation for age group}}$$

An example using (Table 3.11) is the standard score for a 20-year-old man scoring 80 on the IKDC is as follows:

$$-1.68 = \frac{80 - 92.78}{7.59}$$

This means that his score is 1.68 SDs lower than the population mean for men aged between 18 and 24. Another example is a 30 year old man who scores 100 on the IKDC, which gives a standard score of 1.07, showing that his result is 1.07 of an SD higher than the population mean for men aged 25 to 34 years. A patient's result can be converted into a standard score using the Subjective Knee Form, as there is a mechanism that can adjust the results according to the patient's age. This allows for a more accurate comparison between patients who differ according to age.

In this study, the mean scores for IKDC of all respondents were slightly higher than (Anderson et al., 2006; Slobogean et al., 2008) studies. This may be because they included participants with a history of injuries, and they failed to explain how they differentiate between healthy and injured in their findings. However, in the study by (Slobogean et al., 2008) they included only adolescents (aged 12 – 14 years), while (Anderson et al., 2006) they used an amended version of IKDC, also, they estimated the missing questions which may impact on the accuracy of their results. (Xergia et al., 2013) discovered a mean score for healthy people of 100, but as they only included 22 physically active men, it is not possible to generalise these findings.
To understand Subjective Knee Form scores, age and gender are statistically significant factors, with an age-related decrease in scores typically observed (Table 3.11). (Anderson et al., 2006)

have reported no differences in scores for the age category 18 to 34 years old, as the mean scores are 89.1 for the age group 18 to 24, and 88.9 for the age group 25 to 34 years; however, there an inverse relationship was found between scores for age groups above 34 years. Anderson et al (2006) suggest that this is either because there is limited sensitivity in the IKDC Subjective Knee Evaluation Form for highly functioning knees, or because there really is very little difference in the functioning of the knees of young adults. The results from this study do not support this, as there were significant differences in IKDC score outcomes were shown between age groups (Table 3.13). Moreover, the differences between groups exceeded the standard error of measurement value found in the current study for IKDC (3.38 points) for more details see method chapter (section 3.2.11). Therefore, it is likely that the differences were caused by performance and not measurement error and the difference in mean scores overall, suggests that the results should be compared to same age cohorts in clinical studies utilising the IKDC Subjective Knee Form. The study by (Paradowski et al., 2006) is similar to this study with regard to the normative values for KOOS. On the other hand, (Cameron et al., 2013) reported higher normative scores compared to this study. This may be because they included only patients with a history of high-level athletic demands. Also, the participants may have been concerned about their responses being used to determine their level of fitness for military duty. In the study by (Williamson et al., 2016), they included participants with a history of lower limb injuries. Therefore, their findings cannot be generalised as a healthy population normative data.

The construct validity of the KOOS may have affected the variability in the scores observed for the younger and older age groups, because it considers the different lifestyles of the age groups. Those from younger age groups engage in a wider range of activities due to their participation, or indeed not, in strenuous physical activities such as sports, whereas older populations may restrict their activity levels more; therefore, but the level of age related changes may cause this greater variability. While statistically significant differences between age groups for KOOS was noted for ADL and Sport/Rec subscale in the current study, the way that participants experience a decline in scores with age shows the importance of age specific normative data for evaluating patients using the KOOS.

Several limitations should be considered when interpreting the results of the study, which are as follows:

- No clinical examination of participants was carried out to check whether they were healthy and had no lower limb injuries.
- Those with injuries were excluded on the basis of the question: Do you have a lower limb injury? However, some participants may have failed to disclose that they had lower limb injuries.

Overall, however, the results help to provide a benchmark for future comparisons with healthy populations. The findings from the current study also demonstrate how knee health and self-reported knee function can change over time in the older population.

3.3.8.2 Single-leg hop for distance

The aims of this study were to:

1- Establish normative scores for single-leg hop for distance and LSI in an active healthy population according to age groups.

2- Investigate the differences between right and left leg performances for single-leg hop for distance.

3- Investigate the differences between age groups performances for single-leg hop for distance.

The main aim of this study, as described previously, is to discover and set out normative data for single-leg hop for distance. Previous normative data scores for single-leg hop for distance are limited, as they all have included high school population only in their study. The data shown in (Table 3.14) sets out baseline data, which can be used by researchers and clinicians to compare with a point of reference. It is useful for evaluating treatment options according to the characteristics of the patient attending a clinic; the data enables a comparison between patients who are a similar age. Moreover, the sample size used in this study is bigger than the sample size used in other similar studies investigated normative data for hop test, for example (Munro & Herrington, 2011; Xergia et al., 2013), thereby suggesting an adequate sample size has been attained.

This study shows the raw and normalised scores, which while useful for carrying out a comparison between an individual’s raw and normalised scores, is not particularly useful when carrying out cross-comparisons with other groups or individuals. It has been noted in previous studies that taller individual’s usually hop further in a single hop test (Gaunt & Curd, 2001; Kramer, Nusca, Fowler, & Webster-Bogaert, 1992); therefore it may be assumed differences in leg length will cause hop distance to vary, and so normalising hop distance scores according to leg length would be useful and help to reduce between subject variability. This should facilitate more accurate comparisons between individuals, as well as for scores between limbs for the same subject.

In this study, the mean scores for all age groups in the single-leg hop for distance was 136 cm. In addition, normalising the hop for all of the age groups achieved 151%, which is a little lower than the hop normality findings of Onate et al. (2018), which was 187.8%; Myers et al. (2014), which was 181 cm for single-leg hop for distance; Baltaci et al. (2012), which was 177 cm; Munro and Herrington (2011) for the single-leg hop for distance, which was 163.6 cm and 176.9% for normalising hop; and De Carlo and Sell (1997), which was 155cm for single-leg hop for distance. Despite these results, the comparison has some shortcomings in that the research studies included samples of different sizes, age ranges, and activity levels.

The results have revealed no differences between right and left leg performance for the middle age group (25-34), although for the youngest and oldest age groups (18-24 and 35-44) there were statically significant differences between the performance of the right and left leg, although the effect sizes were minimum, and the differences not functionally relevant as they fell within the standard error of measurement values found in other studies (Bolgla & Keskula, 1997; Booher, Hench, Worrell, & Stikeleather, 1993; Munro & Herrington, 2011; Myers et al., 2014) for single hop for distance (4.56 cm - 7.93 cm); in addition, the differences were lower than the standard deviations of the normative values proposed. Therefore, it is likely that the changes were caused by measurement error and not performance.

In the single-leg hop for distance test, all of the participants scored 85% of LSI, similar to Noyes et al. (1991) who discovered a limb symmetry index of 85% or greater during single-leg hop for distance test, which is within the normal range. Munro and Herrington (2011) discovered the average LSI in the single-leg hop for distance to be 100.35 percent, with 100 percent of healthy participants revealing an LSI of at least 90%, thus according to these results, it may be beneficial for the return to sport LSI criteria for hop tests to be increased to 90% as opposed to the previously recommended 85% (Noyes et al., 1991). Although 103.4% of LSI was achieved in the current study, in the range with (De Carlo & Sell, 1997; Munro & Herrington, 2011), but greater than the results of Onate et al. (2018) (94.5%), it is still hard to determine the dominant and non-dominant limb. This is because some individuals may think that the dominant leg is the one they use when kicking a ball, whereas others may define it as the one planted on the floor when kicking a ball. The dominant leg could be identified according to fore production or performance during a functional task, such as hop distance, although specific criteria for this would need to be set out. There will also be a problem if the individual shows strength dominance in one leg but performance dominance in the other during a functional task. In the current study we calculated the LSI as described by De Carlo and Sell (1997), the average of performance on the right leg was divided by the average of performance on the left leg and the result was multiplied by 100.

An examination of the link between hop performance and age has flagged up some specific relationships, in particular, the significant difference in hop performance according to age, as aging results in changes and a decrease in hop performance, and in older adulthood, hop performance decreases are considerable. There were statistically significant differences between age groups in the right and left leg hop performance. The differences in hop distance between the youngest age group and oldest age group was more than 40 cm, which could present clinical consequences because 40 cm could be as much as 35 percent of the hop performance shown in the current study. Hop distance to leg length between the different age groups was 32%, which could also have clinical consequences because 32% could be as much as 25 percent of hop performance in the current study. Moreover, the differences between groups exceeded the standard error of measurement values found in other studies (Bolgla & Keskula, 1997; Booher et al., 1993; Munro & Herrington, 2011; Myers et al., 2014) for single hop for distance (4.56 cm - 7.93 cm); in addition, the differences were higher than the standard deviations of the normative values proposed. Therefore, it is likely that the differences were caused by performance and not measurement error.

Therefore, the importance of using age-matched reference data for specific functional tests is clear, as this should help to avoid over or under representation of the performance ability of individuals.

3.3.8.3 Isometric muscle strength

The aims of this study were to:

1- Establish normative scores for quadriceps muscle isometric strength, quadriceps strength/body mass and quadriceps LSI in an active healthy population according to age groups.
2- Establish normative scores for hamstring muscle isometric strength, hamstring strength/ quadriceps strength ratio and hamstring LSI in an active healthy population according to age groups.

3- Investigate the differences between right and left leg isometric strength for quadriceps and hamstring muscles.
4- Investigate the differences between age groups muscle strength for quadriceps and hamstring muscles.

The main aim of this study, as described previously, is to discover and set out normative data for isometric muscles strength. Previous normative data scores for isomeric muscles strength are limited, as they have compared narrow age ranges, for example children or elderly, or have used only specific devices to measure the strength, such as Biodex system Pro. Others have included a wide age range but have not taken into consideration the participants' history of knee-related injuries, which is a confounding factor for normative scores. The data shown in (Table 3.17) sets out baseline data, which can be used by researchers and clinicians to compare with a point of reference. It is useful for evaluating treatment options according to the characteristics of the patient attending a clinic; the data enables a comparison between patients who are a similar age. Moreover, the sample size used in this study is bigger than the sample size used in other similar studies investigated normative values for muscle strength, for example (Andrews et al., 1996; Bohannon, 1997b; Xergia et al., 2013), thereby suggesting an adequate sample size has been attained.

Past studies have noted the impact that the individual's mass has on muscle strength (Wren & Engsberg, 2007), and to address lower limb muscle strength differences, some researchers have divided the individual's muscle force values by their body mass (Hébert, Maltais, Lepage, Saulnier, & Crête, 2015; Jaric, 2002). It is fair to assume that differences in body mass will have an impact on muscle strength, and so normalising force scores according to body mass could help to reduce between subject variability and facilitate a more accurate comparison of individuals. In addition, it would help in obtaining accurate comparisons for scores between limbs for the same subject.

This study shows the raw and normalised scores (N, N/kg and Nm, Nm/kg), which while useful for carrying out a comparison between an individual's raw and normalised scores, is not particularly useful when carrying out cross-comparisons with other groups or individuals.

For the quadriceps peak force, the mean scores in this study for all age groups was 415.5 N (170.5 Nm), and for hamstring peak force it was 221.5 N (91 Nm) for all age groups. This is similar to Andrews et al. (1996) findings who found 406 N and 233 N for quadriceps and hamstring muscles respectively, and lower than the results of previous study that used HHD on quadriceps peak force, which was 531 N, as well as hamstring peak force, which was 406 N, for the research conducted by (Bohannon, 1997b) respectively. However, these studies have used a non-fixed HHD method, and this could have increased the risk of the strength of the rater or the subject affecting the result.

The only research into the HHD for measuring isometric peak force for quadriceps and hamstring among different young people of different ages was (Douma et al., 2014) who found that quadriceps peak force was lower than the current study at 353 N, whereas hamstring peak force was higher at 255 N. This is not surprising because the current study used the make method, whereas the Douma et al. (2014) used the break method, which can result in higher results when measuring muscle strength (Burns & Spanier, 2005). Furthermore, Douma et al. (2014) have used a non-fixed HHD method, and this could have increased the risk of the strength of the rater or the subject affecting the result; moreover, in their study they found a hand-held dynamometer is not suitable for measuring the quadriceps muscle force of stronger participants, it’s obvious that the rater could not give enough resistance to the subject which resulted in decrease the quadriceps strength in their findings. In addition, it is not possible to make direct comparisons when there are differences such as age range, population, sample size, and activity levels of the participants, as well as the method employed.

For the quadriceps peak force normalisation to body mass, the mean scores in this study were (2.84 Nm/kg, 2.40 Nm/kg and 2.26 Nm/kg) for (18-24, 25-34 and 35-44) age groups respectively, this findings however, within the literature range for quadriceps strength normalisation to body mass (2 Nm/kg, 2.32 Nm/kg, 2.56 Nm/kg and 2.75 Nm/kg) (Hannon et al., 2017; Kaminska et al., 2015; Kuenze et al., 2017; Pamukoff, Pietrosimone, Ryan, Lee, & Blackburn, 2017) respectively. Also, hamstring/quadriceps ratio in our study were ranged from 52% to 57% which is found to be in the literature range for hamstring/quadriceps ratio 50% to 80% (Ardern, Pizzari, Wollin, & Webster, 2015). The results have revealed no differences between the performance of the right and left leg for all age groups.

During the quadriceps and hamstring muscle strength tests, the majority of the participants achieved more than 85% of the LSI for the majority of the variables. This is important because if the difference between limbs is greater than 15 % in healthy athletes, this is substantial asymmetry and can place the limbs at an increased risk of injury (Knapik et al., 1991).

The findings of Douma et al. (2014) show that the average LSI for the quadriceps was 103% percent and 104% for the hamstring. In addition, (Andrews et al., 1996; Bohannon, 1997b) discovered that the average LSI for the quadriceps was 102% and Bohannon (1997b) found that it was 99%. According to Willigenburg, McNally, and Hewett (2014), the asymmetries between limbs for strength and function may affect athletic performance, as they discovered that LSI for quadriceps was 98.93, while for hamstrings it was 94.19, when comparing between the dominant and non-dominant limbs in 22 healthy athletes. Similar to previous study we found high LSI for the quadriceps was 101.3% and 99.2% for the hamstring.

Regression equations highlight the importance of gender and mass when it comes to muscle force, yet they found that age is less significant. A number of regression analyses show that the impact of age is small, but significant, because of the considerable sample (Andrews et al., 1996; Bohannon, 1997b; Douma et al., 2014). These researchers also found that gender, age and mass are predictors of muscle force, with age correlating significantly, although limited to muscle force. The outcomes of the current study in comparison to earlier studies revealed a statically significant difference in quadriceps and hamstring isometric muscle tests between age groups, also, an important clinical difference between the age groups. This is because the differences in quadriceps and hamstring isometric muscle tests between age groups were major, for example the differences in muscle force between the youngest and oldest age group was 43 Newton for knee extension; which may make up to 11 percent of maximum knee extension force. In addition, differences were found in the current study in hamstring muscle force for between age groups at 30.5 Newton, which may cover up to 15 percent of the maximum knee extension force. Moreover, in the current study (section 3.1.10) we have concluded that, it is necessary to achieve changes of 7.68 N when measuring quadriceps and hamstring muscle strength using HHD in order to measure true difference rather than measurement error for more details see method chapter (section 3.1.10). However, the differences between age groups exceeded 7.68 Newton and this could have clinical consequences.

This emphasises how important it is to use age-matched reference data for specific muscle tests so that overrepresentation or underrepresentation of the force capabilities of a particular muscle group does not occur. The results of the current study show that it is not possible to generalise reference values to a specific country, geographical area, or population. Therefore, it is important to generate reference values for different countries and geographical areas.

3.3.9 Conclusion

Based on the results of the study, all the hypotheses have been accepted and the following results can be highlighted:

- Statistically significant differences were found between the right and left leg performances in single-leg hop for distance test.
- No significant differences were found between the right and left leg performances in all isometric muscle tests.
- Symmetry between limbs exists for all tests, LSI were more than 95% between right leg and left leg.
- There were differences between age groups performances for all tests.

This study has generated normative reference data that may be used to determine the impairments linked to musculoskeletal and neuromuscular disorders, along with ways of monitoring the progression of disease over time. The reference values and associated age-gender matched scores may be used for developing more precise outcome measures and increase responsiveness, which will be useful for clinical trials.

It must be borne in mind that an absence of normative values for functional assessments, muscle strength and self-reported knee function presents challenges to clinicians as they attempt to determine whether patients' functional characteristics and strength are abnormal or not. The results of the current study should assist clinicians in making age-specific functional and physical performance comparisons for improving patients' health and assessing performance levels and return to participation criteria.

Chapter 4

4 Functional Recovery at discharge from Rehabilitation Following Anterior Cruciate Ligament Reconstruction

(Question four): Are there differences in outcomes measures between injured and uninjured leg in ACLR patients at discharge from rehabilitation?

(Question five): Are there any correlations between single-leg hop for distance, isometric muscle strength, self-reported knee function, and psychological factors of ACLR patients at discharge from rehabilitation?

4.1 Introduction

Rupturing of the anterior cruciate ligament (ACL) is common among sportspersons, especially in sports that require cutting and pivoting (Prodromos et al., 2007), and it has major negative consequences. To facilitate return to sport, an anterior cruciate ligament reconstruction (ACLR) is typically performed; however, it has been shown in recent meta-analysis data from over 7000 participants following ACL reconstruction that just 65% returned to their previous level of sporting activity following ACLR, with only 55% returning to competitive sport (Ardern, Taylor, et al., 2014).

Barber-Westin and Noyes (2011) carried out a review which examined the factors used to decide clearance to return to sports following ACLR. They found that 32% of studies only used the postoperative timeline as a guideline for making the decision on returning to sport, with just 13% of studies taking objective measures and specific criteria into account to determine whether an athlete should return to sport. Many of the studies that claim to have used objective criteria for return-to-sport decision making have involved assessments that test strength, functional based performance, self-reported knee function, and psychological readiness, bearing in mind that the specific criterion and values vary among these studies (Gokeler et al., 2017).

In order to objectively assess the patient’s readiness for return to sports following ACLR, several indicators of return-to-sport success are usually considered, in particular, strength tests for the quadriceps and hamstrings (Czuppon et al., 2014) and the single-leg hop test (Abrams et al., 2014). Hop tests are often used to measure performance scores and assess the muscle strength of the lower extremities. Assessing the quadriceps and hamstrings' maximum strength is also essential to monitoring recovery following an ACLR (Moisala et al., 2007), and the results can be used as a baseline to determine and develop tailor made treatment plans for individual patients (Felson et al., 2000).

Previous studies also recommend the use of patient reported measures of function, as well as the aforementioned strength and physical performance measures, in order to assess return-to-sport readiness following ACLR. The measures most commonly used for self-reported knee function, in return-to-sport decision making after ACL reconstruction, are the IKDC and the KOOS (Hambly & Griva, 2010). In addition, psychological factors following injury and fear of re-injury need to be considered, as these may prevent RTS following an ACLR (Kvist et al., 2005).

Knowledge of the knee and functional performance, as well as objective and subjective measures, and psychological factors, among patients with ACLR is poor, whether they are recreationally active or professional athletes. This lack of knowledge isn't then available to be used to guide patients with ACL injuries towards more realistic expectations concerning knee function and activity levels, assisting clinicians with adapting treatment measures and rehabilitation. Therefore, this chapter will be divided to two parts.

The first part is to investigate single-leg hop for distance, isometric muscle strength, self-reported knee function and psychological factors for ACLR patients at discharge from rehabilitation. The second part is to assess the relationship between these outcomes.

4.2 Aim and Objectives

- To examine single-leg hop for distance of ACLR patients at discharge from rehabilitation on the injured leg and compare it with uninjured leg.
- To examine isometric muscle strength of ACLR patients at discharge from rehabilitation on the injured leg and compare it with uninjured leg.
- To examine patients' self-reported knee function of ACLR patients at discharge from rehabilitation and compare it with return to sport criteria.
- To assess psychological factors of ACLR patients at discharge from rehabilitation and compare it with return to sport criteria.
- To correlate single-leg hop for distance, strength, self-reported knee function and psychological factors of ACLR patients at discharge from rehabilitation to discover whether any of these factors can predict the others.

4.3 Hypothesis

1) To investigate the single-leg hop for distance of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   1-a There are differences between injured leg and uninjured leg of ACLR patients.

2) To investigate the isometric quadriceps muscle strength of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   2-a There are differences between injured leg and uninjured leg of ACLR patients.

3) To investigate the isometric hamstring muscle strength and hamstring to quadriceps ratio H/Q of ACLR patients at discharge from rehabilitation

   Hypothesis:

   3-a There are differences between injured leg and uninjured leg of ACLR patients, the isometric hamstring muscle strength.

   3-b There are differences between injured leg and uninjured leg of ACLR patients, the H/Q ratio.

4) To investigate self-reported knee function (KOOS) of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   4-a There are differences between ACLR patients, and the cut-off score for return to sport (score ≥ 90) in (KOOS).

5) To investigate self-reported knee function (IKDC) of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   5-b There are differences between ACLR patients, and the cut-off score for return to sport (score ≥ 90) in (IKDC).

6) To investigate psychological factors (ACL-RSI, TSK) of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   6-a There are differences in ACL-RSI at discharge from rehabilitation and return to sport criteria ≥ 54%.

   6-b There are differences between TSK at discharge from rehabilitation and return to sport criteria ≤ 37.

7) To investigate the relationship between single-leg hop for distance test, isometric muscles strength of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   7-a There is a moderate to high correlation between single-hop for distance and isometric quadriceps muscles strength of ACLR patients at discharge from rehabilitation.

   7-b There is a moderate to high correlation between single-hop for distance and isometric hamstring muscles strength of ACLR patients at discharge from rehabilitation.

8) To investigate the relationship between single-leg hop for distance test and self-reported knee function of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   8-a There is a weak to moderate correlation between single-hop for distance and (KOOS).

   8-b There is a weak to moderate correlation between single-hop for distance and (IKDC).

9) To investigate the relationship between single-leg hop for distance test and psychological factors of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   9-a There is a weak to moderate correlation between single-hop for distance and (ACL-RSI).

   9-b There is a negative weak to moderate correlation between single-hop for distance and (TSK).

10) To investigate the relationship between isometric muscles strength and self-reported knee function of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   10-a There is a moderate to high correlation between isometric quadriceps muscles strength and (KOOS).

   10-b There is a moderate to high correlation between isometric quadriceps muscles strength and (IKDC).

   10-c There is a moderate to high correlation between isometric hamstring muscles strength and (KOOS).

   10-d There is a moderate to high correlation between isometric hamstring muscles strength and (IKDC).

11) To investigate the relationship between isometric muscles strength and psychological factors of ACLR patients at discharge from rehabilitation.

Hypothesis:

11-a There is a weak to moderate correlation between isometric quadriceps muscles strength and (ACL-RSI).

11-b There is a weak to moderate negative correlation between isometric quadriceps muscles strength and (TSK).

11-c There is a weak to moderate correlation between isometric hamstring muscles strength and (ACL-RSI).

11-d There is a weak to moderate negative correlation between isometric hamstring muscles strength and (TSK).

12) To investigate the relationship between self-reported knee function of ACLR patients at discharge from rehabilitation.

Hypothesis:

12-a There is a high correlation between (KOOS) and (IKDC) of ACLR patients at discharge from rehabilitation.

13) To investigate the relationship between self-reported knee function and psychological factors of ACLR patients at discharge from rehabilitation.

Hypothesis:

13-a There is a weak to moderate correlation between (KOOS) and (ACL-RSI) of ACLR patients at discharge from rehabilitation.

13-b There is a negative weak to moderate correlation between (KOOS) and (TSK) of ACLR patients at discharge from rehabilitation.

13-c There is a weak to moderate correlation between (IKDC) and (ACL-RSI) of ACLR patients at discharge from rehabilitation.

13-d There is a negative weak to moderate correlation between (IKDC) and (TSK) of ACLR patients at discharge from rehabilitation.

4.4 Ethical Considerations and Risk Assessment

This study had been ethically approved by the Research, Innovation and Academic Engagement Ethical Approval Panel at University of Salford HSCR 1617-43 (Appendix 8.6), and the Medical Rehabilitation Hospital in Saudi Arabia (Ethical Application 13/03/17) (Appendix 8.7). Every participant in this study had been given a written information sheet providing details about the study. This also described the purpose and procedures of the study, the length of time required, the physical risks involved, and advised of their right to withdraw (Appendix 8.10). Participants were informed that they could ask questions before, during and after the study. After the participants decided to take part, they were checked to see if they met the inclusion criteria, then they were asked to complete and sign a consent form (see Appendix 8.8). All data collected from patients were held on a secure password protected computer. Each subject was given a reference number so that no individual details could be identified from the data (Protection Act, 2018). A risk assessment was conducted according to the study protocol and based on the risk assessment policy and risk control procedures.

4.5 Methods

4.5.1 Participants

The demographic profile of all participants involved in this study was ACLR patients aged between 18-44 and were divided into three groups:

1- (18-24) years old
2- (25-34) years old
3- (35-44) years old

4.5.2 Inclusion criteria

1- Aged between 18 to 44 years old.
2- Adult with unilateral ACL injury and had an ACL reconstruction.
3- Subjects with no other lower limb injury, pelvic or spinal pathology that limits the ability to hop comfortably.
4- They are confident and able to hop without an adverse reaction. This was determined by the referring clinicians and approved the individual to hop.

4.5.3 Exclusion criteria

1- Unable to give informed consent or comply with the study procedures.
2. Subjects with cardiovascular, pulmonary or neurological conditions that limited physical activity.
3. Subjects with any other lower limb, pelvic or spinal pathology that limits the ability to hop comfortably.
4. Have any apprehension about doing hop test.

4.5.4 Recruitment

The recruitment of participants was via orthopaedic consultants at the Medical Rehabilitation Hospital in Saudi Arabia. Invitation letters were available to give to patients with the participant information sheet and data access form. Individuals returned the forms during their regular hospital appointment at the rehabilitation class. The principal investigator saw the individual during their regular hospital appointment at the rehabilitation class to determine eligibility, then they were briefed on the study and had all of the equipment and procedures explained to them. Any questions were answered in full.

4.5.5 Sample size and population demographics

A sample size calculation for this study was performed, using the G-power software, to estimate the number of participants required to answer research question. The primary outcome in this study was single-leg hop for distance and based on the pilot study, the data showed mean (SD) injured leg hop for ACLR patients was 108.72% (48.40) and for non-injured leg 138.04% (34.42). With $\alpha = 0.05$ and a power of 0.8 based on using a two-tailed test, the required minimum sample size for the study is n=20 (Faul, Erdfelder, Lang, & Buchner, 2007).

The study included 47 ACLR Saudi male patients with a mean (SD) age of 29.26 years (6); and a mass of 70.7 kg (15.31) before the injury and 76.48 kg (12.29) after the rehabilitation. All the subjects (100%) engaged in sport regularly. 27 (57.45%) have suffered injury to the right knee, and 20 (42.55%) to the left knee. 37 (78.72%) have had hamstring tendon graft reconstruction for the ACL, and 10 (21.28%) have had patellar tendon grafts. 30 (64%) of the ACL injuries occurred without physical contact; 17 (36%) were contact injuries. 29 (61.7%) had concurrent meniscus injuries, and 3 (6.4%) had combined injuries. 43 (91.5%) of ACL ruptures occurred while playing football; 2 (4.3%) while playing volleyball; 1 (2%) while running; 1 (2%) during skating. The average waiting time of the ACL patients before their operation was 6.9 months (+/- 5.1), and this ranged from 1-24 months. 26 (55%) have had pre-operative rehabilitation, which ranged from 2 weeks to 2 months. The average period for post-operative rehabilitation was 5.4 months (+/- 0.5) with no patient having less than 5 months or more than 6 months with 72 rehabilitation sessions attendances for each patient. The discharge criteria defined as completing 72 rehabilitation sessions, 3 sessions every week for 24 weeks. Characteristics of the ACLR patients stratified by age group shown in (Table 4.1).

Table 4.1: Characteristics of the ACLR patients stratified by age group

Age Group	n	Age (years) (SD)	Height (m) (SD)	Mass (kg) (SD)
18-24 years	9	22.6 (0.7)	170.6 (2.5)	64.2 (3.8)
25-34 years	26	28.5 (2.7)	171.9 (8.7)	78.60 (16.6)
35-44 years	12	38.6 (2.7)	174.2 (7.8)	83.4 (11.0)

4.5.6 Procedures

Once subjects have demonstrated that they were interested in the study, they were seen again during their regular hospital appointment at the rehabilitation class. When participants attend the rehabilitation department for their last visit, they were briefed on the study and have all of the equipment and procedures explained to them. Any questions were answered in full, and if happy, they were asked to sign the consent form (Appendix 8.8). Each subject was given a reference number and his age, height, mass and legs length were noted on the data collection sheet (see Appendix 8.9).

Each participant was asked to:

1. Complete the International Knee Documentation Committee (IKDC) (see Appendix 8.1)
2. Complete the Knee injury and Osteoarthritis Outcome Score (KOOS) (see Appendix 8.2)
3. Complete the Anterior Cruciate ligament Return to Sport after Injury (ACL-RSI) scales (Appendix 8.3)
4. Complete the Tampa Scale for Kinesiophobia (TSK) (see Appendix 8.4)
5. Measure isometric muscle strength for both legs for knee extensors and knee flexors muscles, using (HHD).
6. Perform single-leg hop for distance on both legs.

4.5.7 Tests

4.5.7.1 Psychological factors

The participants were asked to complete The Tampa Scale for Kinesiophobia (fear of movement) (TSK) which is a questionnaire assessing pain-related fear of movement (Appendix 8.4). Then Anterior Cruciate Ligament Return to Sport after Injury (ACL-RSI) scales (Appendix 8.3) which is a questionnaire measuring athletes' emotions, confidence in performance and risk appraisal in relation to returning to sport after an ACL injury was performed.

4.5.7.2 Self-reported knee function

For more details see method chapter (section 3.3.5.7.1)

4.5.7.3 Isometric muscle strength

For more details see method chapter (section 3.1.7.3)

4.5.7.4 Single-leg hop for distance

For more details see method chapter (section 3.3.5.7.3)

4.6 Statistical analysis

The statistical analyses were carried out using Statistical Package for Social Sciences software (version 24, SPSS Statistics 20. Ink). Descriptive statistics (mean, range of scores and standard deviations) and scatter graphs were presented the data descriptively. The mean value of the three measures (trials) for each test was calculated. Data were tested for normal distribution using Shapiro-Wilk test. A paired-sample t-test were conducted to evaluate the differences between injured and non-injured leg, effect sizes were calculated using the equations described by Field (2009) and were determined using the Cohen δ method (Thomas et al., 2015), which defines 0.2, 0.5 and 0.8 as small, medium and large respectively. Relationships, including nonparametric variables, were tested using Spearman's rank correlation (p), while Pearson's correlation coefficient (*r*) was used for parametric data to explore the relationships between the outcomes from ACLR patients. Bonferroni correction was applied in instances where significant differences were found for all comparisons. The Bonferroni correction is a modification made to P values when numerous statistical tests are being performed concurrently on a single data set (Napierala, 2012). The Bonferroni correction is used to reduce the chances of obtaining false-positive results (type I errors) when multiple pair wise tests are performed on a single set of data (Napierala, 2012). To perform a Bonferroni correction, we divided the critical P value (α) by the number of comparisons being made. The statistical power of the study is then calculated based on this modified P value.

4.7 Results

In the previous chapter, we found that there were significant differences in the scores between age groups in heathy population. Therefore, in this chapter the results of ACLR patients will be presented and discussed based on age group. A total of 47 ACLR patients at discharge from rehabilitation recruited in this study. Characteristics of the population stratified by age group shown in (Table 4.1).

4.7.1 Self-reported knee function

Mean scores for IKDC scores were determined in each of 3 age categories. However, the mean score for all participants was 76.64 (SD, 15.39; 95%CI, 72.12 - 81.16; range, 46 -99). The oldest groups reported more knee related complaints than younger groups. The 25-34 group reported the highest score (81.3) (Table 4.2).

The mean scores for 5 subscales of the KOOS (Pain, Symptoms, Functional ADL, Sports and Recreation Function and Knee-Related QOL) were measured in each of 3 age categories. However, mean scores for all subscales were 78.84 (SD, 12.48; 95%CI, 75.17 – 82.50; range 55 – 97), the KOOS subscale with the lowest score for all age groups was Quality of life (58.11) (Table 4.2).

Table 4.2: [a]KOOS, IKDC, ACL-RSI and TSK outcomes for ACLR patients age groups

Age Group	Mean ± SD	95%CI	Median
18-24 year			
KOOS Symptoms	78.9 ± 8.6	72.3 – 85.5	82.0
KOOS Pain	83.2 ± 10.6	75.0 – 91.4	83.0
KOOS ADL	90.2 ± 7.2	84.7 – 95.8	91.0
KOOS Sport/Rec	67.2 ± 30.4	43.8 – 90.6	75
KOOS QOL	53.11 ± 24	34.7 – 71.6	44
IKDC	73.5 ± 15.7	61.4 – 85.6	72.4
ACL-RSI	87.3 ± 10.7	79.1 – 95.6	90.0
TSK	36.7	30.2 – 43.1	38.0
25-34 year			
KOOS Symptoms	82.5 ± 9.6	78.6 – 86.4	85.9
KOOS Pain	91.0 ± 9.7	87.1 – 95.0	94.2
KOOS ADL	93.7 ± 8.6	90.3 – 97.2	97.0
KOOS Sport/Rec	81.1 ± 17.2	74.2 – 88.1	85.0
KOOS QOL	63.8 ± 22.3	54.8 – 72.8	68.9
IKDC	81.3 ± 13.2	76.0 – 86.6	83.9
ACL-RSI	62.8 ± 23.1	53.8 – 72.2	60.8
TSK	38.5 ± 8.0	35.3 – 41.8	37.0
35-44 year			
KOOS Symptoms	84.5 ± 7.3	79.9 – 89.2	87.5
KOOS Pain	83.7 ± 13.7	75.1 – 92.5	81.9
KOOS ADL	85.2 ± 13.5	76.6 – 93.8	85.1
KOOS Sport/Rec	68.3 ± 22.1	54.3 – 82.4	60.0
KOOS QOL	49.5 ± 15.2	39.9 – 59.2	46.8
IKDC	68.9 ± 17.1	58.1 – 79.8	65.5
ACL-RSI	57.4 ± 18.9	45.4 – 69.4	50.8
TSK	34.5 ± 6.5	30.5 – 38.7	34.5

[a]KOOS, Knee Injury and Osteoarthritis Outcome Score; SD, standard deviation; QOL, quality of life; ADL, activities of daily living; Sport/Rec, Sport / recreation; IKDC, International Knee Documentation Committee; ACL-RSI, the Anterior Cruciate Ligament Return to Sport Index; TSK, Tampa Scale of Kinesiophobia.

(Table 4.3 and 4.4) below shows the number and percentage of participants achieving 90% or more according to return to sport criteria for KOOS and IKDC. It seems that only (25%) of the participants achieved 90% for IKDC and (19%) for all KOOS subscales.

Table 4.3: [a]Number and percentage of participants achieving specific scores for KOOS and IKDC according to age group

Self-reported knee function	≥ 50	≥ 60	≥ 70	≥ 80	≥ 90	100
(18-24) years n=9						
IKDC	9	7	5	3	2	-
KOOS Symptoms	-	9	7	7	-	-
KOOS Pain	-	9	7	5	2	-
KOOS ADL	-	-	-	9	5	2
KOOS Sport/Rec	7	7	5	4	2	2
KOOS QOL	4	4	2	2	-	-
(25-34) years n=26						
IKDC	25	25	21	17	8	-
KOOS Symptoms	-	26	23	16	5	-
KOOS Pain	-	26	25	22	17	6
KOOS ADL	-		26	23	21	4
KOOS Sport/Rec	23	23	20	15	9	5
KOOS QOL	17	15	10	7	3	1
(35-44) years n=12						
IKDC	11	8	5	3	2	0
KOOS Symptoms			12	8	2	0
KOOS Pain		12	10	6	5	3
KOOS ADL		12	10	10	5	2
KOOS Sport/Rec	5	5	5	4	4	2
KOOS QOL	6	4	1	0	0	0

[a]KOOS, Knee Injury and Osteoarthritis Outcome Score; QOL, quality of life; ADL, activities of daily living; IKDC, International Knee Documentation Committee.

Table 4.4: [a]Number and percentage of all participants achieving scores for KOOS and IKDC

Self-reported knee function	≥ 50	≥ 60	≥ 70	≥ 80	≥ 90	100
n = 47						
IKDC	45 (94%)	40 (85%)	31 (66%)	23 (49%)	12 (25%)	0 (0%)
KOOS Symptoms	-	47 (100%)	42 (89%)	31 (66%)	7 (15%)	0 (0%)
KOOS Pain	-	47 (100%)	42 (89%)	31 (66%)	25 (53%)	9 (19%)
KOOS ADL	-	47 (100%)	45 (96%)	42 (89%)	31 (66%)	8 (17%)
KOOS Sport/Rec	35 (74%)	35 (74%)	30 (64%)	23 (49%)	15 (32%)	9 (19%)
KOOS QOL	27 (57%)	23 (49%)	13 (28%)	9 (19%)	3 (6%)	1 (2%)

[a]KOOS, Knee Injury and Osteoarthritis Outcome Score; QOL, quality of life; ADL, activities of daily living; IKDC, International Knee Documentation Committee.

4.7.2 Single-leg hop for distance

(Table 4.5) below shows the descriptive statistics for single-hop test scores both injured and non-injured leg. Furthermore, it also provides a summary of the mean and standard deviation for the hop normalisation to leg length, normalisation to leg length by dividing the distance reached by leg length, then multiplying by 100 and LSI which calculated by dividing the normalised distance hopped on the injured leg by the normalised distance hopped on the non-injured leg, and multiplying the result by 100, giving a percentage value. Detail results of single-hop test including the mean and standard deviation, p-value, effect size and LSI for the hop distance (cm) in (Appendix 8.13). There were statically significant differences in single hop distance between injured and non-injured leg. see (Table 4.5).

Table 4.5: Mean (SD) and p-value, Comparison of Significant (P = 0.05) between injured and non-injured in single-leg hop test in ACLR men age groups

Test	Injured leg (SD)	Non-injured leg (SD)	p-value	Effect size	Single hop LSI (%)
Men (18-24) n=9					
Single hop (%)	127.10 (28.47)	167.19 (10.74)	0.002*	1.66	76.02
Men (25-34) n=26					
Single hop (%)	116.43 (45.08)	133.54 (26.96)	0.003*	0.82	87.19
Men (35-44) n=12					
Single hop (%)	98.66 (49.34)	114.52 (35.21)	0.02*	0.78	86.15

(*) Statistically significant

(Table 4.6) below shows the number and percentage of participants achieving LSI values for single-leg hop test. It seems that only (43%) of the participants achieved 90% of LSI.

Table 4.6: Number and percentage of participants achieving LSI values for single-leg hop test

LSI	≥ 50	≥ 60	≥ 70	≥ 80	≥ 90	≥ 100
Men (18-24) n=9						
Single leg hop	9	7	5	5	1	1
Men (25-34) n=26						
Single leg hop	26	23	22	18	14	2
Men (35-44) n=12						
Single leg hop	12	10	10	9	5	2
Total n = 47	47 (100%)	40 (85%)	37 (79%)	32 (68%)	20 (43%)	4 (1%)

4.7.3 Isometric muscle strength

(Table 4.7) below shows the descriptive statistics for isometric muscle strength test scores both injured and non-injured leg. Furthermore, it provides a summary of the mean and standard deviation for the peak force in (Nm) normalized to body mass (Nm/Kg), normalisation to body mass in by dividing the peak force by body mass, then multiplying by 100, hamstring/quadriceps ratio by dividing the hamstring peak force by quadriceps peak force and multiplying the result by 100, and LSI which calculated by dividing the normalised peak force on the injured leg by the normalised peak force on the non-injured leg, and multiplying the result by 100, giving a percentage value. Detailed results of the peak force in N, N/kg and Nm including the mean and standard deviation, p-value, effect size and LSI for the quad recipes and hamstring muscle strength in (Appendix 8.13). There were statically significant differences in quadriceps and hamstring isometric muscles strength and no differences in quadriceps/ hamstring ratio between injured and non-injured leg (p=0.05), see (table 4.7).

Table 4.7: Mean (SD) and p-value, Comparison of Significant (P = 0.05) between injured and non-injured leg peak force test in ACLR men age groups

Test	Injured leg (SD)	Non-injured leg (SD)	p-value	Effect size	LSI (%)
Men (18-24) n=9					
Quadriceps / body mass (Nm/kg)	2.07 (0.59)	2.49 (0.66)	0.03*	0.84	83.13 (18.21)
Hamstring peak force (Nm/kg)	1.28 (0.10)	1.52 (0.16)	0.002*	1.72	84.20 (8.41)
Hamstring / Quadriceps ratio (%)	65.95 (16.43)	65.94 (19.15)	0.99	0.00	100.02 (29.03)
Men (25-34) n=26					
Quadriceps / body mass (Nm/kg)	1.72 (0.43)	1.98 (0.45)	0.003*	1.35	86.87 (9.06)
Hamstring peak force (Nm/kg)	1.06 (0.26)	1.27 (0.37)	0.001*	0.78	83.46 (17.79)
Hamstring / Quadriceps ratio (%)	64.61 (19.88)	65.72 (19.37)	0.74	0.07	98.31 (24.02)
Men (35-44) n=12					
Quadriceps / body mass (Nm/kg)	1.43 (0.20)	1.66 (0.09)	0.001*	1.34	86.14 (10.10)
Hamstring peak force (Nm/kg)	0.95 (0.17)	1.13 (0.20)	0.002*	2.11	84.07 (6.70)
Hamstring / Quadriceps ratio (%)	66.31 (10.05)	67.97 (11.21)	0.38	0.26	97.56 (9.13)

(*) Statistically significant

(Table 4.8) below shows the percentage of participants achieving LSI values for isometric muscle test. It seems that only (43%) and (32%) of the participants achieved 90% of LSI for quadriceps and hamstring isometric muscle test respectively.

Table 4.8: Number and percentage of participants achieving LSI values for isometric muscle tests.

LSI	≥ 50	≥ 60	≥ 70	≥ 80	≥ 90	≥ 100
Men (18-24) n=9						
Quadriceps peak force	-	9	7	5	4	3
Hamstring peak force	-	-	9	6	2	-
Men (25-34) n=26						
Quadriceps peak force	-	26	25	18	12	-
Hamstring peak force	26	23	21	16	10	5
Men (35-44) n=12						
Quadriceps peak force	-	-	12	8	4	1
Hamstring peak force	-	-	12	9	3	-
Total Quadriceps n = 47	-	47 (100%)	44 (94%)	31 (66%)	20 (43%)	4 (1%)
Total Hamstring n = 47	47 (100%)	44 (94%)	42 (89%)	31 (66%)	15 (32%)	5 (1%)

4.7.4 Psychological factors

(Table 4.9) below shows the number and percentage of participants achieving 54 or more which indicated the ability to return to play and 74 or more which indicated the ability to return to a competitive play for ACL-RSI. (66%) of the participants passed the return to play for ACL-RSI and only (43%) can return to a competitive level of sport.

Table 4.9: [a]Number and percentage of participants achieving ≥ 54 and ≥ 74 in ACL-RSI

ACL-RSI	≥ 54	≥ 74
Men (18-24) n=9	9 (100%)	7 (78%)
Men (25-34) n=26	17 (65%)	10 (38%)
Men (35-44) n=12	5 (42%)	3 (25%)
Total n= 47	31 (66%)	20 (43%)

[a] ACL-RSI, the Anterior Cruciate Ligament Return to Sport Index

(Table 4.10) below shows the number and percentage of participants who scored ≤ 37 the cut-off score of TSK. (47%) of the participants seen to be have a high score and indicating high fear of movement or re-injury.

Table 4.10: [a]Number and percentage of participants achieving ≤ 37 in TSK

TSK	≤ 37
Men (18-24) n=9	4 (44%)
Men (25-34) n=26	14 ((54%)
Men (35-44) n=12	7 (58%)
Total n= 47	25 (53%)

[a]TSK, Tampa scale of Kinesiophobia

4.7.5 The relationship between the functional outcomes

(Table 4.11) below shows the relationship between single-hop test for a distance, quadriceps and hamstring isometric muscle strength, KOOS subscales, IKDC, ACL-RSI and TSK. There is a strong and medium correlation between IKDC and all others outcomes measure apart from ACL-RSI, a strong correlation between hop test and quadriceps and hamstring muscle strength, a strong and medium correlation between quadriceps muscle strength and all others outcome measures apart from ACL-RSI and KOOS symptoms, and week correlation between ACL-RSI and all others outcome measures apart from KOOS QoL and TSK, and there is a strong correlation between psychological factors ACL-RSI and TSK, also, there is a strong correlation between patients-reported outcome measures KOOS and IKDC (See Appendix 8.17) for more detail.

Table 4.11: [a]Pearson's and Spearman's correlation between the outcome measures, Bonferroni corrected *p*-value (**α** = 0.0009)

		Hop	**Flexion Strength**	**Extension Strength**	**KOOS pain**	**KOOS Symptoms**	**KOOS ADL**	**KOOS** Sport/ Rec	**KOOS QoL**	**IKDC**	**ACL-RSI**	**TSK**
Hop	Cor.		[a] **.53***	[a] **.50***	[b] .16	[b] .19	[b] .16	[b] .180	[b] .18	[b] .42	[a] .26	[a] -.02
Flexion Strength	Cor.	[a] **.53***		[a] .36	[b] .18	[b] .03	[b] .20	[b] .29	[b] .19	[b] .32	[a] .03	[a] -.06
Extension Strength	Cor.	[a] **.50***	[a] .36		[b] .37	[b] .14	[b] .34	[b] **.50***	[b] .32	[b] **.57***	[a] .13	[a] -.32
KOOS Pain	Cor.	[b] .16	[b] .18	[b] .37		[ǂ] .42	[b] **.88***	[b] **.81***	[b] **.79***	[b] **.70***	[b] .22	[b] -.32
KOOS Symptoms	Cor.	[b] .19	[b] .03	[b] .14	[b] .42		[b] .28	[b] .31	[b] .39	[b] .33	[b] .10	[b] -.10
KOOS ADL	Cor.	[b] .16	[b] .20	[b] .34	[b] **.88***	[b] .28		[b] **.86***	[b] **.65***	[b] **.76***	[b] .24	[b] -.40
KOOS Sport/Rec	Cor.	[b] .18	[b] .29	[b] **.50***	[b] **.81***	[b] .31	[b] **.86***		[b] **.63***	[b] **.75***	[b] .21	[b] -.39
KOOS QoL	Cor.	[b] .18	[b] .19	[b] .31	[b] **.79***	[b] .39	[b] **.65***	[b] **.63***		[b] **.66***	[b] .46	[b] -.35
IKDC	Cor.	[b] .42	[b] .32	[b] **.57***	[b] **.70***	[b] .33	[b] **.76***	[b] **.75***	[b] **.66***		[b] .26	[b] -.33
ACL-RSI	Cor.	[a] .26	[a] .03	[a] .13	[b] .22	[b] .10	[b] .24	[b] .21	[b] .46[*]	[b] .26		[a] **-.53***
TSK	Cor.	[a] -.02	[a] -.06	[a] -.32	[b] -.32	[b] .11	[b] -.40	[b] -.39	[b] -.35	[b] -.33	[a] **-.53***	

[a]KOOS, Knee Injury and Osteoarthritis Outcome Score; QOL, quality of life; ADL, activities of daily living; Sport/Rec, Sport / recreation; IKDC, International Knee Documentation Committee; ACL-RSI, the Anterior Cruciate Ligament Return to Sport Index; TSK, Tampa Scale of Kinesiophobia.
*Statistically significant (α = 0.0009).
([a]) Pearson Correlation
([b]) Spearman Correlation.

(Figure 4.1) below shows the number and percentage of the participants who passed in return to sports criteria (LSI ≥ 90%) in each outcome measure, it seems that only 2 (4%) of the participants passed in return to sport criteria in all outcome measures.

4.7.6 Passing the return to sport criteria

Passing the return to sport criteria was defined to pass all the outcome measures of the following criteria:

1. LSI ≥ 90 % for single-leg hop test (Thomeé et al., 2011).
2. LSI ≥ 90 % for quadriceps and hamstrings strength (Thomeé et al., 2011).
3. H/Q ratio ≥ 60% (Hewett, Myer, & Zazulak, 2008).
4. IKDC & KOOS ≥ 90 % (Adams et al., 2012).
5. ACL-RSI ≥ 56 points (Ardern et al., 2013).
6. TSK ≤ 37 points (Vlaeyen et al., 1995).

Figure 4.1: [a]Number and percentage of participants passing the return to sport criteria in each outcome measure and in all outcome measures.

[a] H/Q ratio, hamstring/quadriceps ratio; IKDC, International Knee Documentation Committee; ACL-RSI, the Anterior Cruciate Ligament Return to Sport Index; KOOS, Knee Injury and Osteoarthritis Outcome Score; TSK, Tampa Scale of Kinesiophobia.

4.8 Discussion

The aims of this study were to:

1- Examine single-leg hop for distance and LSI of ACLR patients at discharge from rehabilitation.
2- Examine isometric muscle strength and LSI of ACLR patients at discharge from rehabilitation.
3- Examine patients' self-reported knee function of ACLR patients at discharge from rehabilitation.
4- Assess psychological factors of ACLR patients at discharge from rehabilitation.
5- Investigate the relationships between single-leg hop for distance, strength, self-reported knee function and psychological factors of ACLR patients at discharge from rehabilitation to discover whether any of these factors can predict the others.

4.8.1 Demographic Information

47 physically active individuals age 18 to 44, who were between five- and six-months post ACL reconstruction, took part in the study. Their functional performance, along with the objective and subjective measures were examined, as well as psychological factors.

In line with the ages of ACLR participants involved in a range of previous studies conducted with international populations (Kaminska et al., 2015; Risberg, Holm, Myklebust, & Engebretsen, 2007; Shaw, Williams, & Chipchase, 2005; Xergia et al., 2013), the average age of the participants in the current study was 29 ±6 years. In addition, the average waiting time between injury and surgery for the ACL patients was 6.9 months, although this varied between one and 24 months, even though delaying the surgery is thought to be a risk factor for meniscal injuries (O'Connor, Laughlin, & Woods, 2005; Papastergiou, Koukoulias, Mikalef, Ziogas, & Voulgaropoulos, 2007), and studies have shown that time to surgery could have an impact on functional outcomes post ACLR (Åhlén & Lidén, 2011; Curran, Lepley, & Palmieri-Smith, 2018; Laxdal et al., 2005).

After ACLR, it is essential to maintain an active lifestyle because a reduction in physical activity may result in weight gain and other detrimental impacts on health; in particular, a high BMI presents a risk factor for knee OA (Johnson & Hunter, 2014). However, it is notable that the ACLR patients in the current study had a higher BMI following injury compared to before it occurred, as well as compared to the healthy population within the same age range and living in the same geographical area.

The participants in the current study were not full-time athletes but enjoyed sport as an activity, therefore they may have had less motivation for returning to preoperative activity levels compared to athletes. In addition, some of the participants stated that they were satisfied with their activity levels post ACLR, and did not want to return to their previous sporting activities due to the risk of being injured again. Myklebust and Bahr (2005) found that patients with a weak motivation are less likely to return to sports.

4.8.2 Measuring knee function

Several aspects must be addressed when estimating knee function and it is difficult to clearly define good knee function as no gold standard exists for measuring outcomes after ACL rehabilitation, although there are several scores and tests that can be used. Some scoring systems, and functional tests, have been designed to evaluate the extent of an ACL injury; the effectiveness of treatment, and the person’s decision to return to sport or not. Moreover, it may be more beneficial to test dimensions such as the persons’ level of satisfaction with treatment outcomes, and whether they are able to engage in activities at work; physical activities in general, and various social activities. In the current research, the outcome variables have mainly been classified in the ICF dimensions of body (structure and function), activity and participation. The functional domain includes muscle strength and self-reported knee function, and a single-hop test was used to assess this under activity domain. In addition, self-reported knee function, fear of re-injury and psychological factors have been covered under the participation domain (see Table 2.4).

Two personal factors that affect ICF’s dimensions are age and gender, and these lead to a number of outcome variables; however, no scores or tests have so far been designed to date that are age or gender specific, even though IKDC and KOOS differ concerning both gender and age (Anderson et al., 2006; Frobell et al., 2008; Hamrin Senorski, Svantesson, Baldari, et al., 2018), as physical capacity, including strength and hop, are affected by the age and gender of the subject (Ageberg et al., 2001; Haillotte et al., 2017; Kim, Lockhart, & Nam, 2010; Thomeé et al., 2013). This means that outcomes may need to be adjusted to account for the impact of age and gender, including when comparing groups that have undergone ACLR and their recovery.

In our study we found significant differences between age groups in quadriceps muscle strength (p = 0.01) and in hamstring muscle strength (p = 0.01). The mean age groups differences reached up to 43 N and 30 N in quadriceps and hamstring muscle strength respectively, this would be defined as true differences beyond the measurement error because it is more than the SDD of quadriceps and muscle strength found in this study (SDD between 5.82 N and 7.68 N), see method chapter (section 3.1.9.1) and (Appendix 8.13). For single hop test, there was statistically significant difference between age groups (p= 0.01) for right and left leg respectively. The mean differences between age groups ranged from 10.21% to 35%, which surpassed the SDD of single-hop test (SDD = 8.09%) (Reid et al., 2007). Similar results for KOOS there were statistically significant difference between age groups in KOOS subscales p = 0.05. The differences in ACLR patients' scores were as following KOOS symptoms = 5.6 pts, KOOS pain = 7.8 pts, KOOS ADL = 8.5 pts, KOOS sport/rec= 13.9 and KOOS QoL = 14.3 pts, which all exceed SDD (5 pts, 6 pts, 7 pts, 5.8 pts and 7 pts) respectively (Collins et al., 2011). Also, there was significant difference between age groups in IKDC p = 0.03, the difference in score was 12.4 which is more than the SDD found in this study (SDD = 9.63 pts) see method chapter (section 3.2.11.2), and more than the SDD found by previous research (SDD = 6.7 pts) (Collins et al., 2011). This emphasises how important it is to use age-matched groups for outcomes so that overestimating or underestimating of the outcome measures does not occur. Therefore, in this chapter the results of ACLR patients were presented and discussed based on age group.

For physical capacity, a LSI lower than 90 % is viewed as unsatisfactory for both strength and hop performance (Haillotte et al., 2017; Thomeé et al., 2011), although few studies have focused in assessing the cut-off values for different levels of functional performance. For example, in the current study, the mean LSI for the ACLR subjects ranged from 76 to 100 %, and the lowest LSI was for single-leg hop distance for the 18 to 24 years age group see (Table 4.5 and 4.6). The number of failed patients to achieve LSI more than 90% in each outcome will be discussed in detail.

4.8.3 Rehabilitation

Pre-operative rehabilitation

Over half of the sample (55%) in the current study participated in rehabilitation between the time of injury and surgery, and pre-operative rehabilitation varied from one week to two months. Even so, it should be borne in mind that only patient recollection was used to measure the length of rehabilitation, and so recall bias may have been involved; although it is unlikely that the participants who completed the type of goal oriented rehabilitation programme described in the literature would forget it (Hartigan, Axe, & Snyder-Mackler, 2009; Logerstedt et al., 2013). Patients are usually identified late after an injury when symptomatic and suffering from recurrent instability, as at that point, rehabilitation is not usually as viable an option. It is common practice for all ACLD patients to engage in pre-operative rehabilitation (Frobell, Roos, Roos, Ranstam, & Lohmander, 2010b; Hartigan et al., 2009; Logerstedt et al., 2013) whether they have a surgical or non-surgical management plan, therefore it is likely that insufficient numbers of subjects partook in pre-operative rehabilitation, to potentially impact on the outcomes measured.

Post-operative rehabilitation

A standardised rehabilitation program was followed by all patients, including providing guidelines on multimodal therapies to deal with acute impairments such as pain, swelling and motion restriction, along with a progressive strength and neuromuscular training programme (Kruse, Gray, & Wright, 2012; Lobb, Tumilty, & Claydon, 2012). Positive outcomes have been shown from neuromuscular training compared to strength training in short term (Risberg et al., 2007) and long term follow up (Hartigan et al., 2009), and it is well supported in the literature (Kruse et al., 2012; Lobb et al., 2012).

Neuromuscular is defined by Zouita Ben Moussa, Zouita, Dziri, and Ben Salah (2009) as aiming to “improve muscle activation, increase dynamic joint stability and relearn movement patterns and skills of ADL and sports”. According to the principles of neuromuscular training, rehabilitation usually involves practicing skills related to specific movements, although improvements in these skills does not always lead to better functional performance (Shumway-Cook & Woolacott, 2016).

Some problems with performance do not seem to be addressed by current rehabilitation methods, as they do not fully consider muscle strength and knee function, or psychological factors, which could explain why a full recovery at discharge from rehabilitation is rare. Therefore, an additional criterion including functional testing; objective and subjective outcomes, and psychological factors, should be incorporated into rehabilitation programmes.

4.8.4 Self-reported knee function

Self-reported knee function following ACLR, the current study confirms other similar studies reports using the IKDC and KOOS. For example, the groups mean IKDC of 77 is similar to Smale et al. (2018) and Lepley, Pietrosimone, and Cormier (2018), as they also found a mean score for IKDC of 77 for 20 ACLR patients at both 10 and seven months post-reconstruction, respectively, which is a similar functional recovery to this research. For Knezevic, Mirkov, Kadija, Milovanovic, and Jaric (2014), they found 76 at four and 83 at six months, which is slightly lower than (Lepley & Palmieri-Smith, 2016) as their results were a mean IKDC of 80, as well as Logerstedt et al. (2012) who found a mean of 83 at six months. Lentz et al. (2012) split their participants according to success at return to sport, and the IKDC scores for the less successful group were similar to those found in the current study; on the other hand, the successful group at return to pre-injury sport, reported higher mean IKDC scores of 94. A number of researchers (Curran et al. (2018); Edwards et al. (2018); Gokeler et al. (2017) and Werner et al. (2018) state a mean IKDC of 81, 81, 84 and 87 respectively, although the difference with the current study may be attributed to the sample being one to four years post-surgery, and the younger age groups in their studies.

ACL registries in the US, the UK, Australia, Sweden, Norway and Denmark contain KOOS data from more than 60,000 patients after reconstructive surgery (Dunn & Spindler, 2010; Ingelsrud, Granan, Terwee, Engebretsen, & Roos, 2015; Werner et al., 2018). The data contained in these registries includes postoperative mean KOOS values according to mild pain (mean range of 84-89), bearing in mind it is 88 in the current study; moderate to mild symptoms (mean range of 60-86) compared to 82 in this study; no problems performing activities of daily living (ADL) (mean range of 90-97) compared to 91 in this study; moderate to mild problems playing sport and doing recreational activities (Sport/Rec) (mean range of 63-78) compared to 75 in this study, and moderate to mild reductions in knee-related QoL (mean range, 60-69), which is higher than the mean of 58 in this study. This shows that, overall, the results from the current study are in line with global data, yet the KOOS subscale "Sports and recreational activities" which refers to "Kneeling", showed the lowest score. In addition, the result for QoL is a little lower than the global KOOS data. Moreover, for the "pain "subscale the question "Bending knee fully" which represents a kneeling position while sitting, also scored the lowest. Culture has been defined by (Williams, 1981) as “the whole way of life of a distinct people”, and it involves the various social processes. Relevant to this research and the aforementioned kneeling position is the Muslim prayer, as this requires sitting in that position at least 26 times a day as most Muslims in Saudi Arabia pray at least five times a day. Filbay et al. (2015) conducted a systematic review and meta-analysis, and they found that lifestyle modifications and reduced knee confidence are likely to lead to lower KOOS-QOL scores, which may be why the knee-related QoL subscale impairment in the current study is lower in comparison to the global data (see Appendix 8.15).

Overall, the data shows that although the recovery of knee function measured using the IKDC and KOOS is within the limits reported in the literature, the scores for functional recovery are on the low side. Even though some other studies have found higher self-reported knee function one or two years post-surgery, the comparison is problematic due to the variations in duration of recovery, the different age ranges of participants, and various pre-injury activity levels (Filbay et al., 2015; Hamrin Senorski, Svantesson, Baldari, et al., 2018).

4.8.5 Single-leg hop for distance

A commonly used benchmark measurement for RTS is single-leg hop tests used to clinically measure the quality of knee function, and provide baseline measurements, along with determining overall function and neuromuscular control among patients that have a functional deficit (Logerstedt et al., 2012).

The single-leg hop test was chosen for use in the current study because it is efficient time-wise; cost effective; easy to conduct, and requires little space and equipment (Swart et al., 2014). In addition, the single-leg hop test has been shown to be useful for assessing the risk of ACL re-injury (Kyritsis et al., 2016), and can measure asymmetry which is thought to increase the risk of an ACL injury (Grindem et al., 2016). Hop tests are not sport specific, but they imitate the forces involved in sport-specific activities under controlled conditions. Moreover, apart from complex laboratory-biased biomechanical analyses, hop tests are seen as the best measurement tool for the clinical assessment of lower limb function (Clark, 2001).

Myer, Schmitt, et al. (2011) examined lower extremity performance deficits in a cohort of athletes who had undergone unilateral ACLR and returned to sport, using a series of functional performance-based assessments, including various types of hop tests. They found that single-legged hop tests could differentiate between ACLR and control groups, as well as between limbs. This suggests hop tests usefulness in clinical screening and ACL injury-risk mitigation programs, as well as the importance of isolating single-legged performance during functional assessment in order to clearly identify any functional deficits.

The LSI can be easily calculated without the need for statistical software, making it highly useful to clinicians; in addition, the uninjured limb can be used as the control for within-subject between-limb comparisons, adding to its ease of use (Clark, 2001). Noyes et al. (1991) claim that an LSI of 85% or over shows that the athlete will be able to return to pre-injury levels of sport, based on their findings, which showed 93% of healthy individuals scored an LSI of 85% or over (Noyes et al., 1991); although other researchers suggest an LSI of 90% or more. On the other hand, Asik et al. (2007), claim that an LSI of 80% or over is normal. (Ardern et al., 2011b) conducted a study using single-leg hop tests involving 503 post ACLR patients, and they found that those with good hop test results (85% LSI) were more likely to RTS than those with poor results (LSI < 85%).

In the current study the LSI result was below the safe range at 84.7, with values of ≥ 90% in 20 (43%) of the patients at discharge from rehabilitation for single-leg hop tests for distance, which is similar to the findings of Mattacola et al. (2002), Wilk, Reinold, and Hooks (2003) Thomeé et al. (2012), Xergia et al. (2013), Ebert et al. (2017), Werner et al. (2018) and Edwards et al. (2018); although Ebert et al. (2017) discovered that a mean of 53% of their participants had an abnormal LSI at 11 months postoperatively. Wren et al. (2018) stated that the LSI for single-leg hops for patients from five to 12 months post-ACLR was 76.6 for the asymmetry group and 99.9 for the symmetry group. In addition, in a medium-term follow-up study of ACLR patients carried out by Ageberg, Thomee, Neeter, Silbernagel, and Roos (2008), they found that only 44–56% of patients had normal limb symmetry two to five years following their injury or surgery.

Mohammadi et al. (2013) conducted research on soccer players and compared the functional outcomes of a patellar tendon group (PTG) to a hamstring tendon group (HTG). They found no differences between the groups at RTS, and the LSI of a single hop were 90.41 (7.9) (PTG) and 90.57 (8.4) (HTG) group. Similarly, Shaw et al. (2005) found no differences at six months post ACLR in single hop (LSI%) results between a non-quadriceps exercise group (mean and SD) 81.7 (12.7), and a quadriceps exercise group (mean and SD) 83.8 (10.1).

In the current study, the group mean hop distance was 112 cm (123% leg length), which is quite different to previous studies, as most previous studies have reported greater hop distances, ranging from 1.1 m to 1.86 m (Ageberg et al., 2008; Baltaci et al., 2012; Chung et al., 2015; Ebert et al., 2017; Herrington, Ghulam, & Comfort, 2018; Keays et al., 2001; Knezevic, Mirkov, Kadija, Milovanovic, et al., 2014; Mattacola et al., 2002; Ross et al., 2002; Welling et al., 2018; Xergia et al., 2013; Zwolski et al., 2016), but one study by Gokeler et al. (2010) revealed lower results of 0.94m six months following ACLR. However, the samples in the previous studies were military recruits and athletes of a young age and further away from surgery, as well as discharged from formal rehabilitation. All these reasons combined could explain the greater hop distance revealed in those studies. Furthermore, Paterno et al. (2010) claim nine months is not enough time to maximise functional recovery following ACLR, and this could explain the low scores for this sample, making it possible that further improvements may be apparent after more than one year.

Gokeler et al. (2017) conducted hop tests and note the importance of interpreting tests carefully if the non-operated limb is used for comparison, as even if a normal ratio can be found, the absolute values are pathological. Wren et al. (2018) found that asymmetric patients hopped shorter distances on the side operated on, and they presented LSIs up to 89%, although symmetric patients typically hopped shorter distances compared to controls on both sides; therefore, it may be possible to achieve symmetry by reducing the difficulty of the task. This is in line with other research that has shown lower contralateral-limb performance among ACLR patients who meet limb symmetry criteria (Gokeler et al., 2017; Wellsandt et al., 2017). Moreover, it could be due to factors such as fear, deconditioning, or poor motivation. Wellsandt et al. (2017) discovered that eight out of 11 patients who suffered a second ACL injury had passed 90% LSI criteria for strength as well as four different hop tests, yet six out of eight of them would not have passed these tests if the ACLR limb had been compared with the contralateral-limb function before surgery. Therefore, Wellsandt et al. (2017) stated that the benchmark for operative-limb function should be the performance of the contralateral limb before, and not after, surgery; alternatively, they suggest basing their performance on healthy matched controls as the performance of the contralateral limb may decrease following surgery.

Who were not able to hop and why?

Surgery to the knee is traumatic and can cause serious physical impairments; limit activity and restrict participation (Ardern et al., 2011b; Risberg, Holm, Tjomsland, Ljunggren, & Ekeland, 1999). The quadriceps weakness and hop performance differences are more apparent during the first few months after reconstruction (Andrade, Cohen, Picarro, & Silva, 2002; Chung et al., 2015; de Jong, van Caspel, van Haeff, & Saris, 2007; Ebert et al., 2017; Edwards et al., 2018). In addition, the deficits in hop performance after ACL (Werner et al., 2018; Wren et al., 2018) may still be there several months after ACLR is conducted. In this study, there were two patients who refused to hop out of 49 patients who underwent ACLR, 47 (96%) performed hop testing. Also, there was low correlation between hop test with TSK and ACL-RSI. In the research by Arden et al (2011b), the fear of re-injury was the reason for giving up hop participation.

4.8.6 Isometric muscle strength

Following ACL reconstruction, strength is an essential clinical measure of function, and is typically used as a benchmark for developing specialised individual treatment plans (Felson et al., 2000). The European Board of Sports Rehabilitation (EBSR) recommends muscle strength is expressed as an LSI as well in absolute values (Thomeé et al., 2011). Absolute values can be normalised to body mass (Nm/kg) for isometric testing, and the threshold for isometric quadriceps strength following ACLR is recommended to be set at >3.0 Nm/kg (Kuenze, Hertel, Saliba, et al., 2015).

There is evidence to suggest that the best way to test muscle strength is isometrically at 90° of knee flexion (Hsiao, Chou, Hsu, & Lue, 2014) so that any asymmetries can be detected in patients following ACLR (Lepley, 2015; Palmieri-Smith, Thomas, & Wojtys, 2008). Therefore, in the current study, the muscle strength of patients was assessed isometrically at 90° of knee flexion. In addition, some studies have used different units to measure muscle strength LSI, but these may alter the LSI value reported, for example, muscle strength can be recorded using force (Newtons) or torque (Nm) or normalised in accordance with the patient's body mass (Nm/kg, N/kg). When the quadriceps/hamstring strength is recorded to assess force, the assumption is that force is applied in a linear direction; however, quadriceps/hamstring force is actually applied across the knee joint, resulting in an angular force (torque). This means that using muscle strength as torque has more validity than force. It should also be borne in mind that heavier individuals tend to be able to produce more torque because of their higher quadriceps muscle mass. The recommendation, therefore, is for the patient's peak torque be normalised in accordance with their body mass, which has been done in the current study. Furthermore, the different methodological approaches to assessing quadriceps strength used in various studies should be considered when comparing results.

Most studies that have explored knee outcomes following ACLR have used isokinetic dynamometry in their assessments, but its validity has only been proven for sport-specific activities when muscles are engaging in isotonic action, yet muscle function produces force as a result of a combination of isometric and isotonic actions. While isokinetic dynamometry has content, face and construct validity (Clark, 2001), the results may lack validity with regard to measuring functional muscle strength, such as physiological criteria related to validity, and there is evidence for this in the literature. According to (Clark, 2001), a fairly weak to moderate relationship has been found between functional performance tests and the isokinetic strength of the thigh muscles. Therefore, isometric testing rather than isokinetic testing has been used to test muscle strength in the current study, as isometric testing mimics the pattern of ACL injury as it involves knee flexion in a static position (Silva, Ribeiro, & Oliveira, 2012; Silvers & Mandelbaum, 2007).

Confirming our hypothesis, the quadriceps and hamstring strength assessment showed side-to-side differences among the ACLR patient participants. For isometric quadriceps and hamstring strength assessment, the mean LSI was 86.3% and 85.3% respectively, which is below the clinically acceptable RTS threshold of ≥ 90%. This suggests that muscle strength deficits may persist after ACLR, even when the patient is discharged from rehabilitation.

For the 47 participants in the current study, the group means for the quadriceps and hamstring indexes revealed less than 90% symmetry at RTS, with quadriceps strength affected among 27 (57%) participants and hamstring strength among 32 (68%) participants. Recent reports support these findings, as patients with ACLR cleared for RTS still had low values for muscle strength according to the index (Palmieri-Smith & Lepley, 2015; Schmitt, Paterno, Ford, Myer, & Hewett, 2015), and the LSI results at time of RTS in the current research, are similar to those in the literature (Kuenze, Hertel, Saliba, et al., 2015; Schmitt et al., 2012; Toole et al., 2017), although they are better than the findings of other researches, which found quadriceps LSI to range from 69% to 80% (Curran et al., 2018; Edwards et al., 2018; Herrington et al., 2018; Huber et al., 2018). On the other hand, for side-to-side difference in peak quadriceps strength and normalised quadriceps strength at discharge from rehabilitation following ACLR, the results of this study are 130.4 Nm and 1.71 Nm/kg, which is somewhat lower than other studies on ACLR in the literature (Curran et al., 2018; Herrington et al., 2018; Huber et al., 2018; Lepley et al., 2018; Lepley, 2015; Palmieri-Smith et al., 2008). These other studies revealed peak quadriceps strength ranging from 163 Nm to 201 Nm, and normalised quadriceps strength ranging from 2.2 Nm/kg to 2.9 Nm.kg, although only a few studies reported lower results (Büchler et al., 2016; Huber et al., 2018; Zwolski et al., 2016). Thus, the results for the LSI index in the current research are higher than previous research studies, whereas absolute strength and normalised strength values seem to be lower than the results reported in the literature. This could be due to the differences in muscle strength and activity levels at baseline for the injured leg included in this study leading to lower results than the previous research.

A key finding of this study is that most of the ACLR patients' performance was lower than the recommended criterion (≥ 90% LSIs), and despite the assumption they could RTS, only 20 (43%) and 15 (32%) passed the strength criterion for LSI quadriceps and hamstring. This result aligns with the findings from a systematic review carried out by Larsen et al., (2015), which revealed that 6–9 months post-ACLR, patients had low muscle strength and differences of between 16% and 39% for LSI, and therefore they were not within an acceptable LSI range. In addition, some studies that have revealed asymmetries in quadriceps strength of 30% and over in patients six months after ACLR (Knezevic, Mirkov, Kadija, Milovanovic, et al., 2014; Kobayashi et al., 2004; Lee, Seong, Jo, Park, & Lee, 2004; Nicholas, Tyler, McHugh, & Gleim, 2001; Thomas, Villwock, Wojtys, & Palmieri-Smith, 2013). Furthermore, Grindem et al. (2016) discovered that symmetrical quadriceps strength is linked to lower re-injury rates, and that 38% of patients that did not pass the RTS criteria (≥ 90% LSI in strength and hop performance) suffered re-injuries. The results of Kyritsis et al. (2016) show a four times higher risk of an ACL re-tear among individuals who RTS without passing important criteria, such as > 90% symmetry for muscle strength and hop tests. Asymmetry in muscle strength is associated with the development of knee osteoarthritis and the risk of a second ACL injury (Andriacchi et al., 2004; Paterno et al., 2010). Moreover, individuals with limb-to limb asymmetry could overuse the uninjured limb, leading to overuse injuries to that limb, or they could underuse the injured limb due to a lack of confidence (Andriacchi et al., 2004). Major deficits in strength have been reported up to 12 months post ACLR (Hartigan, Axe, & Snyder-Mackler, 2010; Kvist, 2004; Thomeé et al., 2012), and for certain muscle groups, this greatly increases the risk of re-injury (Myer et al., 2006; Thomeé et al., 2011; Thomeé et al., 2012).

The importance of the hamstrings, in particular their role in protecting the ACL, has been highlighted by several researchers, including how the hamstrings contribute towards proprioception (Beard, Kyberd, Fergusson, & Dodd, 1993). Moreover, deficits in hamstring strength could be a risk factor for ACL due to the way they work to resist anterior tibial translation (Hiemstra et al., 2007; Thomas et al., 2013). Strong hamstrings are also essential during initial contact when performing a jump landing and decelerating the forward movement of the shank, as well as to avoid excessive extension during landing. In the current study, the hamstring deficit was found to be 15% with absolute strength 81 NM, and normalised strength

1.1 Nm/kg. These results are similar to those reported by (Chung et al., 2015) as they found normalised strength 1 Nm/kg, as well as the results of Huber et al. (2018) who conducted their study with a large cohort (n = 464) five months post ACLR surgery and found 1.1 Nm/kg. In addition, similar studies have reported higher results of 127 Nm six months post ACLR and 113 Nm eleven months post ACLR for hamstring strength at (Ebert et al., 2017; Welling et al., 2018). Most previous studies have reported higher LSIs of 94% (Thomeé et al., 2012); 91% (Ebert et al., 2017); 92% (Toole et al., 2017); 97% (Werner et al., 2018); 90% (Huber et al., 2018); 96% (Welling et al., 2018) and 90% (Edwards et al., 2018) .

A meta-analysis conducted by Xergia, McClelland, Kvist, Vasiliadis, and Georgoulis (2011) showed that twelve months postoperatively, hamstring strength deficits persisted in individuals who underwent hamstring grafts, and that quadriceps deficits continued in individuals who underwent a PT graft. Therefore, lower hamstring strength LSI may be a feature among patients who undergo hamstring tendon autografts for ACLR. In the current study, most of the patients (79%) underwent hamstring tendon autografts, and this could be the reason for the large strength difference in side-to-side hamstrings noted at discharge from rehabilitation following ACLR.

Muscular balance across the knee joint is essential, including a high H:Q ratio, as a low H:Q ratio is a risk factor for suffering an ACL injury (Myer et al., 2009), as well as discriminatory knee OA (Keays et al., 2010). The results from this study reveal ratios close to the physiological values: 65.3 ± 17.2, which is significant because following ACL reconstruction, a physiological H:Q ratio seems to predict improved functional results (Fossier, Christel, Djian, Darman, & Witvoet, 1993). In addition, this ratio is important in preventing injury to the muscles and tendons during sporting activities (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008; Middleton et al., 2013); even so, physiological ratios should be interpreted with care. This is because other factors may have an impact even if the absolute values in the numerator and the denominator appeared to be within the normal range. In the current study, the ACL-injured limb showed a similar H:Q ratio to the non-injured leg, but the quadriceps strength in the injured leg was reduced rather than hamstrings strength. Therefore, the H:Q ratio is not a useful form of measurement if quadriceps strength is reduced.

The number of research findings of strength deficits at RTS suggests a widespread issue with assessing ACLR patients post operatively. However, it has not been determined whether such deficits are a result of ineffective strength training set out in standard rehabilitation protocols, or due to limitations in the muscular structures' ability to recover and strengthen within standard rehabilitation timeframes.

It has been shown that using LSI alone does not provide an entirely accurate assessment of the level of impairment that persists in the ACLR population, as shown in the current study's results. A more thorough indicator of quadriceps and hamstring strength may require comparing strength and performance values with the normative values of healthy control participants.

4.8.7 Psychological factors

Exploring the impact of psychosocial factors after ACL injuries has been receiving increasing attention in clinical research in recent years, and it has been found to support the assessment and management of rehabilitation for patients with ACL injuries, as well as assisting decision-making and improving patient outcomes. Thus, the specific psychological factors related to the rehabilitation process that contribute towards an improved good recovery, need to be specified and explored, and the two most common psychological terms used in the context of RTS after ACLR are fear of re-injury and psychological readiness (Webster, Nagelli, Hewett, & Feller, 2018).

In this research, fear of movement/re-injury and psychological readiness have been used for the emotional dimension of participation in ICF (see Table 2.4). Encouraging participation in physical activity is a key way of ensuring and maintaining both physical and mental health (Andrew et al., 2014). Te Wierike et al. (2013) conducted a systematic review and found that a range of psychosocial factors affect the management of an ACL injury, such as coping strategies; fear of movement/re-injury; adjusting goals; confidence in physical functioning; self-efficacy, and optimism. Moreover, Ardern et al. (2016) discovered that individuals who reported better scores for psychological factors tended to be more satisfied with the outcomes of their ACL reconstruction.

One of the main reasons for failing to return to sport is fear of re-injury (Ardern, Webster, Taylor, & Feller, 2011a; Flanigan, Everhart, Pedroza, Smith, & Kaeding, 2013; Kvist et al., 2005; Lee, Karim, & Chang, 2008), and (Chmielewski et al., 2008) found that fear of re-injury was greatest at the points when the patients attempted to return to sport. In addition, those who did not return to pre-injury activity levels still feared movement/re-injury more when using a TSK score, three to four years after the occurrence of the injury (Kvist et al., 2005).

A persons' perception and response to an illness, including fear of movement or re-injury, may affect their level of functioning after an ACL injury (Everhart et al., 2015; Kvist et al., 2005), and this fear could also lead patients to avoid behaviours that could potentially result in re-injury. In addition, an ACL injury may cause uncertainty and worry about the extent to which the injury will impact on future function (Osterberg et al., 2013). In the current study, fear of re-injury (as stated by the participants) caused two of the participants to refuse to perform the hop test; this may have been expected due to the rehabilitation programme not including any functional exercises, including hop tests.

Fear of movement/re-injury has been measured using TSK in the current study, with a total mean score of 34.5 for ACLR out of a maximum of 68. In other studies on low back pain, a score higher than 37 was taken to indicate a high level of fear of movement (Lundberg, 2006; Vlaeyen et al., 1995), and Ardern et al. (2013) reported a similar cut-off for patients who did not return to sport following ACLR. The results from this study are lower than this cut-off, although half of the patients 23 (47%) stated a high level of fear of movement, scoring > 37 on the TSK.

Several studies have explored fear of movement after ACLR, and the results are similar to those in the current study, for example, Norte, Hertel, Saliba, Diduch, and Hart (2018) conducted research with 34 ACLR patients nine months after surgery and the mean score for TSK was 34.4. In addition, Ardern et al., 2014b found the mean TSK to be 35.6 for 164 ACLR patients one to seven years post-surgery. Ardern et al. (2016) classified patients according to their satisfaction with ACLR outcomes- satisfied, mostly satisfied and dissatisfied- and the TSK scores for each were 31, 35 and 42 respectively, and the results for the ACL-RSI score were: 62 satisfied; 47 mostly satisfied, and 33 dissatisfied.

The ACL-RSI scale assesses psychological readiness to return to sport and recreational activity following ACL reconstruction, and it has been used in a number of studies. Ardern et al., 2014a discovered that the likelihood of returning to sport decreased according where the time between surgery and follow-up was longer; in addition, they found that age, sex and preinjury activity level are not related to returning to a preinjury level of sport or recreational activity. Readiness to return to sport was examined in a qualitative study conducted by Podlog et al., (2015), and they suggest that psychological components are made up of three main factors, which are confidence in returning to sport; realistic expectations of one's sporting capability, and motivation to reach preinjury performance levels. In particular, they found that confidence in returning to sport was greatly affected by the athlete's faith in the rehabilitation program and their belief that the injury had healed (Podlog, Banham, Wadey, & Hannon, 2015; Webster & Feller, 2016).

Psychological readiness can be measured using the ACL-RSI scale, which has items that consider a range of factors, for example, it includes fear of re-injury as an item within the emotions domain (Webster & Feller, 2016). Ross, Clifford, and Louw (2017) aimed to find out the factors that affect patients' fear following ACLR by carrying out interviews, and they found that fear of re-injury is the main reason why the participants in their study were unwilling to return to sport; moreover, surgery that involved a long recovery and led to restricted functioning played the main role in fear of re-injury.

Ardern et al. (2013) examined a number of sport-specific psychological measures using the ACL-RSI score before surgery and four months post-surgery, and they found that it is a good predictor of whether patients return to pre-injury level sport at one year post ACLR (Ardern et al., 2013). Ardern et al. (2013) have presented the ACL-RSI cut-off scores that discriminated between athletes who did and did not eventually return to pre-injury levels of sport following surgery, and a score of 56 points showed the likelihood of returning to sport at one year post ACLR and a score of 74 indicated the ability of returning to a competitive level of sport, suggesting that that ACL-RSI scores can be used an indicator of which athletes are more at risk of not returning to pre-injury levels of sport.

In the study conducted by (Ardern, Osterberg, et al., 2014) with Swedish recreational and competitive athletes, they used the ACL-RSI to measure psychological readiness to return to sport, and discovered that the psychological factor was highly linked to whether the patient returned to pre-injury levels of physical activity.

In this research, psychological readiness to return to sport and recreational activity has been measured using the ACL-RSI. It was found that the mean ACL-RSI score was 69 points, and almost two thirds (66%), of the participants seemed psychologically ready to return to sport; however, only 20 participants (43%) had the ability to return to competitive sport. As mentioned previously, these findings correlate with recent research (Lepley et al., 2018; Webster et al., 2008; Welling et al., 2018). In addition, Ardern, Osterberg, et al. (2014) found the mean ACL-RSI score to be 49, although the average score for their return to sport group was 62, which could be because of the long follow up time of up to seven years in their study.

In addition, Ardern et al., (2014a) found that the longer the time from surgery to follow-up, the greater the decrease in the likelihood of returning to pre-injury activity levels. The reasons for this may be that other commitments in the patients' lives were given priority over participating in sport and recreational activities, or that some patients did return to sport or recreational activities after surgery but stopped before the follow-up or chose to participate in a different sport or activity (Ardern, Osterberg, et al., 2014).

4.8.8 Relationships between the outcome measures

This section will present an analysis of the association between single-leg hop performance and muscles strength; self-reported knee function, and psychosocial factors. The hypothesis is that there is a correlation between lower single-leg hop performance, lower muscles strength; lower self-reported knee function, as well as negative psychosocial factors. Also, there is a correlation between higher single-leg hop performance, higher muscles strength; higher self-reported knee function, as well as positive psychosocial factors. The Bonferroni correction is used to reduce the chances of obtaining false-positive results (type I errors) when multiple pair wise tests are performed on a single set of data (Napierala, 2012). However, although the Bonferroni correction can become very conservative as the number of tests increases. This, in turn, increases the risk of generating false negatives results (type II errors), the risk of making erroneous false-positive conclusions is increased when testing multiple hypotheses on a single set of data. To discover the risk of generating false negatives results in our findings, we compared the significant differences were found for all comparisons before and after Bonferroni correction and we found that all the significant strong correlation before Bonferroni correction remained significant with no changes after the correction. Thus, there was no risk of increasing false negatives by using Bonferroni correction in this study see (Appendix 8.17).

Weak associations were found between hop tests and subjective function, aside from a moderate association with IKDC, for all ACLR participants in the current study. The literature contains several studies that show similarly low correlations between subjective function and single-leg hop for ACLR patients (Reinke et al., 2011c; Sernert et al., 1999). Even so, Werner et al. (2018) found that according to IKDC and KOOS scores, patients who returned to sport considered their level of knee function to be better than those who had not returned to sport. Czuppon et al. (2014) carried out a systematic review and they found contrasting evidence concerning associations between RTS and the IKDC subjective form score; post-operative strength, and single hop for distance. Moreover, (Logerstedt et al., 2014) state that the IKDC should not be relied on as the only indicator of normal knee function, and the ability to pass RTS criteria is questionable. They found patients who scored poorly on the IKDC were four times more likely to fail RTS tests, for athletes did well on the IKDC, almost 50% overestimated their level of recovery. In our study IKDC was statically significant correlated with the majority of other outcomes. However, 12 patients scored more than 90% in IKDC and only 2 of them passed RTS criteria. That is, good IKDC scores do not automatically confirm that athletes will pass RTS tests (Logerstedt et al., 2014). Thus, decisions about RTS cannot be made based only on IKDC results.

Sharma et al. (2003) explains that strength correlates with physical function, and may sometimes correlate with reduced pain and greater function. Steultjens et al. (2001) discovered a link between quadriceps muscle weakness and an increase in disability, and greater strength has been linked to improved physical performance and a decrease in the likelihood of sustaining a repeat injury (Mendias et al., 2013). The results from the current study confirm a significant strong relationship for the hamstring and quadriceps to hop test. Schmitt et al. (2012) discovered strength deficits in the affected limb correlated with decreased function and performance at hop tests and reduced functioning. A number of studies have also found a link between quadriceps weakness and poor functional outcomes following ACLR (Decker, Torry, Noonan, Riviere, & Sterett, 2002; Keays et al., 2003; Petschnig et al., 1998; Wojtys & Huston, 2000).

Similar to other research (Moisala et al., 2007; Tsepis, Vagenas, Giakas, & Georgoulis, 2004), the data from the current study reveals a weak to moderate correlation between strength for knee flexion and extension, and self-reported knee function scores; that is, apart from a strong correlation between quadriceps muscles strength and IKDC and KOOS Sport/Rec. In addition, the strongest relationship to subjective function was found to be quadriceps muscle strength. In a previous study, knee extension isometric torque of 3.00 Nm/kg was found to be a good indicator of subjective functioning in 22 ACLR patients (Kuenze, Hertel, Saliba, et al., 2015), which suggests that strengthening exercises are important for ACLR patients to unilaterally normalise measures to gain more subjective outcomes. Ithurburn et al. (2015) found that the KOOS Sport/Rec scores of individuals eight months after ACLR differed according to their level of isometric quadriceps strength. In comparison to patients with high quadriceps strength (LSI ≥ 90%), patients with low quadriceps strength (LSI < 85%) produced lower KOOS-Sport/Rec scores (89.5 ± 11.7 pts vs. 79.6 ± 15.5 pts). Similarly, in our study patients with high quadriceps strength (LSI ≥ 90%) had higher KOOS-Sport/Rec scores compared to patents with low quadriceps strength (81.3 ± 18.2 pts vs. 73.9 ± 21.7 pts). Also, patients with high hamstring strength (LSI ≥ 90%) had higher KOOS-Sport/Rec scores compared to patents with low hamstring strength (80.3 ± 23.6 pts vs. 71.0 ± 20.9 pts).

As well as the KOOS Sport/Rec scores, some studies have revealed clear correlation between IKDC scores and quadriceps strength following ACLR (Lepley & Palmieri-Smith, 2015; Logerstedt et al., 2013; Schmitt et al., 2012; Zwolski et al., 2015). In particular, the study by (Pietrosimone et al., 2016) highlights this association, they assessed the isometric peak strength and IKDC scores of 15 ACLR patients and carried out linear regression analysis to discover the extent of variability in self-reported knee function that may be explained by the patients' quadriceps strength. They found that isometric quadriceps strength predicted over 60% of the variance in the IKDC scores of patients with a history of ACLR, which shows that most IKDC scores have been affected by the patient's quadriceps strength following ACLR, with quadriceps weakness greatly limiting their self-perceived function. In our study, 50% of the patients who achieving LSI more than 90% in isometric quadriceps strength passed also in IKDC.

For patients-reported outcome measures, there are significant strong correlations between patients-reported outcome measures KOOS subscales and IKDC. Therefore, we suggested that the IKDC is enough as a patients-reported outcome measure tool to be demonstrated at discharge from rehabilitation as it is shorter version and more suitable than KOOS for short term (Roos & Toksvig-Larsen, 2003), also IKDC better than KOOS for ACLR patients due to its overall performance (Hambly & Griva, 2008).

Fear of re-injury appears to influence function following ACLR, especially for athletes in the late phase of rehabilitation, when fear of re-injury is linked to a reduction in self-report functioning (Hartigan, Lynch, Logerstedt, Chmielewski, & Snyder-Mackler, 2013; Kvist et al., 2005; Lentz et al., 2009). Thus, fear of re-injury seems to influence function more when return to sport is imminent, and athletes with a high fear of re-injury could limit their physical activities to those that are low risk of causing a re-injury, thereby causing the athlete to perceive themselves as low functioning. Therefore, athletes with a low self-reported function should be tested for high fear of re-injury (Hsu, George, & Chmielewski, 2016), as fear of re-injury will create a distraction and affect the athlete's post-injury performance (Nippert & Smith, 2008; Podlog, Dimmock, & Miller, 2011; Podlog & Eklund, 2005, 2007). The current study did not find a link between fear of movement/re-injury and the single leg hop, which is confirmed by other studies (Hartigan et al., 2013; Hsu et al., 2016; Lentz et al., 2009). In addition, this study found a negative weak to moderate relationship between fear of injury and the other outcome measures explored, apart a strong negative relationship with psychological readiness.

Webster et al. (2018) explain that for younger patients; where there is a shorter time between injury and surgery; greater limb symmetry, and higher subjective knee scores, all had a positive impact on psychological readiness. Subjective knees scores for all patients showed the most significant association with psychological readiness. A number of validation studies have found IKDC subjective knee scores to have a moderate univariate correlation with ACL-RSI scores (Bohu et al., 2015; Chen et al., 2017; Harput et al., 2017); although psychological readiness has been strongly associated more so with subjective knee scores than physical functioning. Therefore, self-report outcomes are clearly linked to psychological readiness to RTS. In the current study, a weak correlation was discovered between psychological readiness and the other outcome measures examined, except for a moderate and strong correlation with KOOS QoL and TSK. Due to the strong correlation between Psychological factors ACL-RSI and TSK we suggested that the ACL-RSI is enough as a psychological tool to be demonstrated at discharge from rehabilitation as it is especially designed to capture the psychological readiness for ACLR patients.

The findings from this study emphasise how the relationship between muscle strength, function, psychological factors and subjective functioning are not the same for all athletes following ACL surgery, and these criteria describe different aspects of the ACLR patient, showing the need for a range of outcome measures to be considered within a comprehensive evaluation of the patient. These findings show that successful performance on one outcome measure does not reflect a similar successful performance on other outcome measures. Moreover, it is preferable to use comprehensive criteria to determine patients' readiness to return to their preinjury levels of activity, as this would provide clinicians with essential information about patients, including any impairments, muscle strength, functional deficits and psychological factors.

4.8.9 Recovery following ACLR

This study's main finding is that only two (4.3%) of the participants passed all of the RTS criteria at discharge from rehabilitation following ACLR, which suggests that the performance criteria is probably too stringent to pass before returning to sport, or rehabilitation programme was insufficient to achieve these criteria which lead to poor outcome measures after ACLR. Furthermore, other studies have reached similar conclusions when using similar criteria, apart from the psychological factors, which are among the most demanding reported in the literature and in clinical practice (Adams et al., 2012; Gokeler et al., 2017; Wellsandt et al., 2017). However, the clearance criteria used in this study is similar to that used by Kyritsis et al. (2016) who found that athletes who did not meet the clearance requirement criteria before returning to sport were four times more likely to sustain an ACL graft rupture in comparison to those who met the criteria. In addition, the criteria is the same as that used by Grindem et al. (2016) who found lower knee re-injury rates of 84% among patients who passed return-to-sport criteria within a two year period after ACLR. On the other hand, Wellsandt et al. (2017) found that limb symmetry for quadriceps strength and in the single-leg hop test following ACLR, overestimates knee function, which can lead to false assurances that patients are ready to return to sport when they are not functionally ready. In fact, symmetry measures have become commonplace as a guideline for evaluating patient outcomes post-ACLR (Abrams et al., 2014; Grindem et al., 2011; Grindem et al., 2016; Logerstedt et al., 2013; Noyes et al., 1991). With regard to LSI, caution is necessary as it can hide bilateral deficits where the non-injured leg is affected by the injury and length of inactivity (Gokeler et al., 2017). Moreover, some researchers disagree on the value of symmetry measures and claim that unilateral normalised values can predict outcome measures within the ACLR population more effectively (Kester, Behery, Minhas, & Hsu, 2017; Pietrosimone et al., 2016), which supports the use of normalised measures following ACLR (Kuenze, Hertel, Saliba, et al., 2015; Pietrosimone et al., 2016). In addition, contralateral weakness could increase symmetry values while providing a false representation of the strength and function of the affected limb, again suggesting the use of normative data. The following chapter will analyse the performance of the injured and non-injured leg of ACLR patients compared to a healthy, age matched group. The injured leg will be compared to the reference value from matched leg-age of healthy group, while the non-injured leg will be compared to the reference value from the other matched leg-age of the healthy group.

A limitation of the current study is the analysing by subgroup of age reduced the statistically power of the analyses. Also, the study has assessed the ACLR patients only on one occasion at discharge from rehabilitation, based on the discharge time to return-to-sport following ACLR. Thus, conducting further evaluations 9 and 12 months after ACLR could lead to a useful additional information on successful return to sport and maintenance of sports participation after ACLR. Moreover, this study was limited to Arabic male patients with ACLR; therefore, the findings cannot be generalised to both genders and patients from other countries.

4.9 Conclusion

Based on the results of the study, all the hypotheses have been accepted and the following results can be highlighted:

- Functional performance, muscle strength, knee function deficits may persist after ACLR, even when the patient is discharged from rehabilitation
- Significant differences were found between the injured and non-injured leg performances during all the tests.
- Asymmetry between limbs exists for all tests, LSI were less than 90% between injured and non-injured leg.
- There was limited correlation between outcome measures for all tests.
- IKDC only is enough as a patient-reported outcome measure.
- ACL-RSI only is enough as a psychological factors tool.

This study has compared injured with non-injured leg of ACLR patients to determine the impairments in the injured leg linked to musculoskeletal and neuromuscular disorders, along with ways of monitoring the progression of ACLR patients over time. In this study, the non-injured leg represented the normal value, however, non-injured leg weakness could overestimate the injured leg performance. The reference values from healthy population and associated age and leg matched scores may be used for developing more accurate outcome measures and increase responsiveness, which will be useful for clinical trials to determine whether patients' functional characteristics and strength are normal or not.

Chapter 5

5 A comparison of different return to sport criteria following ACLR

(Question six): Are there differences between LSI return to sport criteria and the comparison with an age matched group from a healthy active population?

5.1 Introduction

Success following ACLR has been defined as a return to pre-injury or healthy levels of function and activity (Heijne et al., 2008; Lynch et al., 2015b). Therefore, outcomes should be assessed according to this standard. There are some discrepancies between statistical significance and clinical significance in the literature with regard to activity measures and functional performance tests, which is mainly because the contralateral limb is usually used as the comparator, mostly through hop tests, muscle strength and outcomes stated according to a limb symmetry index (LSI). In addition, the categories applied to performance indices vary. Although symmetrical performance is important, but it does not provide a full picture of normal performance.

The LSI is used to assess the performance of the injured limb compared the non-injured limb as a percentage score according to the performance. This is because it is assumed that symmetry will help to prevent overuse of the affected limb and therefore reduce the risk of injury when returning to activities that present a risk of injury (Thomeé et al., 2011). The validity of LSI is based on the following two assumptions: symmetry as representing the individual's pre-injury functional state, and secondly that the non-injured limb is representative of healthy normality and has not been affected by the injury (Bent et al., 2009; Clark, 2001; English et al., 2006; Fitzgerald et al., 2001; Herrington, 2013; Hewit, Cronin, & Hume, 2012). However, the literature on this issue is split between those who recommend using the LSI (Logerstedt et al., 2012; Logerstedt et al., 2013; Petschnig et al., 1998) and those warning against its use (Ageberg, 2002; Chmielewski et al., 2011; Fitzgerald et al., 2001; Thomeé et al., 2012) and preferring comparisons to healthy control values (Ageberg et al., 2001; Ageberg et al., 1998; English et al., 2006; Fitzgerald et al., 2001; Tegner et al., 1986) or using absolute measures to provide context to the symmetry values (Kuenze, Hertel, Saliba, et al., 2015; Reid et al., 2007).

The aim of this study is to assess the performance of ACLR patients on the injured and non-injured leg compared to age matched group from a healthy active population.

5.2 Aim and Objectives

- To compare single-leg hop for distance of healthy matched group with injured and non-insured leg of ACLR patients at discharge from rehabilitation.
- To compare isometric muscle strength of healthy matched group with injured and non-insured leg of ACLR patients at discharge from rehabilitation.
- To compare subjects' self-reported knee function of healthy matched group with injured leg of ACLR patients at discharge from rehabilitation.

5.2.1 Hypothesis

1) To investigate the single-leg hop for distance of healthy matched group with injured and non-insured leg of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   1-a There are differences between injured leg of ACLR patients and healthy matched group, in the single-hop for distance.

   1-b There are differences between non-injured leg of ACLR patients and healthy matched group, in the single-hop for distance.

2) To investigate the isometric quadriceps muscle strength of healthy matched group with injured and non-insured leg of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   2-a There are differences between injured leg of ACLR patients and healthy matched group, the isometric quadriceps muscle strength.

   2-b There are differences between non-injured leg of ACLR patients and healthy matched group, the isometric quadriceps muscle strength.

3) To investigate the isometric hamstring muscle strength and hamstring to quadriceps ratio H/Q of healthy matched group with injured and non-insured leg of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   3-a There are differences between injured leg of ACLR patients and healthy matched group, the isometric quadriceps muscle strength.

   3-b There are differences between non-injured leg of ACLR patients and healthy matched group, the isometric quadriceps muscle strength

   3-c There are differences between injured leg of ACLR patients and healthy matched group, the H/Q ratio.

3-d There are no differences between non-injured leg of ACLR patients and healthy matched group, the H/Q ratio.

4) To investigate self-reported knee function (KOOS) of healthy matched group with injured leg of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   4-a There are differences between ACLR patients and healthy matched group in (KOOS).

5) To investigate self-reported knee function (IKDC) of ACLR patients at discharge from rehabilitation.

   Hypothesis:

   5-b There are differences between ACLR patients and healthy matched group in (IKDC).

5.3 Methods

5.3.1 Healthy group:

For more details see methods chapter section (3.3.5)

5.3.2 ACLR patients

For more details see chapter four section (4.5)

5.3.3 population demographics

Table 5.1: *Characteristics of the subjects stratified by age group

		Control N= 35	**ACLR N= 9**
18-24 years	Age (years) (SD)	20.5 ± 2.2	22.6 ± 0.7
	Height (m) (SD)	172.9 ± 5.4	170.6 ± 2.5
	Mass (kg) (SD)	66.1 ± 14.4	64.2 ± 3.8
	Students (%)	25 (71%)	4 (44%)
	Employed (%)	10 (29%) [d]	5 (56%) [a]
25-34 years		**Control N= 35**	**ACLR N=26**
	Age (years) (SD)	29.6 ± 2.6	28.5 ± 2.7
	Height (m) (SD)	170.3 ± 5.6	171.9 ± 8.7
	Mass (kg) (SD)	70.5 ± 8.8	78.60 ± 16.6
	Students (%)	3 (9%)	4 (15%)
	Employed (%)	32 (91%) [e]	22 (85%) [b]
35-44 years		**Control N= 35**	**ACLR N=12**
	Age (years) (SD)	36.3 ± 1.25	38.6 ± 2.7
	Height (m) (SD)	171.3 ± 3.7	174.2 ± 7.8
	Mass (kg) (SD)	72.7 ± 9.8	83.4 ± 11.0
	Students (%)	0 (0%)	0 (0%)
	Employed (%)	35 (100%) [h]	12 (100%) [c]

[a], 2 (22%) sedentary work; [b], 7 (27%) sedentary work; [c], 3 (25%) sedentary work; [d], 9 (26%) sedentary work; [e], 15 (43%) sedentary work; [h], 22 (63%) sedentary work.

* Sedentary work: Office work.

5.4 Statistical analysis

The statistical analyses were carried out using Statistical Package for Social Sciences software (version 24, SPSS Statistics 20. Ink). Descriptive statistics (mean, range of scores and standard deviations) and scatter graphs were presented the data descriptively. Two-way mixed analysis of variance (ANOVA, 2 X 2) with Bonferroni correction was used to assess the interaction of groups and limbs (injured and non-injured) in ACLR groups with (right and left) matched leg from healthy population. Epsilon (**ε**) correction was applied using Greenhouse-Geisser method (Maxwell, Delaney, & Kelley, 2018). One sample t-tests for parametric variables and Wilcoxon signed rank test for non-parametric variables were used to assess side-to-side difference, right and left injured leg of ACLR patients with the reference number from matched leg and age of healthy group, right and left non-injured leg of ACLR patients with the reference number from matched leg and age of healthy group for each test.

5.5 Results

5.5.1 Self-reported knee function

Mean scores for IKDC in each of 3 age categories in ACLR patients were compared with matched age group of healthy population. There were statistically significant different between ACLR patients' groups and matched healthy groups. The majority of the patients scored more than 85% of healthy scores. The younger ACLR patents group reported more differences with the matched healthy group in IKDC 76.53%.

The mean scores for 5 subscales of the KOOS (Pain, Symptoms, Functional ADL, Sports and Recreation Function and Knee-Related QOL) in each of 3 age categories in ACLR patients were compared with matched age group of healthy population. The younger ACLR patients group reported more differences with the matched healthy group in knee related complaints than older groups. QoL subscale in (35-44) age group was the lowest scores between ACLR patients' group to healthy matched group 53.62% see (Table 5.2).

Table 5.2: [a]A comparison of KOOS and IKDC outcomes between ACLR patients age groups and healthy matched groups

	Injured leg vs matched control leg			
Test	**ACLR Group**	**Healthy Group**	**p-value**	**SI (%)**
(18-24)				
KOOS Symptoms	78.9 ± 8.6	89.8 ± 6.5	0.02*	86.53
KOOS Pain	83.2 ± 10.6	94.4 ± 5.5	0.01*	86.07
KOOS ADL	90.2 ± 7.2	95.2 ± 8.3	0.04 *	92.80
KOOS Sport/Rec	67.2 ± 30.4	93.5 ± 8.5	0.02*	70.21
KOOS QOL	53.11 ± 24	93.3 ± 11.1	0.01*	55.32
IKDC	73.5 ± 15.7	92.78 ± 7.59	0.02*	76.53
(25-34)				
KOOS Symptoms	82.5 ± 9.6	89.6 ± 9.4	0.38	96.48
KOOS Pain	91.0 ± 9.7	93.5 ± 7.3	0.001*	91.19
KOOS ADL	93.7 ± 8.6	94.3 ± 7.6	0.19	98.50
KOOS Sport/Rec	81.1 ± 17.2	87.7 ± 15.2	0.07	91.44
KOOS QOL	63.8 ± 22.3	90.0 ± 11.1	0.002*	71.12
IKDC	81.3 ± 13.2	89.53 ± 9.78	0.002*	89.32
Men (35-44)				
KOOS Symptoms	84.5 ± 7.3	92.0 ± 7.8	0.08	89.55
KOOS Pain	83.7 ± 13.7	93.2 ± 8.5	0.01*	91.52
KOOS ADL	85.2 ± 13.5	92.9 ± 9.5	0.05*	91.32
KOOS Sport/Rec	68.3 ± 22.1	89.9 ± 14.0	0.02*	76.39
KOOS QOL	49.5 ± 15.2	92.0 ± 12.4	0.001*	53.62
IKDC	68.9 ± 17.1	89.31 ± 11.18	0.01*	76.56

[a]KOOS, Knee Injury and Osteoarthritis Outcome Score; QOL, quality of life; ADL, activities of daily living; IKDC, International Knee Documentation Committee; SI, Symmetry Index (Injured leg / Control leg).
(*) Statistically significant

There was a statistically significant interaction between the limb and group on hop test, isometric quadriceps and hamstring muscles strength in the interaction of groups and limbs (injured and non-injured) in ACLR groups with (right and left) leg from healthy population see (Table 5.3).

Table 5.3: [a]The interaction of limbs in hop test, quadriceps muscle, hamstring muscle and Hamstring/Quadriceps ratio, *p*-value (p = 0.05)

Age group	Hop test	Quadriceps muscle	Hamstring muscle	H/Q ratio
18-24	0.001*	0.02*	0.001*	0.79
25-34	0.002*	0.003*	0.002*	0.95
35-44	0.02*	0.002*	0.002*	0.59

[a]H/Q ratio, Hamstring muscle/Quadriceps muscle ratio.

5.5.2 Single-leg hop for distance

(Table 5.4 and 5.5) below shows the comparison descriptive statistics for single-hop test scores both injured and non-injured leg with matched control leg. A one-sample t-test was conducted to evaluate the differences between injured and non-injured leg with control matched leg performance. There were statically significant differences in single-leg hop for distance between injured and matched control leg from healthy people. The majority of the patients scored less than 90% of healthy performance. The older ACLR patients group reported more differences in the left leg performance with the matched healthy group in single-hop test 71.66% see (Table 5.4). Also, there were no statically significant differences between non-injured and matched control leg from healthy people apart from the right leg performance in (25-34 and 35-44) age groups see (Table 5.5).

Table 5.4: [α]Mean (SD) and p-value, Comparison of significant (P = 0.05) between injured with matched control leg in single-leg hop test

	Injured leg vs healthy matched leg				
Test	**Injured**	**Control**	**p-value**	**Effect Size**	**SI (%)**
(18-24)					
Right Single hop (%)	128.24 ± 22.03	170.16 ± 12.13	0.001*	1.86	75.36
Left Single hop (%)	126.19 ± 32.49	165.80 ± 15.64	0.01*	1.22	76.11
(25-34)					
Right Single hop (%)	117.46 ± 41.91	148.06 ± 21.88	0.002*	0.7	79.33
Left Single hop (%)	115.47 ± 47.69	147.74 ± 16.78	0.002*	0.68	78.16
Men (35-44)					
Right Single hop (%)	100.15 ± 45.74	137.85 ± 32.05	0.001*	0.83	72.65
Left Single hop (%)	95.41 ± 55.98	133.14 ± 37.93	0.001*	0.68	71.66

[α] SI, Symmetry Index (Injured leg / Control leg).
(*) Statistically significant

Table 5.5: [a]Mean (SD) and p-value, Comparison of significant (P = 0.05) between non-injured with matched control leg in single-leg hop test

	Non-injured leg vs healthy matched leg				
Test	**Non-injured**	**Control**	**p-value**	**Effect Size**	**SI (%)**
(18-24)					
Right Single hop (%)	169.76 ± 13.03	170.16 ± 12.13	0.75	0.12	99.76
Left Single hop (%)	164.53 ± 10.22	165.80 ± 15.64	0.71	0.22	99.23
(25-34)					
Right Single hop (%)	131.28 ± 26.24	148.06 ± 21.88	0.01*	0.64	88.66
Left Single hop (%)	135.26 ± 27.54	147.74 ± 16.78	0.28	0.34	91.55
Men (35-44)					
Right Single hop (%)	120.59 ± 33.67	137.85 ± 32.05	0.02*	0.50	87.47
Left Single hop (%)	111.48 ± 39.28	133.14 ± 37.93	0.11	0.64	83.73

[a] SI, Symmetry Index (Non-injured leg / Control leg).
(*) Statistically significant

5.5.3 Isometric muscle strength

(Table 5.6 and 5.7) below shows the comparison descriptive statistics for quadriceps isometric muscle strength test scores both injured and non-injured leg with matched control leg. A one-sample t-test was conducted to evaluate the differences between injured and non-injured leg with control matched leg muscle strength. There were statically significant differences in quadriceps muscle strength (Nm/kg) between injured and matched control leg from healthy people. The majority of the patients scored less than 90% of healthy muscle strength. The older ACLR patients group reported more differences in the right injured leg compared to the matched healthy group in quadriceps muscle strength 58.85% (Table 5.6).

Table 5.6: [a]Mean (SD), p-value and effect size, Comparison of Significant (P = 0.05) between injured and matched control leg in quadriceps isometric muscle strength

	Injured leg vs healthy matched leg				
Test	Injured	Control	p-value	Effect Size	SI (%)
(18-24)					
Right Quadriceps (Nm/kg)	2.09 ± 0.47	2.84 ± 0.57	0.03*	1.59	73.59
Left Quadriceps (Nm/kg)	2.05 ± 0.67	2.83 ± 0.71	0.02*	1.66	72.44
(25-34)					
Right Quadriceps (Nm/kg)	1.80 ± 0.43	2.39 ± 0.43	0.001*	1.37	75.31
Left Quadriceps (Nm/kg)	1.69 ± 0.40	2.41 ± 0.60	0.002*	1.77	70.12
Men (35-44)					
Right Quadriceps (Nm/kg)	1.33 ± 0.15	2.26 ± 0.28	0.002*	2.24	58.85
Left Quadriceps (Nm/kg)	1.48 ± 0.20	2.26 ± 0.30	0.001*	3.65	65.49

[a] SI, Symmetry Index (Injured leg / Control leg).
(*) Statistically significant

Also, there were statically significant differences between non-injured and matched control leg from healthy people for the older group and right leg of (25-34) age group (Table 5.7).

Table 5.7: [a]Mean (SD), p-value and effect size, Comparison of Significant (P = 0.05) between non-injured and matched control leg in quadriceps isometric muscle strength

	Non-injured leg vs healthy matched leg				
Test	Non-injured	Control	p-value	Effect Size	SI (%)
(18-24)					
Right Quadriceps (Nm/kg)	2.66 ± 0.59	2.84 ± 0.57	0.46	0.33	93.66
Left Quadriceps (Nm/kg)	2.40 ± 0.70	2.83 ± 0.71	0.12	0.62	84.81
(25-34)					
Right Quadriceps (Nm/kg)	1.94 ± 0.38	2.39 ± 0.43	0.001*	1.17	81.17
Left Quadriceps (Nm/kg)	2.05 ± 0.52	2.41 ± 0.60	0.07	0.67	85.06
Men (35-44)					
Right Quadriceps (Nm/kg)	1.69 ± 0.1	2.26 ± 0.28	0.001*	3.02	74.78
Left Quadriceps (Nm/kg)	1.64 ± 0.1	2.26 ± 0.30	0.001*	4.18	72.57

[a] SI, Symmetry Index (Non-injured leg / Control leg).
(*) Statistically significant

(Table 5.8 and 5.9) below shows the comparison descriptive statistics for hamstring isometric muscle strength test scores both injured and non-injured leg with matched control leg. A one-sample t-test was conducted to evaluate the differences between injured and non-injured leg with control matched leg muscle strength. There were statically significant differences in hamstring muscle strength normalisation (Nm/kg) between injured and matched control leg from healthy people. The majority of the patients scored less than 90% of healthy muscle strength. The older ACLR patients group reported more differences in the left injured leg compared to the matched healthy group in quadriceps muscle strength 77.50% (Table 5.8).

Table 5.8: [a]Mean (SD), p-value and effect size, Comparison of Significant (P = 0.05) between injured and matched control leg in hamstring isometric muscle strength

	Injured leg vs healthy matched leg				
Test	**Injured**	**Control**	**p-value**	**Effect Size**	**SI (%)**
(18-24)					
Right Hamstring (Nm/kg)	1.32 ± 0.13	1.50 ± 0.35	0.03*	1.39	88
Left Hamstring (Nm/kg)	1.24 ± 0.1	1.55 ± 0.37	0.002*	3.06	80
(25-34)					
Right Hamstring (Nm/kg)	1.01 ± 0.28	1.28 ± 0.27	0.002*	0.96	78.90
Left Hamstring (Nm/kg)	1.11 ± 0.20	1.30 ± 0.30	0.01*	0.90	85.38
Men (35-44)					
Right Hamstring (Nm/kg)	0.98 ± 0.17	1.17 ± 0.18	0.02*	1.1	83.76
Left Hamstring (Nm/kg)	0.93 ± 0.17	1.20 ± 0.26	0.001*	1.6	77.50

[a] SI, Symmetry Index (Injured leg / Control leg).
(*) Statistically significant

Surprisingly, there were no statically significant differences between non-injured and matched control leg from healthy people for the all age group and legs (Table 5.9).

Table 5.9: [a]Mean (SD), p-value and effect size, Comparison of Significant (P = 0.05) between non-injured and matched control leg in hamstring isometric muscle strength

	Non-injured leg vs healthy matched leg				
Test	Non-injured	Control	p-value	Effect Size	SI (%)
(18-24)					
Right Hamstring (Nm/kg)	1.50 ± 0.19	1.50 ± 0.35	0.97	0.01	100
Left Hamstring (Nm/kg)	1.53 ± 0.11	1.55 ± 0.37	084	0.13	98.70
(25-34)					
Right Hamstring (Nm/kg)	1.22 ± 0.39	1.28 ± 0.27	0.49	0.17	95.31
Left Hamstring (Nm/kg)	1.30 ± 0.25	1.30 ± 0.30	0.92	0.02	100
Men (35-44)					
Right Hamstring (Nm/kg)	1.15 ± 0.22	1.17 ± 0.18	0.88	0.08	98.29
Left Hamstring (Nm/kg)	1.10 ± 017	1.20 ± 0.26	0.18	0.01	91.67

[a] SI, Symmetry Index (Non-injured leg / Control leg).

(Figure 5.1) below shows the number and percentage of the participants who passed in return to sports criteria SI (injured leg/control matched healthy leg) in each outcome measure, it seems that none of the participants passed in return to sport criteria in all outcome measures.

5.5.4 Passing the return to sport criteria

Passing the return to sport criteria was defined to pass all the outcome measures of the following criteria:

1. ≥ 90 % of healthy gender–age-matched subjects for single-leg hop test (Thomeé et al., 2011).
2. ≥ 90 % of healthy gender–age-matched subjects for quadriceps and hamstrings strength (Thomeé et al., 2011) .
3. H/Q ratio ≥ 60% (Hewett et al., 2008)
4. ≥ 85 % of healthy gender–age-matched subjects for IKDC & KOOS (Grindem et al., 2011)
5. ACL-RSI ≥ 56 points (Ardern et al., 2013)
6. TSK ≤ 37 points (Vlaeyen et al., 1995)

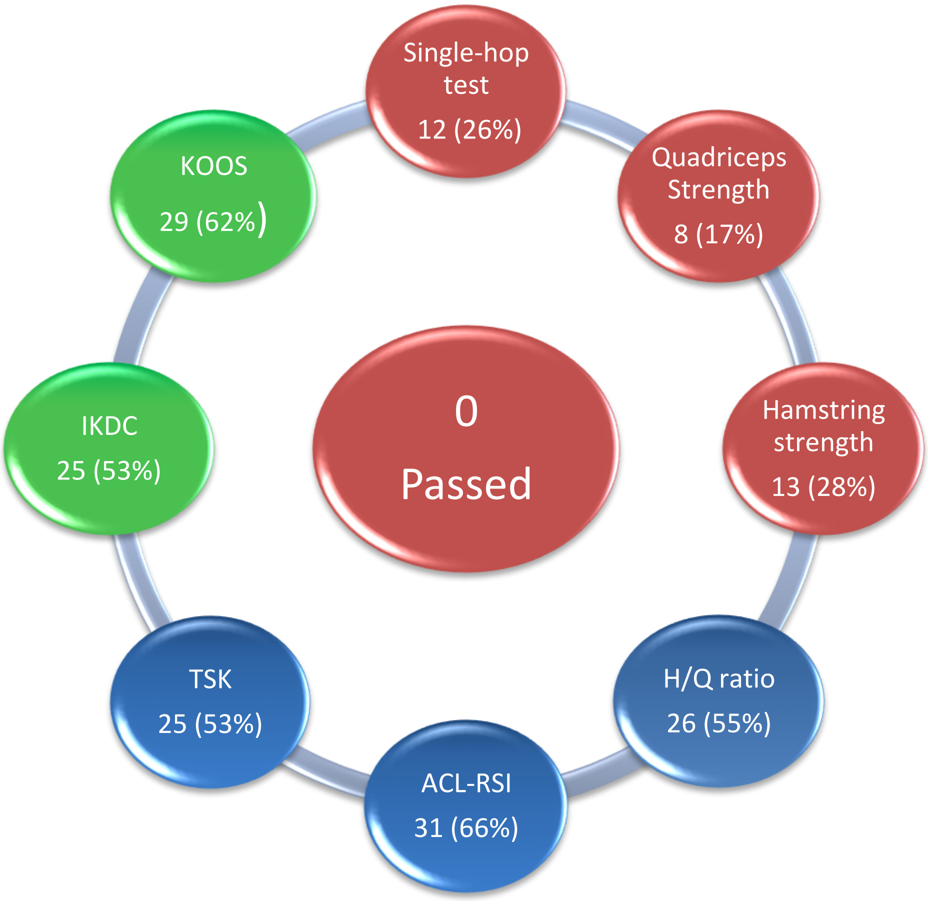


Figure 5.1: [α]Number and percentage of participants passing the return to sport criteria

[α] H/Q ratio, hamstring/quadriceps ratio; IKDC, International Knee Documentation Committee; ACL-RSI, the Anterior Cruciate Ligament Return to Sport Index; KOOS, Knee Injury and Osteoarthritis Outcome Score; TSK, Tampa Scale of Kinesiophobia.

outcome measures in blue icons remained the same as previous chapter's criteria (chapter 4), outcome measures in red icons have a lower number of passing participants and outcome measures in green icons have a higher number of passing participants than the LSI criteria from (chapter 4). See figure 4.1 section (4.7.6).

5.6 Discussion

The aims of this study were to:

1. Compare single-leg hop for distance of healthy matched group with injured and non-injured leg of ACLR patients at discharge from rehabilitation.
2. Compare isometric muscle strength of healthy matched group with injured and non-insured leg of ACLR patients at discharge from rehabilitation.
3. Compare subjects' self-reported knee function of healthy matched group with injured leg of ACLR patients at discharge from rehabilitation.

5.6.1 Matching sample characteristics

The ACLR patients and the healthy control participants were mostly healthy active men, included before the injury occurred for the former group. The ACLR and the control group participants were matched according to the leg being assessed, and their age and level of activity, although it was not possible to match all of them for height and mass. Such differences were not found to be statistically significant, and the difference only resulted in a small effect size, the distribution of the parameters shows that the aforementioned matching was adequate, with any bias dealt with by normalising individual parameters were possible to body mass and leg length, as shown in (Table 5.1).

5.6.2 A comparison of return to sport criteria: LSI and matched healthy group

Limb Symmetry Index (LSI) criteria between subject is defined as injured leg/non-injured leg, and a comparison with a matched healthy subject is defined as injured leg/matched leg-age of heathy control.

According to Zwolski et al. (2016), using just the LSI may not provide all of the information necessary on the extent of the impairment, and quadriceps strength performance can be better assessed by also conducting a comparison of strength performance values with the normative values displayed by healthy controls. This is in line with Wellsandt et al. (2017) as they claim that subjects who had the required 90% symmetry criterion for strength and hop tests conducted six months after ACLR would not have passed this criterion if the performance of the contralateral limb was compared to its performance prior to surgery, and not after, ACLR surgery. Therefore, symmetry, assessed through comparison to the contralateral leg, with regard to strength and hop distance does not necessarily mean that adequate recovery has taken place or confirm that the patient is ready to return to sport.

Currently, LSI is the most popular method for reporting strength and function outcomes as part of the discharge criteria (Gustavsson et al., 2006; Thomeé et al., 2011; Thomeé et al., 2012); however, this method does not take the possible deconditioning of the non-operated side into consideration (Thomeé et al., 2012). Furthermore, Wellsandt et al. (2017) discovered that postoperative LSI could even overestimate function, and so LSI should involve "estimated preinjury capacity," whereby limb symmetry is determined through a comparison of the injured limb measurements at a specific time point postoperatively with the uninvolved limb measurements prior to ACLR surgery (Wellsandt et al., 2017).

Importantly, the current study has found that comparing the injured leg to a matched healthy control led to just 8 (17%) patients meeting the criterion for quadriceps muscles strength, whereas 20 (43%) passed when using the LSI, as illustrated in (Figure 5.1). That is, 60% of the participants with 90% symmetry criterion for quadriceps muscle strength failed the RTS criterion when they were compared to matched healthy subjects. Similarly, (Gokeler et al., 2017) examined quadriceps strength and cut-off peak strength values (> 3.0 Nm/kg) for referencing and RTS criterion. The current study has revealed that none of the ACLR subjects scored a peak extensor strength higher than 3.0 Nm/kg. In addition, recent studies have also highlighted the importance of considering normal quadriceps strength in order to prevent recurrent ACL injuries (Grindem et al., 2016; Kyritsis et al., 2016). Where a patient has a strength deficit, RTS may be delayed for up to two years to prevent a further ACL injury (Nagelli & Hewett, 2017). Considering quadriceps strength is particularly important when considering that weakness of this muscle is linked to early onset osteoarthritis following ACLR surgery (Norte et al., 2018).

Hamstring muscle strength has also been tested in the current study, and no significant difference has been found between both criteria, as 13 (28%) patients passed the matched healthy group criterion for hamstring strength, in comparison to 15 (32%) for the LSI criterion, as shown in (Figure 5.1). The absence of a difference in knee flexion strength between the non-injured leg and matched healthy controls for all age ranges, and for both the right and left leg, is in line with previous research findings by (Mattacola et al., 2002), who state that no significant difference in hamstring muscle strength was found between the non-injured limb and matched healthy controls. As most of the population in Saudi population are practising

Muslims, they pray five times a day, which involves bowing and standing after bowing 17 to 29 times a day, and this necessitates good hamstring muscle strength (see Appendix 8.19); these movements can be likened to strengthening exercises for both legs. Even so, these movements during the prayer are unlikely to generate sufficient load to strengthen the muscle, although they may help to maintain some strength.

In single-leg hop tests involving a comparison between the injured leg and a matched control group, just 12 (26%) patients passed the criterion compared to 20 (43%) when comparing the injured leg to the non-injured leg (LSI), as shown in (Figure 5.1). This shows that 40% of the participants revealed a 90% symmetry criterion for the single-leg hop test failed the RTS criterion when compared to matched healthy control subjects.

Alternatively, the use of the Knee Injury and Osteoarthritis Outcome Score (KOOS) and the International Knee Documentation Committee Subjective Knee Form (IKDC) showed that more participants passed the criterion in comparison to healthy gender and age matched controls at ≥ 85 % (Grindem et al., 2011). When applying ≥ 85% to healthy and gender and age matched criterion, 25 (53%) and 29 (62%) of the patients passed the RTS criterion in comparison to 9 (19%) and 12 (26%) when applying ≥ 90 for KOOS and IKDC. These results are expected as the mean result for healthy groups for KOOS is 92.6 and for IKDC 91.42. The results from the current study for IKDC are in agreement with research conducted by Welling et al. (2018) who also used the criterion ≥ 85% for healthy, gender and age matched subjects for IKDC, as they found that 58% of patients passed the criterion.

The results from LSI should be viewed tentatively, as this approach can hide bilateral deficits due to the non-injured leg also possibly being affected by the injury and the length of time of inactivity (Gokeler et al., 2017). Therefore, normative data is recommended for analysing patients. In the current study, using normative data as a comparison revealed that the participants did not meet the normal required performance for both the injured and non-injured leg six months post ACLR when examining single-leg-hop test, as the results were 151% of the leg length for the normative data; 139% for the non-injured leg, and 123% for the injured leg. For quadriceps muscle strength, the results were 2.50 Nm/kg for the normative data, 2.0 Nm/kg for the non-injured leg, and 1.71 Nm/kg for the injured leg. For Hamstring muscle strength, the results were 1.33 Nm/kg for the normative data, 1.31 Nm/kg for the non-injured leg, and 1.10 Nm/kg for the injured leg. These results show that LSI can underestimate performance deficits, therefore this approach should be used with caution to assess RTS after

ACLR surgery (Gokeler et al., 2017; Welling et al., 2018; Wellsandt et al., 2017). In general, it has been found that the ACL-reconstructed leg is weaker than the uninjured leg, but the uninjured leg is weaker than the leg of healthy matched controls.

When comparing the injured leg to the leg of an age matched heathy control against LSIs obtained from injured leg/matched healthy leg, the results for hop tests revealed a much higher LSI (77%) compared to quadriceps strength (69%) or hamstring strength (72%), which is in line with a recent study conducted by (Nagai et al., 2019), as they found that LSI values from hop tests overestimated the subjects' functional outcomes. In addition, Ageberg (2016) found that LSI for single-leg hops stayed the same in a final multivariable model, but hop performance for the injured leg did not; therefore, they claim that LSI is likely to be more sensitive for knee confidence compared to absolute values once the patient has completed rehabilitation. Importantly, in the recent systematic review and meta-analysis Kotsifaki, Korakakis, Whiteley, Van Rossom, and Jonkers (2019) warns that surgeons and therapists should not use only hop test results in isolation when analysing a patient's readiness to RTS and assessing knee function after ACLR (Ageberg, 2016; Kotsifaki et al., 2019) as the hop test can be undertaken in a number of discrete biomechanical ways, whilst generating similar results.

The findings from the current study are in agreement with the findings from a systematic review conducted by (Larsen et al., 2015), which reveals that 6–9 months post-ACLR, patients have significantly lower muscle strength in comparison to control groups, and the variations in LSI are between 16 and 39%, and so fall outside the acceptable LSI limit (Larsen et al., 2015). Thus, following ACLR, patients have a side-to-side deficit, yet the uninjured leg is also significantly weaker when compared to the leg of a matched control subject. This shows the extent of the impact of an ACL injury has on the uninvolved leg, and it calls into question the credibility of using the LSI as the criterion for RTS (Larsen et al., 2015).

As explained above, an ACL injury may be described as a double leg problem, rather than a single leg injury, as muscle strength deficits, performance issues, and shortcomings in neuromuscular control and proprioception, have been found in the contralateral uninjured limb, as well as the injured limb (Trulsson, 2018). The current study's results concerning reduced performance in hop tests and reduced muscle strength in the injured limb is in line with other studies that have carried out comparisons with healthy groups (Baltaci et al., 2012; Button et al., 2014; Chung et al., 2015; Clagg, Paterno, Hewett, & Schmitt, 2015; Hannon et al., 2017; Kaminska et al., 2015; Kuenze, Hertel, Saliba, et al., 2015; Kuenze et al., 2017; Lepley et al., 2019; Mattacola et al., 2002; Pamukoff et al., 2017; Roos, Button, Sparkes, & van Deursen, 2014; Wren et al., 2018; Xergia et al., 2013; Zwolski et al., 2016). Furthermore, the results concerning reduced performance in hop tests and reduced muscle strength in the uninjured limb are in agreement with past research studies that have carried out comparisons with healthy control groups (Baltaci et al., 2012; Chung et al., 2015; Lepley et al., 2019; Wren et al., 2018; Xergia et al., 2013; Zwolski et al., 2016).

5.6.3 Recovery following ACLR

It should be noted that if the participants in the current study had to meet the standards suggested above (≥ 90%) of healthy people regarding functional symmetry and strength symmetry, and (≥ 85%) for healthy people regarding self-reported function, as well as the cut-off score for psychological factors, to be cleared for RTS, none of them would have been discharged from rehabilitation, as illustrated in (Figure 5.1). These findings are in line with other research studies that involved stringent criteria (Curran et al., 2018; Gokeler et al., 2017; Thomeé et al., 2012; Welling et al., 2018). Thomeé et al. (2012) conducted a prospective study involving six tests: three hop tests and three strength tests. They found that six months post ACLR, if success was defined as scoring an LSI of >90 % in all six tests, none of the patients would have passed their criteria, and only 23 % of the patients in the study by Thomeé et al. (2012) succeeded in reaching the criteria at two years post ACLR. In addition, Gokeler et al. (2017) and Welling et al. (2018) found that only two patients out of 28 and 62 respectively passed the RTS criteria six months post ACLR, and another recent study by Curran et al. (2018) showed that no patients would have been cleared in the initial test six months post after ACLR, with just one participant passing the RTS criteria after one year.

Curran et al. (2018) discovered asymmetries of more than 10% in muscle strength, hop tests and self-reported knee function over 12 months after ACLR, and Graziano et al. (2017) found that none of the young patients in their study were ready to RTS before nine months post ACLR. These figures for RTS are really low compared to the 83% reported in a large meta-analysis conducted by Lai, Ardern, Feller, and Webster (2018), and a number of other studies in the literature (Ardern et al., 2011a, 2011b; Brophy et al., 2012; Grindem, Eitzen, Moksnes, Snyder-Mackler, & Risberg, 2012; McCullough, Phelps, Spindler, Matava, Dunn, Parker, Group, et al., 2012; Thomeé et al., 2013). Due to the various other factors involved, it is difficult to make entirely accurate comparisons concerning rate of RTS, as this is affected by age range, activity levels population, and the RTS criterion and the assessment methods used.

In a research study carried out by Grindem et al. (2016), they found that patients who did not pass all assessments as part of their discharge criteria, including quadriceps strength and hop testing with symmetry scores of greater than 90%, as well as patient-reported outcomes (≥90/100), were at more risk of injury after RTS, including further ACL injuries. Kyritsis et al. (2016) measured a battery of discharge criteria before RTS, including strength testing and functional hop testing, with male professional soccer players who had undergone ACLR. They found that patients who did not meet all the clinical discharge criteria were four times more likely to suffer a graft rupture. These studies are important as they highlight the need to meet all the requirements included in standard discharge criteria to reduce the likelihood of future injury.

A problem with some RTS tests with multiple criteria is the 'penalty' involved as they are more difficult to pass (Toole et al., 2017), for example, some RTS criteria includes multiple tests in different domains, and has requisite pass rates, usually set at 90%. If the athlete passes one test, and a second test with a 90% pass requirement is added, the number of athletes who pass is certain to fall (Toole et al., 2017). For example, if 80% of athletes pass every test in the RTS criteria, the overall pass rate will depend on the total number of tests; that is, if the pass rate for the first test is 80%, but 64% (0.8 × 0.8) for two tests, 51% (0.64 × 0.8) for three tests, 40% (0.5 × 0.8) for four tests, and so on, the overall results drop (Webster & Hewett, 2019). Even so, it is possible to correct this problem, and testing should be conducted at various points in time, so that once a test has been passed, it can be removed from the criteria requirement for that athlete. However, care should be take, as athletes may pass the criterion at one time point, but fail it later on (van Melick et al., 2016).

In a practical sense, the low pass rates call into question whether such tests should be used if most patients fail them; that is, because the RTS tests have large floor effects. It is important to address whether RTS tests are designed to measure if the patient is capable of RTS at a certain level, or if they are designed to determine patient safety for RTS. Regarding the patient's capability for RTS, passing an RTS criteria six months after surgery has been shown to lead to higher RTS rates (Nawasreh et al., 2018), although the cohort that passed included significantly more male patients and a younger age group. The ability of RTS testing to predict whether it is safe to return to sport has studied, and passing an RTS criteria has been found to result in an overall reduction in risk of a subsequent knee injury of 75% (Graziano et al., 2017; Grindem et al., 2016). In addition, according to Grindem et al. (2016), if patients wait at least nine months before RTS, the risk of further knee injury is reduced by 51% for each month it is delayed up until the nine month point. Moreover, Dekker et al. (2017) found that there was a 13% of second ACL injury risk reduction for every month waited.

5.6.4 Clinical implications

Assessing whether an athlete is ready to RTS is complicated, and while it is not possible to guarantee that an injury will not reoccur if an athlete RTS, a number of factors that should be considered to determine whether the risk is acceptable; particularly because meeting RTS criteria as a prerequisite to RTS has been found to lower the risk of re-injury by 75 to 84% (Grindem et al., 2016; Kyritsis et al., 2016).

Putting thorough rehabilitation and RTS processes in place, including criterion-based progression goals and essential discharge criteria, should reduce the risk of re-injury and improve outcomes post ACLR (Grindem et al., 2016; Kyritsis et al., 2016). Even so, passing RTS criteria does not guarantee an athlete is safe upon RTS. However, it has been shown in a prospective study of 158 professional male football players, that those players who failed to meet the RTS criteria in place, were four times more likely to suffer a second ACLR when compared to those athletes who met all of the criteria (Kyritsis et al., 2016): 12 out of 26 players with a second ACLR met the RTS criteria, while 28 out of 132 players with no second ACL injury did not pass the RTS criteria.

A very recent systematic review by (Losciale et al., 2019) has shown that passing RTS criteria does not reduce the risk of second ACL injury significantly, which emphasises the shortcomings in current RTS testing approaches and their ability to predict those at greater risk of a secondary ACL injury. Similarly, Ithurburn et al. (2019) reported that, at time of RTS no differences were observed between those who sustained a second ACL injury after one year of RTS and those who successfully returned to their pre-injury sport level. However, (Losciale et al., 2019) review was based on limited number of studies and a very low quality of evidence. In addition, all these studies used LSI as a criterion to RTS after ACLR, LSI could overestimate knee function, which can lead to false assurances that patients are ready to return to sport when they are not functionally ready (Wellsandt et al., 2017).

Webster and Hewett (2019) conducted a systematic review and meta-analysis, and they discovered that passing an RTS test battery significantly reduces the risk of a subsequent graft rupture by 60%; however, passing RTS criteria increased the risk of a contralateral ACL injury by 235%. Therefore, it is essential consider the outcomes and rehabilitation of both knees, as a further ACL injury would be devastating to the athlete. One of the reasons for the increased risk may be the increased activity level among RTS patients due to being cleared for RTS, and a major shortcoming in the literature on RTS testing is that exposure to sport is not considered in much of the analysis, even though an increase in training load may greatly increase the risk of re-injury (Blanch & Gabbett, 2016). However, Capin et al. (2019) claim that (Webster & Hewett, 2019) did not perform a risk of bias assessment, and the study includes two articles at high risk of bias, therefore this influenced their conclusions (Capin et al., 2019).

No consensus has been reached on when an athlete should be deemed ready to RTS, or the optimal testing procedures that should be put in place to determine readiness. While having RTS criteria in place is seen as important to conducting and optimising the decision-making process, RTS criteria is not currently specific enough, or sensitive enough, to determine when the patient is actually ready to RTS, especially with regard to an acceptable injury risk and performance level. Therefore, researchers and practitioners should consider a range of factors, such as whether the athlete has fully restored neuromuscular performance; quality of movement, and a sport-specific fitness profile, including specific loading requirements, to ensure they can cope with the demands of their particular sport (Buckthorpe, 2019).

5.7 Conclusion

The results of the current study show that all the hypotheses have been accepted, and the following points should be emphasised:

- Functional performance, muscle strength, and knee function deficits can persist following ACLR, despite going through a structured rehabilitation programme, as shown in the comparison of patients with a matched healthy control group.
- Major differences in performance were found between the injured leg and the matched healthy control group during all the tests.
- The differences in performance between the non-injured leg and the matched healthy control group varied in accordance with age, which leg, and the test conducted.
- Asymmetry between limbs exists for all tests (LSI) were lower than 90% between the injured and matched healthy control group.

This study has compared two different RTS criterion, (LSI), and comparisons with matched healthy control group to investigate the differences between the injured leg, un-injured leg and the matched leg of healthy control, to determine whether there are impairments to the uninjured leg. The results of this study highlight the issues around clinical RTS decision making for individuals following ACL reconstruction. In particular, the significant difference between the non-injured and matched leg of a heathy control. Therefore, it is suggested that rehabilitation should include exercises aimed at improving functional tasks and the muscle strength of both the injured and non-injured leg. Moreover, the use of LSI should be questioned, as this method does not show bilateral deficits, even though the non-injured leg is often affected by the injury due to the length of the inactivity time (Gokeler et al., 2017). Overall, the evidence contained in this study suggests that all of patients six months post ACLR should receive additional rehabilitation to pass RTS criteria.

Chapter 6

6 Overall Summary, Conclusion and Future recommendations

6.1 Summary

The majority of athletes who have undergone ACLR surgery aim to return to pre-injury levels of sport (Feucht et al., 2016); however, at one year post ACLR only around half are ready to do so, and two years post ACLR two-thirds are able to reach this goal; moreover, athletes who return to sport are at greater risk of another ACL injury (Ardern, Taylor, et al., 2014; Ardern et al., 2011a). Young athletes are more likely to suffer a second ACL injury (Dekker et al., 2017; Wiggins et al., 2016), with figures of up to 35% reported (Webster & Feller, 2016). Furthermore, there has been more interest and an increase in research into RTS criteria recently, with the aim of reducing the risk of second ACL injuries; in particular, by producing a set of criteria that can be used to ensure the athlete is ready to return to sport during the last stage of rehabilitation (Dingenen & Gokeler, 2017).

A wide range of results can be found in relation to the discharge criteria used for the ACLR rehabilitation process and to assess athletes' readiness to safely RTS. The various measures that have been used to determine the patient's readiness to be discharged from physical therapy include knee function (Frobell et al., 2013), time passed after surgery (Myer et al., 2012), muscle strength (Schmitt et al., 2012), psychological readiness (Ardern & Kvist, 2016), and functional performance such as by using hop tests (Barber et al., 1990). Moreover, no published studies have been found that have researched the four main components of the hop test, muscle strength, self-reported function and psychological factors of ACLR patients altogether. Furthermore, measuring a patient's performance can be compared to the normative data attained on normal individuals to make an assessment of the extent of the impairment. Even though some studies have explored the normative values for muscle strength, functional performance and self-reported knee function, the usefulness of this data is restricted due to several factors, including the ages and levels of activity of the participants, as well as the specific tools used for measuring. Importantly, there is no study compare the ACLR patients (injured and contralateral leg) with matched leg, age, gender and activity level of the healthy group, and no published study has been conducted on ACLR patients' recovery in Saudi Arabia.

The aim of this thesis has been to investigate the functional recovery at discharge from rehabilitation following ACLR, and to compare this with a matched age group from the healthy adult population; therefore, specific elements needed to be explored:

1. To investigate the reliability and validity of isometric strength testing of the knee flexor and extensors (quadriceps and hamstring muscles), within-day and between-days using hand-held dynamometry (HHD).
2. To translate and culturally adapt the IKDC and ACL-RSI to make them suitable for Arabic speaking patients with ACL injuries.
3. To establish normative scores for single-leg hop for distance, isometric muscle strength, self-reported knee function in a healthy active population according to age groups.
4. To investigate the functional recovery at discharge from rehabilitation following Anterior Cruciate Ligament Reconstruction ACLR.
5. To assess the performance of ACLR patients on the injured and non-injured leg and to compare it with age matched group from a healthy active population.

6.2 Conclusion

With respect to aim one, the reliability and validity of the HHD when testing the strength of the knee extensors and flexors muscles was investigated, ICC variables were shown to be good for all tests, both within and between-days (ICC = 0.91 = 0.96) with low SEM (SEM = 2.1 N to 2.77 N) and SDD between (5.82 N and 7.68 N) for all of the tests. A Spearman correlation analysis showed that the correlation coefficients of the HHD extensor muscles measurements were: r = 0.98 (right) and r = 0.93 (left). The correlation coefficients for the HHD flexors muscles measurements were r = 0.99 (right) and r = 0.97 (left). These results also revealed a high correlation with the measurements from the Biodex System 4 PRO dynamometer r = 0.93 - 0.99, (p = 0.05) of the knee extensors and flexors muscles for both legs.

Regarding aim two, Cross-cultural adaptation and translation of the IKDC and ACL-RSI was performed. ICC variables were shown to be good for both tests (ICC = 0.95 and 0.93) with low SEM (SEM = 3.38 and 5.61 points) and SDD 9.36 and 15.54 points for IKDC and ACL-RSI respectively. The a priori hypotheses have been confirmed for the correlations between the scores of IKDC, ACL-RSI, TSK and the KOOS subscales, Rand-36. The results have shown that the Arabic-versions of the IKDC and ACL-RSI are valid and reliable instruments for Arabic patients with ACLR.

For the third aim, it was necessary to establish normative data scores for single-leg hop for distance, isometric muscle strength and self-reported knee function in a healthy active population according to age groups. Normative mean scores for IKDC and KOOS scores were determined in each of 3 age categories. However, the mean IKDC score for all participants was 91.42, and mean scores for all KOOS subscales for all age groups were 92.57. Single-leg hop for distance ranged from 133.14% to 170.16% leg length. Quadriceps muscle strength was tested and found to be ranged from 2.84 Nm/kg to 2.26 Nm/kg and hamstring between 1.55 Nm/kg and 1.17 Nm/kg, based on the tested leg and age group. The results have showed that statistically significant differences were found between the right and left leg performances during single-leg hop test, although the effect sizes were minimum, and the differences not functionally relevant as they fell within the standard error of measurement values, no significant differences were found between the right and left leg performances during all isometric muscle tests, symmetry between limbs exists for all tests, LSI were more than 95% between right leg and left leg and there were statistically significant differences between age groups performances for all tests.

To reach the fourth and fifth aims, it was necessary to investigate single-leg hop for distance, isometric muscle strength, self-reported knee function and psychological factors for ACLR patients at discharge from rehabilitation. It was also important to assess the performance of ACLR patients on the injured and non-injured leg compared to age matched group from a healthy active population. mean scores for IKDC and KOOS scores were determined in each of 3 age categories. However, the mean IKDC score for all ACLR patients was 76.6, and mean scores for all KOOS subscales for all age groups were 78.8. When examining single-leg-hop for distance, the results for all age groups were 151% for the normative data; 139% for the non-injured leg, and 123% for the injured leg. For quadriceps muscle strength/body mass, the results were 2.5 Nm/kg for the normative data, 2.0 Nm/kg for the non-injured leg, and 1.71 Nm/kg for the injured leg. For Hamstring muscle strength/body mass, the results were 1.33 Nm/kg for the normative data, 1.31 Nm/kg for the non-injured leg, and 1.10 Nm/kg for the injured leg.

The findings of this thesis suggest that LSI should be viewed tentatively, as this approach can hide bilateral deficits due to the non-injured leg also possibly being affected by the injury and the length of time of inactivity. Subjects who had the required 90% symmetry criterion for strength and hop tests would not have passed this criterion if they compared to healthy matched controls performance. Therefore, normative data is recommended for analysing patients. In the current study, using normative data as a comparison revealed that the participants did not meet the normal required performance for both the injured and non-injured leg six months post ACLR when examining single-leg-hop test, quadriceps and hamstring muscle strength. These results show that LSI can underestimate performance deficits, therefore this approach should be used with caution to assess RTS after ACLR surgery. In general, it has been found that the ACL-reconstructed leg is weaker than the uninjured leg, but the uninjured leg is weaker than the leg of healthy matched controls.

The data collected in this study has provided several insights into clinical RTS decision making for ACLR patients at discharge from rehabilitation. For ACLR patients at the time of return-to-sport clearance, a comparison of the injured leg with a matched healthy control resulted in only eight (17%) patients meeting the criterion for quadriceps muscles strength; 13 (28%) for hamstring strength, and only 12 (26%) patients passed the single-leg hop test. For IKDC and KOOS when applying ≥ 85% to healthy and gender and age matched criterion, 25 (53%) and 29 (62%) of the patients passed the RTS criterion respectively. For ACL-RSI, nearly two thirds (66%) of participants appeared psychologically ready to return to sport, with 24 (52%) claiming they had a low level of fear of movement on the TSK. It should be borne in mind that none of the ACLR patients met the cut-off for a combination of criteria, and none of them would actually been discharged from rehabilitation based on this criterion.

This thesis has presented the research and provides a more thorough understanding of the presence of strength and functional deficits at RTS, leading to the efficacy of the current standard of RTS criteria to be called into question. Furthermore, several authors have not published their criteria for RTS (Barber-Westin & Noyes, 2011), and for those who have, there are major variations and there is no consensus. The criteria typically used for RTS involve the assessment of knee-joint effusion, range of motion, and laxity, along with a minimum time from surgery, in order to produce a recommended protocol for RTS. Although meeting such criteria to a satisfactory standard is essential for a minimum level of function during activity, the criteria do not include strength and functional symmetry; therefore, a consensus on RTS criteria that includes appropriate assessments for evaluating these functions is required. Because of the current lack of consensus on the minimum criteria for RTS is leading to wide variations in patient outcomes, and even impairs standard of care. Furthermore, specific sport training could be added to the last part of the rehabilitation, such as field training that focuses on reactive agility, including when the individual is fatigued (Dingenen & Gokeler, 2017), as fatigue may be a risk factor for re-injury as neuromuscular control changes under fatigued circumstances (Santamaria & Webster, 2010).

It may be claimed that current rehabilitation protocols are lacking due to a failure to target the mechanisms that often lead to poor outcome measures following ACLR. Potential improvements in rehabilitation strategies are early targeting of knee function, measuring muscle strength and assessing psychological factors, as this should support better strength and function (Lepley, Wojtys, & Palmieri-Smith, 2015a, 2015b). In addition, whether rehabilitation paradigms are changed or not, clinicians should consider whether the time from surgery is enough and appropriate for clearing a patient to RTS. It is likely that these research-based objective measures of strength and function would help to establish an appropriate time frame for patients to RTS, including at competition level. Some researchers claim that five to seven months post ACLR is a good time period for identifying differences (Graf et al., 2004), while other researchers suggest nine months to one year, which is generally considered an appropriate time for predicting return-to-sport status following ACLR (Grindem et al., 2016; Wright et al., 2007). On the other hand, Curran et al. (2018) claim that due to the deficits found at RTS and at more than 12 months post ACLR, the current path of care for patients with ACLR needs to be re-evaluated.

This research has several limitations: Firstly, because peak strength has been measured throughout the strength assessment, despite some participants only using submaximal strength; therefore, practice trials were conducted, as well as rest periods were offered, to support the participants to produce maximum force. Secondly, we did not measure other factors that affect muscle strength such as arthrogenic muscle inhibition (AMI), (AMI) appears to be present after knee surgery, resulting in muscle weakness (Rice, McNair, Lewis, & Dalbeth, 2014). As well as being a major cause of muscle weakness, (AMI) may restrict effective muscle strengthening (Pietrosimone et al., 2011), leading to long-term muscle atrophy. Thirdly, although the most commonly reported return-to-sport criteria (single-leg hop test, quadriceps and hamstring muscle strength, self-reported function and psychosocial factors) have been explored, other factors also exist which affect return to sports following ACLR, and these should also be investigated. Fourthly, the study has assessed the ACLR patients only on one occasion at discharge from rehabilitation, based on the discharge time to return-to-sport following ACLR. Thus, conducting further evaluations 9 and 12 months after ACLR could lead to a useful additional information on successful return to sport and maintenance of sports participation after ACLR. fifthly, for a normative study, the research has included healthy active participants, but it is not possible to generalise the results to professional or recreational athletes, as they may differ. Finally, no female participants have been included, so the findings cannot be generalised to both genders.

6.3 Future recommendation

6.3.1 Recommendation for Practice

The current study's results concerning reduced performance in hop tests and reduced muscle strength in the injured and non-injured limb Therefore, it is suggested that rehabilitation should include exercises aimed at improving functional tasks and the muscle strength of both the injured and non-injured leg to reduce the risk of contralateral leg injury. Moreover, the use of LSI should be questioned, as this method does not show bilateral deficits, even though the non-injured leg is often affected by the injury due to the length of the inactivity. The findings from this study showing the need for a range of outcome measures to be considered within a comprehensive evaluation of the patient. These findings show that successful performance on one outcome measure does not reflect a similar successful performance on other outcome measures. Moreover, it is preferable to use comprehensive criteria to determine patients' readiness to return to their preinjury levels of activity, as this would provide clinicians with essential information about patients, including any impairments in muscle strength, functional deficits and psychological factors. Overall, the evidence contained in this study suggests that all of patients six months post ACLR should receive additional rehabilitation to pass RTS criteria.

6.3.2 Recommendation for Further Studies

Based on the results and the subsequent discussion, some questions remain regarding future research. In particular, it is recommended that post-operative rehabilitation is assessed in the long term with regard to patient outcomes and passing specific RTS criteria. Additional research could be conducted to investigate the impact of post-operative rehabilitation on long-term knee function and QoL in patients, along with the time it takes to return to pre-injury levels of activity, for example, sports participation, and long-term complications such as osteoarthritis and the recurrence of an ACL injury. In addition, research could be conducted to investigate the long-term impact of early discharge from rehabilitation without passing RTS criteria, and the risk of a repeat ACL injury or suffering a new injury.

The research presented in this thesis focuses only on males from Saudi Arabia, and so comprehensive studies in other countries are required in order to investigate whether the findings from the current study can be generalised other countries. In addition, the inclusion of active female participants is important for further research as females have been shown to be more at risk of sports related ACL injuries because of anatomical and hormonal factors (Kobayashi et al., 2010). Therefore, the data presented in the current research could be extended in the future to provide more in-depth knowledge on functional recovery at discharge from rehabilitation following ACLR, with more comprehensive patient samples, such as by including female patients, as that is more representative of society.

For a normative study, further research involving different athletic populations, and a range of different sports and levels of activity, as well as higher numbers of participants, would be useful to find out whether outcome measures differ between sports and level of activity. This could help in identifying those athletes who are considered to have poor outcome measures, as that places them at a greater risk of injury. Furthermore, it is recommended for future research to evaluate "biomechanical symmetry" as well as "performance symmetry," as these may be associated with ACL injuries (Hewett, Di Stasi, & Myer, 2013b; Myer, Ford, Khoury, Succop, & Hewett, 2011; Pappas et al., 2016).

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8 Appendices

8.1 IKDC Knee Evaluation Form

2000 IKDC SUBJECTIVE KNEE EVALUATION FORM

Your Full Name____

Today's Date: _____/______/_____ (Day / Month / Year)   Date of Injury: _____/______/_____ (Day / Month / Year)

SYMPTOMS*:
*Grade symptoms at the highest activity level at which you think you could function without significant symptoms, even if you are not actually performing activities at this level.

1. What is the highest level of activity that you can perform without significant knee pain?

❑Very strenuous activities like jumping or pivoting as in basketball or soccer
❑Strenuous activities like heavy physical work, skiing or tennis
❑Moderate activities like moderate physical work, running or jogging
❑Light activities like walking, housework or yard work
❑Unable to perform any of the above activities due to knee pain

2. During the past 4 weeks, or since your injury, how often have you had pain?

	0	1	2	3	4	5	6	7	8	9	10	
Never	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	Constant

3. If you have pain, how severe is it?

	0	1	2	3	4	5	6	7	8	9	10	
No pain	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	Worst pain imaginable

4. During the past 4 weeks, or since your injury, how stiff or swollen was your knee?

❑Not at all
❑Mildly
❑Moderately
❑Very
❑Extremely

5. What is the highest level of activity you can perform without significant swelling in your knee?

❑Very strenuous activities like jumping or pivoting as in basketball or soccer
❑Strenuous activities like heavy physical work, skiing or tennis
❑Moderate activities like moderate physical work, running or jogging
❑Light activities like walking, housework, or yard work
❑Unable to perform any of the above activities due to knee swelling

6. During the past 4 weeks, or since your injury, did your knee lock or catch?

❑Yes ❑No

7. What is the highest level of activity you can perform without significant giving way in your knee?

❑Very strenuous activities like jumping or pivoting as in basketball or soccer
❑Strenuous activities like heavy physical work, skiing or tennis
❑Moderate activities like moderate physical work, running or jogging
❑Light activities like walking, housework or yard work
❑Unable to perform any of the above activities due to giving way of the knee

Page 2 – 2000 IKDC SUBJECTIVE KNEE EVALUATION FORM

SPORTS ACTIVITIES:

8. What is the highest level of activity you can participate in on a regular basis?

- ❑Very strenuous activities like jumping or pivoting as in basketball or soccer
- ❑Strenuous activities like heavy physical work, skiing or tennis
- ❑Moderate activities like moderate physical work, running or jogging
- ❑Light activities like walking, housework or yard work
- ❑Unable to perform any of the above activities due to knee

9. How does your knee affect your ability to:

		Not difficult at all	Minimally difficult	Moderately Difficult	Extremely difficult	Unable to do
a.	Go up stairs	❑	❑	❑	❑	❑
b.	Go down stairs	❑	❑	❑	❑	❑
c.	Kneel on the front of your knee	❑	❑	❑	❑	❑
d.	Squat	❑	❑	❑	❑	❑
e.	Sit with your knee bent	❑	❑	❑	❑	❑
f.	Rise from a chair	❑	❑	❑	❑	❑
g.	Run straight ahead	❑	❑	❑	❑	❑
h.	Jump and land on your involved leg	❑	❑	❑	❑	❑
i.	Stop and start quickly	❑	❑	❑	❑	❑

FUNCTION:

10. How would you rate the function of your knee on a scale of 0 to 10 with 10 being normal, excellent function and 0 being the inability to perform any of your usual daily activities which may include sports?

FUNCTION PRIOR TO YOUR KNEE INJURY:

Cannot perform daily activities	0	1	2	3	4	5	6	7	8	9	10	No limitation in daily activities
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

CURRENT FUNCTION OF YOUR KNEE:

Cannot perform daily activities	0	1	2	3	4	5	6	7	8	9	10	No limitation in daily activities
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

استبيان اللجنة الدولية لتوثيق وظائف الركبة (IKDC)

أجب عن كل سؤال بوضع علامة (√) واحدة على الإجابة المناسبة أمام كل سؤال, وإذا كنت غير متأكد من الإجابة الرجاء وضع أقرب إجابة ممكنة.

أعراض المرض:

قيم الأعراض من خلال أعلى مستوى نشاط بدني تعتقد أن باستطاعتك القيام به, دون الشعور بأعراض شديدة, **حتى لو لم تكن فعلياً تقوم بنشاطات بهذا المستوى.**

1. ما هو أعلى مستوى يمكنك القيام به من النشاط البدني بدون الشعوربألم شديد في الركبة
   - ❑ الأنشطة الشاقة جدا مثل القفز أو الدوران كما هو الحال في كرة السلة أو كرة القدم.
   - ❑ الأنشطة الشاقة مثل النشاط البدني العالي، كما هو الحال في التزلج أو التنس.
   - ❑ الأنشطة المعتدلة مثل النشاط البدني المعتدل ، كما هو الحال في الجري أو الركض.
   - ❑ الأنشطة الخفيفة مثل المشي والأعمال المنزلية أو ساحة العمل.
   - ❑ غير قادر على أداء أي من الأنشطة المذكورة أعلاه بسبب آلام في الركبة.

2. خلال **الأربعة أسابيع الماضية**، أو منذ إصابتك، كم مرة تشعر بالآلام؟

	0	1	2	3	4	5	6	7	8	9	10	
أبدًا	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	مستمر

3. إذا كنت تشعر بآلام, ما شدتها؟

	0	1	2	3	4	5	6	7	8	9	10	
أبدًا	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	اسوأ ألم ممكن تخيله

4. خلال **الأربعة أسابيع الماضية**، أو منذ إصابتك، ما مدى تيبس أو انتفاخ ركبتك؟
   - ❑ لا يوجد
   - ❑ بسيط
   - ❑ متوسط
   - ❑ شديد
   - ❑ شديد جداً

5. ما هو أعلى مستوى من النشاط البدني الذي يمكن أن تؤديه من دون تورم وانتفاخ ملحوظ في الركبة؟
   - ❑ الأنشطة الشاقة جدا مثل القفز أو الدوران كما هو الحال في كرة السلة أو كرة القدم.
   - ❑ الأنشطة الشاقة مثل النشاط البدني العالي، كما هو الحال في التزلج أو التنس.
   - ❑ الأنشطة المعتدلة مثل النشاط البدني المعتدل ، كما هو الحال في الجري أو الركض.
   - ❑ الأنشطة الخفيفة مثل المشي والأعمال المنزلية أو ساحة العمل.
   - ❑ غير قادر على أداء أي من الأنشطة المذكورة أعلاه بسبب تورم وانتفاخ في الركبة.

6. خلال **الأربعة أسابيع الماضية**, أو منذ إصابتك, هل توقف (علقت) ركبتك بشكل مفاجئ أثناء الحركة؟
   ❑ نعم ❑ لا

7. ما هو أعلى مستوى من النشاط البدني الذي يمكن أن تؤديه من دون خروج الركبة من مكانها بشكل ملحوظ؟
   - ❑ الأنشطة الشاقة جدا مثل القفز أو الدوران كما هو الحال في كرة السلة أو كرة القدم.
   - ❑ الأنشطة الشاقة مثل النشاط البدني العالي، كما هو الحال في التزلج أو التنس.
   - ❑ الأنشطة المعتدلة مثل النشاط البدني المعتدل ، كما هو الحال في الجري أو الركض.
   - ❑ الأنشطة الخفيفة مثل المشي والأعمال المنزلية أو ساحة العمل.
   - ❑ غير قادر على أداء أي من الأنشطة المذكورة أعلاه بسبب خروج الركبة من مكانها.

النشاط الرياضي:

8. ما هو أعلى مستوى من النشاط البدني تشارك فيه في الظروف العادية وبشكل منتظم؟
- ❑ الأنشطة الشاقة جدا مثل القفز أو الدوران كما هو الحال في كرة السلة أو كرة القدم.
- ❑ الأنشطة الشاقة مثل النشاط البدني العالي، كما هو الحال في التزلج أو التنس.
- ❑ الأنشطة المعتدلة مثل النشاط البدني المعتدل ، كما هو الحال في الجري أو الركض.
- ❑ الأنشطة الخفيفة مثل المشي والأعمال المنزلية أو ساحة العمل.
- ❑ غير قادر على أداء أي من الأنشطة المذكورة أعلاه بسبب الركبة.

9. ما مدى تأثير ركبتك في قدرتك على:

		لا يوجد صعوبة أبداً	صعوبة بسيطة	صعوبة متوسطة	صعوبة شديدة	لا أستطيع القيام بذلك
أ	صعود الدرج	❑	❑	❑	❑	❑
ب	نزول الدرج	❑	❑	❑	❑	❑
ج	الوقوف على الركبتين	❑	❑	❑	❑	❑
د	ثني الركبتين والنزول أثناء الوقوف (القرفصاء)	❑	❑	❑	❑	❑
هـ	ثني الركب بالكامل اثناء الجلوس (الجلوس في الصلاة)	❑	❑	❑	❑	❑
و	القيام من الكرسي	❑	❑	❑	❑	❑
ز	الجري بشكل مستقيم للأمام	❑	❑	❑	❑	❑
ح	القفز والهبوط على رجلك المصابة	❑	❑	❑	❑	❑
ط	التوقف بشكل مفاجيء ثم الإستمرار أثناء الجري	❑	❑	❑	❑	❑

وظائف الركبة:

10. كيف تقيم وظائف الركبة, من خلال مقياس من 0 إلى 10, 10 تعني طبيعي ووظائف ممتازة, 0 يعني عدم القدرة على أداء النشاطات اليومية المعتادة, بما في ذلك ممارسة الرياضة؟

وظائف الركبة قبل الإصابة:

لا أستطيع القيام بالنشاطات اليومية	0	1	2	3	4	5	6	7	8	9	10	لا يوجد قصور في الوظائف اليومية
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

وظائف الركبة الحالية

لا أستطيع القيام بالنشاطات اليومية	0	1	2	3	4	5	6	7	8	9	10	لا يوجد قصور في الوظائف اليومية
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

8.2 KOOS Knee Survey

Answer each question by checking the appropriate box, only <u>one</u> box for each question.

Symptoms
These questions should be answered thinking of your knee symptoms during the **<u>last week</u>**.

S1. Do you have swelling in your knee?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S3. Does your knee catch or hang up when moving?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S4. Can you straighten your knee fully?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

S5. Can you bend your knee fully?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

Stiffness
The following questions concern the amount of joint stiffness you have experienced during the **<u>last week</u>** in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your joints.

S6. How severe is your joint stiffness after first wakening in the morning?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S7. How severe is your stiffness after sitting, lying or resting **later in the day**?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Pain
P1. How often do you experience knee pain?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

What amount of knee pain have you experienced the **<u>last week</u>** during the following activities?

P2. Twisting/pivoting on your knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P3. Straightening knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4. Bending knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6. Going up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7. At night while in bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P8. Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9. Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, daily living

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicates the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2. Ascending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

A3. Rising from sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4. Standing

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5. Bending to floor/pick up and object

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A6. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A7. Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A8. Going shopping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A9. Putting on socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A10. Rising from bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A11. Taking off socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A12. Lying in bed (turning over, maintaining knee position)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A13. Getting in/out of bath

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A14. Sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A15. Getting on/off toilet

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A16. Heavy domestic duties (shoveling snow, scrubbing floors etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A17. Light domestic duties (cooking, dusting etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, sports and recreational activities

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your knee.

SP1. Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2. Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3. Jumping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4. Twisting/pivoting on your injured knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5. Kneeling

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Quality of Life

Q1. How often are you aware of your knee problem?

Never	Monthly	Weekly	Daily	Constantly
☐	☐	☐	☐	☐

Q2. Have you modified your lifestyle to avoid potentially damaging activities to your knee?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3. How much are you troubled with lack of confidence in your knee?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q4. In general, how much difficulty do you have with your knee?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

استبانة الإلتهاب المفصلي العظمي وإصابات الركبة

تاريخ اليوم: _____/_____/_____ تاريخ الميلاد: _____/_____/_____

الاسم: ____

التعليمات: هذه الاستبانة صممت لمعرفة رأيك حول ركبتك. معلومات هذه الاستبانة سوف تساعدنا في معرفة شعورك بركبتك وكيف ستكون قادراً على أداء نشاطاتك الاعتيادية.

أجب عن كل سؤال بوضع علامة في المربع المناسب. اختر مربع واحد فقط لكل سؤال. إذا كنت غير متأكد من الإجابة اختر أقرب اجابة مناسبة.

الأعراض:

يجب أن تكون الإجابة على هذه الأسئلة بناء على أعراض ركبتك خلال **الأسبوع الماضي**

S1 هل يوجد تورم في ركبتك؟

أبداً	نادراً	أحياناً	غالباً	دائماً
□	□	□	□	□

S2 هل تشعر بصرير أو تسمع طقطقه أو أي صوت في ركبتك عند تحريك الركبة؟

أبداً	نادراً	أحياناً	غالباً	دائماً
□	□	□	□	□

S3 هل ركبتك تتصلب عند الحركة؟

أبداً	نادراً	أحياناً	غالباً	دائماً
□	□	□	□	□

S4 هل تستطيع مدّ ركبتك بشكل كامل؟

دائماً	غالباً	أحياناً	نادراً	أبداً
□	□	□	□	□

S5 هل تستطيع ثني ركبتك بشكل كامل؟

دائماً	غالباً	أحياناً	نادراً	أبداً
□	□	□	□	□

التصلب: الأسئلة التالية تتعلق **بمقدار تصلب** المفصل الذي عانيت منه **الأسبوع الماضي** في ركبتك.
التصلب هو الإحساس بتقييد أو بطء في سهولة تحريك مفصل الركبة.

S6 كيف تكون شدّة التصلب في ركبتك بعد الاستيقاظ صباحاً؟

لا يوجد تصلب	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

S7 كيف تكون شدّة التصلب في ركبتك بعد الجلوس أو الاستلقاء أو الراحة في نهاية اليوم؟

لا يوجد تصلب	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

الألم

P1 كم مره تشعر بألم في الركبة؟

أبداً	شهرياً	اسبوعياً	يومياً	دائماً
□	□	□	□	□

ما هو مقدار **ألم** الركبة الذي عانيته **الأسبوع الماضي** أثناء أداء الأنشطة التالية:

P2 الإلتواء/اللف على ركبتك

لا يوجد ألم	خفيف	متوسط	شديد	شديد جداً
□	□	□	□	□

P3 مدّ الركبة بالكامل

لا يوجد ألم	خفيف	متوسط	شديد	شديد جداً
□	□	□	□	□

P4 ثني الركبة بالكامل

لا يوجد ألم	خفيف	متوسط	شديد	شديد جداً
□	□	□	□	□

P5 المشي على سطح مستوي

لا يوجد ألم	خفيف	متوسط	شديد	شديد جداً
□	□	□	□	□

P6 صعود أو نزول الدرج

لا يوجد ألم	خفيف	متوسط	شديد	شديد جداً
□	□	□	□	□

P7 في فراشك أثناء لليل

لا يوجد ألم	خفيف	متوسط	شديد	شديد جداً
□	□	□	□	□

P8 الجلوس أو الإستلقاء

لا يوجد ألم	خفيف	متوسط	شديد	شديد جداً
□	□	□	□	□

P9 الوقوف باستقامة

لا يوجد ألم	خفيف	متوسط	شديد	شديد جداً
□	□	□	□	□

الوظائف، أنشطة الحياة اليومية

الأسئلة التالية تتعلق بالوظائف البدنية، ونعني بذلك قدرتك على التنقل والاعتناء بنفسك.
لكل نشاط من الأنشطة التالية يرجى تحديد **درجـة الصـعوبـة** التي واجهتها **الأسبوع الماضي** بسبب الركبة.

A1 نزول الدرج

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A2 صعود الدرج

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

لكل نشاط من الأنشطة التالية يرجى تحديد درجة الصعوبة التي واجهتها **الأسبوع الماضي** بسبب الركبة.

A3 القيام من وضع الجلوس

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A4 الوقوف

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A5 الإنحناء لإلتقاط شيء من الأرض

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A6 المشي على سطح مستوي

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A7 الصعود أو النزول من السيارة

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A8 الذهاب للتسوق

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A9 لبس الجوارب (الشُرابات)

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A10 النهوض من الفراش

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A11 خلع الجوارب (الشُرابات)

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A12 الاستلقاء على السرير (التقلب على أحد الجانبين أو الحفاظ على وضع ثابت للركبة)

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A13 الدخول والخروج من حوض الإستحمام

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A14 وضع الجلوس

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A15 الجلوس أو القيام من المرحاض (قضاء الحاجة)

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

لكل نشاط من الأنشطة التالية يرجى تحديد **درجة الصعوبة** التي واجهتها **الأسبوع الماضي** بسبب الركبة.

A16 الأعمال المنزلية الثقيلة (نقل الصناديق الثقيلة، ونظافة أرضيات المنزل...الخ)

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

A17 الأعمال المنزلية الخفيفة (الطبخ وتنظيف الغبار...الخ)

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

الوظائف، الأنشطة الرياضية والترفيهية

الأسئلة التالية تتعلق بوظائفك البدنية عندما تمارس أنشطة عالية الجهد، يجب أن تكون الإجابة على هذه الأسئلة بناء على **درجة الصعوبة** التي واجهتها **الأسبوع الماضي** بسبب الركبة.

SP1 وضعية القرفصاء (الجلوس على المرحاض العربي)

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

SP2 الجري

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

SP3 القفز

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

SP4 الإلتواء أو اللف على ركبتك المصابة

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

SP5 الارتكاز على الركبتين (الجلوس بين السجدتين)

لا يوجد صعوبة	خفيفة	متوسطة	شديدة	شديدة جداً
□	□	□	□	□

جودة الحياة

Q1 كم مره تدرك وتتذكر أن لديك مشكلة في الركبة؟

أبداً	شهرياً	اسبوعيًا	يومياً	باستمرار
□	□	□	□	□

Q2 هل قمت بتعديل نمط حياتك لتجنب الضرر المحتمل من بعض الأنشطة على ركبتك؟

لا على الإطلاق	بشكل بسيط	بشكل متوسط	بشكل كبير	بشكل كُلي
□	□	□	□	□

Q3 ما مدى تضايقك بسبب ضعف ثقتك في ركبتك؟

لا على الإطلاق	بشكل بسيط	بشكل متوسط	بشكل كبير	بشكل كُلي
□	□	□	□	□

Q4 بشكل عام، ما مقدار الصعوبة التي تواجهها مع ركبتك؟

لا يوجد صعوبة	خفيف	متوسط	شديد	شديد جداً
□	□	□	□	□

شكراً جزيلاً لإجابتك على كل الأسئلة في هذه الاستبانة.

8.3 ACL - RSI Scale

Instructions: Please answer the following twelve questions referring to your MAIN sport prior to injury. Cross a box for each question between the two descriptions in order to indicate how you are feeling at this time.

1. Are you confident that you can perform at your previous level of sport participation?

Not at all Confident	0	1	2	3	4	5	6	7	8	9	10	Fully Confident
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

2. Do you think you are likely to re-injury your knee by participating in your sport?

Extremely Likely	0	1	2	3	4	5	6	7	8	9	10	Not likely at all
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

3. Are you nervous about playing your sport?

Extremely Nervous	0	1	2	3	4	5	6	7	8	9	10	Not Nervous At all
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

4. Are you confident that your knee will not give away by playing your sport?

Not at all Confident	0	1	2	3	4	5	6	7	8	9	10	Fully Confident
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

5. Are you confident that you could play your sport without concern for your knee?

Not at all Confident	0	1	2	3	4	5	6	7	8	9	10	Fully Confident
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

6. Do you find it frustrating to have to consider your knee with respect to your sport?

Extremely frustratin	0	1	2	3	4	5	6	7	8	9	10	Not frustrating At all
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

7. Are you fearful of re-injuring your knee playing your sport?

Extremely fearful	0	1	2	3	4	5	6	7	8	9	10	Not Nervous Fear full all
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

8. Are you confident about your knee holding up under pressure?

Not at all Confident	0	1	2	3	4	5	6	7	8	9	10	Fully Confident
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

9. Are you afraid of accidentally injuring your knee by playing your sport?

Extremely afraid	0	1	2	3	4	5	6	7	8	9	10	Not afraid at all
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

10. Do you thoughts of having to go through surgery and rehabilitation again prevent you from playing your sport?

All the time	0	1	2	3	4	5	6	7	8	9	10	None of the time
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

11. Are you confident about your ability to perform well at your sport?

Not at all Confident	0	1	2	3	4	5	6	7	8	9	10	Fully Confident
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

12. Do you feel relaxed about plying your sport?

Not at all relaxed	0	1	2	3	4	5	6	7	8	9	10	Fully relaxed
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

مقياس العودة للرياضة بعد إصابة الرباط الصليبي

تعليمات: الرجاء الإجابة عن الإثنى عشر سؤال القادمة, بالرجوع إلى <u>رياضتك الرئيسية</u> قبل الإصابة, اختر مربع واحد بين الوصفين في كل سؤال, لغرض وصف شعورك في الوقت الحالي.

1. هل أنت واثق أنك تستطيع الأداء والمشاركة في الرياضة بنفس مستواك السابق قبل الإصابة؟

	0	1	2	3	4	5	6	7	8	9	10	
لست واثقاً	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	واثق تماماً

2. هل تعتقد أنه من المحتمل أن تصاب مرة أخرى في ركبتك لمشاركتك في الرياضة؟

	0	1	2	3	4	5	6	7	8	9	10	
أعتقد بشدة	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	لا أعتقد مطلقاً

3. هل أنت متوتر للعبك رياضتك؟

	0	1	2	3	4	5	6	7	8	9	10	
متوتر بشدة	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	لست متوتراً إطلاقاً

4. هل أنت واثق من أن ركبتك لن تخرج من مكانها بسبب ممارستك لرياضتك؟

	0	1	2	3	4	5	6	7	8	9	10	
لست واثقاً	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	واثق تماماً

5. هل أنت واثق أن باستطاعتك أن تمارس رياضتك بدون القلق من ركبتك؟

	0	1	2	3	4	5	6	7	8	9	10	
لست واثقاً	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	واثق تماماً

6. هل ترى أنه من المحبط أن تفكر في (تحسب حساب) ركبتك في كل ما يتعلق برياضتك؟

	0	1	2	3	4	5	6	7	8	9	10	
محبط بشدة	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	ليس محبطاً إطلاقاً

7. هل تخشى أن تصاب مرة أخرى في ركبتك وانت تمارس رياضتك؟

لا أخشى إطلاقاً	10	9	8	7	6	5	4	3	2	1	0	أخشى بشدة
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

8. هل أنت واثق من تماسك ركبتك تحت ضغط الرياضة؟

واثق تماماً	10	9	8	7	6	5	4	3	2	1	0	لست واثقاً
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

9. هل أنت خائف أن تصاب عن طريق الخطأ أثناء ممارستك لرياضتك؟

ليس خائفاً إطلاقاً	10	9	8	7	6	5	4	3	2	1	0	خائف بشدة
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

10. هل أفكارك بعمل جراحة وتأهيل مرة أخرى تمنعك من ممارستك رياضتك؟

أبداً	10	9	8	7	6	5	4	3	2	1	0	كل الوقت
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

11. هل انت واثق من مقدرتك على الأداء في رياضتك؟

واثق تماماً	10	9	8	7	6	5	4	3	2	1	0	لست واثقاً
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

12. هل تشعر براحة لممارستك رياضتك؟

راحة شديدة	10	9	8	7	6	5	4	3	2	1	0	لا أشعر بالراحة أبداً
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	

8.4 Tampa Scale for Kinesiophobia

1 = strongly disagree

2 = disagree

3 = agree

4 = strongly agree

1. I'm afraid that I might injury myself if exercise	1	2	3	4
2. If I were to try to overcome it, my pain would increase	1	2	3	4
3. My body is telling me I have something dangerously wrong	1	2	3	4
4. My pain would probably be relieved if I were to exercise	1	2	3	4
5. People aren't taking my medical condition seriously enough	1	2	3	4
6. My accident has put my body at risk for the rest of my life	1	2	3	4
7. Pain always means I have injured my body	1	2	3	4
8. Just because something aggravates my pain does not mean it is dangerous	1	2	3	4
9. I am afraid that I might injure myself accidentally	1	2	3	4
10. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening	1	2	3	4
11. I wouldn't have this much pain if there weren't something potentially dangerous going on in my body	1	2	3	4
12. Although my condition is painful, I would be better off if I were physically active	1	2	3	4
13. Pain lets me know when to stop exercising so that I don't injure myself	1	2	3	4
14. It's really not safe for a person with a condition like mine to be physically active	1	2	3	4
15. I can't do all the things normal people do because it's too easy for me to get injured	1	2	3	4
16. Even though something is causing me a lot of pain, I don't think it's actually dangerous	1	2	3	4
17. No one should have to exercise when he/she is in pain	1	2	3	4

Reprinted from:

Pain, Fear of movement/(re) injury in chronic low back pain and its relation to behavioral performance, 62, Vlaeyen, J., Kole-Snijders A., Boeren R., van Eek H., 371.

مقياس الخوف من الحركة وعودة الإصابة (TAMPA)

1= غير موافق بشدة

2= غير موافق

3= موافق

4= موافق بشدة

1. أخاف أن أتعرض للإصابة لو قمت بممارسة التمارين	1	2	3	4
2. إذا حاولت التغلب على الألم الذي أشعر به فمن المحتمل أن يزيد الألم	1	2	3	4
3. جسمي يخبرني بأن لدي إصابة خطيرة في جسمي	1	2	3	4
4. الألم الذي أشعر به من المحتمل أن يتعافى لو كنت أمارس التمارين	1	2	3	4
5. الناس لا يأخذون حالتي الصحية على محمل الجد بشكل كافي	1	2	3	4
6. إصابتي وضعت جسمي في خطر دائم لبقية حياتي	1	2	3	4
7. الألم دائماً يعني أني قد تسببت بإصابة لنفسي	1	2	3	4
8. إذا تفاقم الألم من شيء ما هذا لا يعني أنه أمر خطير	1	2	3	4
9. أخاف من أن أتسبب لنفسي بالإصابة عن طريق الخطأ	1	2	3	4
10. ببساطة أن أكون حريصاً بعدم القيام بحركات غير ضرورية هو أسلم الطرق التي أعملها لمنع الألم من الإزدياد	1	2	3	4
11. لن أشعر بكل هذا الألم ما لم يكن هناك شيء يحتمل أن يكون خطيراً في جسمي	1	2	3	4
12. على الرغم من إصابتي التي تسبب الألم، سأكون أفضل حالاً لو كنت نشيطاً بدنياً وأقوم بالتمارين	1	2	3	4
13. الألم يجعلني أعرف متى أتوقف عن التمارين, لذلك أنا لا أعرض نفسي للإصابة	1	2	3	4
14. انه حقاً غير آمن لشخص لديه مثل إصابتي ويكون نشيطا بدنياً ويقوم بالتمارين	1	2	3	4
15. أنا لا أستطيع القيام بكل الأشياء التي يقوم بها الناس الطبيعيين, لأنه من السهل جداً ان أتعرض للإصابة	1	2	3	4
16. حتى لو كانت بعض الأشياء تسبب لي الكثير من الألم, أنا لا أعتقد بأنها في الواقع خطيرة.	1	2	3	4
17. يجب على أي شخص عدم ممارسة التمارين عندما يشعر بالألم	1	2	3	4

8.5 Ethical approval letter

University of Salford MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk/

27 July 2016

Dear Husam,

RE: ETHICS APPLICATION HSCR 16-75 – Biomechanical changes after ACL injuries.

Based on the information you provided, I am pleased to inform you that application HSCR16-39 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Sue McAndrew
Chair of the Research Ethics Panel

8.6 Ethical approval letter

University of Salford MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk/

31 January 2017

Dear Husam,

RE: ETHICS APPLICATION–HSR1617-43–'What is the functional status of anterior cruciate ligament reconstruction patients at discharge from rehabilitation: (SHOPS) ACLR?'

Based on the information you provided I am pleased to inform you that application HSR1617-43 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Sue McAndrew
Chair of the Research Ethics Panel

8.7 Ethical approval letter

وزارة الصحة
Ministry of Health

Ethical Approval Committee
Medical Rehabilitation Hospital
Medina
41311, Saudi Arabia
T +966(041)8490034

13th March 2017

Dear Husam,

RE: ETHICS APPLICATION – 'The Functional Status Of Anterior Cruciate Ligament Reconstruction Patients At Discharge From Rehabilitation'

Based on the information you provided I am pleased to inform you that your application has been approved.

If there are any changes to the project and/or its methodology, then please inform the Cpmmittee as soon as possible by contacting MED-HOS-ANH@moh.

Yours sincerely,

Dr Hussain Ghulam
Chair of Ethical Approval Committee

8.8 Consent Form

Informed Consent Form

1. Mr Husam Almalki, is a postgraduate research student at the University of Salford, has requested my participation in a research study. My involvement in the study and its purpose has been fully explained to me by given me a participant information sheet (PIS) V.1.0. 1st November 2016. ☐

2. I understand the requirements of the study and my involvement and the possible benefit of my participation in this research. ☐

3. I have been informed that I will not be compensated for my participation. ☐

4. I understand that the results of this research may be published, but my name or identity will not be revealed at any time. In order to keep my records confidential, Mr Husam Almalki will store all the data as numbered codes in a computer that will only be accessed by him. ☐

5. I have been informed that any further questions that I have at any time concerning the research or my participation will be answered by Mr Husam Almalki and I can contact him at his e-mail address H.A.S.Almalki@edu.salford.ac.uk ☐

6. I understand that I may withdraw my consent and participation at any time without objection from the researcher. ☐

7. I understand that if I withdraw from the study, all the information about me will be destroyed and not to be used in the study at all. ☐

Name: ………………………… **Signed:** ………………… **Date:** ….….……

وزارة الصحة
Ministry of Health

الرقم :..............................
التاريخ :....../....../ 1436هـ
المشفوعات:.......................

نموذج طلب الموافقة للمشاركة في بحث

- أنت مدعو (مدعوة) من قبل (حسام عبدالله المالكي) للمشاركة في بحث علمي.
- عنوان الدراسة: الحالة الوظيفية للمصاب بقطع في الرباط الصليبي بعد إنتهاءه من برنامج التأهيل
- اسم المنشأة التي اعتمدت البحث جامعة سالفورد ببريطانيا
- برعاية: جامعة سالفورد ببريطانيا
- الباحث الرئيسي: حسام عبدالله المالكي طالب دكتوراه في العلاج الطبيعي
- هذه دراسة بحثية يتم اجراءها على الافراد الذين سيتم اختيارهم للمشاركة فقط.
- لذا نرجو أخذ الوقت الكافي لمناقشة هذا الامر مع عائلتك وأصدقائك قبل اتخاذ قرار المشاركة.
- سبب اختيارك لهذه المشاركة في هذه الدراسة هو تشخيص حالتكم بانها إجراء عملية الرباط الصليبي والإنتهاء من برنامج التأهيل

الغرض من هذه الدراسة هو معرفة الحالة العامة للمريض بعد الإنتهاء من برنامج التأهيل ومقارنة حالته مع ناس سليمين

- طريقة الدراسة:

1- يتم قياس قوة العضلة الرباعية الأمامية في الفخذ وقوة العضلة الخلفية للفخذ في الرجلين باستخدام جهاز يدوي محمول
2- يتم تقييم الوظائف الحركية بالقفز على قدم واحده لأبعد مسافة ممكن ثلاث مرات.
3- سيتم تقييم وظائف الركبة بتعبئة استبانتين: - استبانة الالتهاب المفصلي العظمي وإصابات الركبة (KOOS)
   - استبانة اللجنة الدولية لتوثيق وظائف الركبة (IKDC)
4- سيتم تقييم العوامل النفسية المؤثرة في عودة اللاعب لممارسة الرياضة بعد الإصابة بالرباط الصليبي بتعبئة استبانتين: - استبانة الخوف من الحركة وعودة الإصابة (TAMPA)
   - استبانة مقياس العودة للرياضة بعد الرباط الصليبي (ACL-RSI)

- حيث متوقع أن يشارك حوالي 50 فرد في هذه الدراسة والتي ستستمر لمدة ثلاثة أشهر
- يمكنكم التوقف عن المشاركة في هذه الدراسة في أي وقت دون أي عقوبة أو فقدان منفعة .
- المخاطر المحتملة:لا يوجد مخاطر محتملة خلال اختبار قوة العضلات أو اختبار القفز على قدم واحدة
- الاجراءات المتخذة لتقليل المخاطر:-عن طريق إعطائك كل ما يكفي من الوقت للتدريب، الاحماء. بالإضافة إلى ذلك، في حال الإصابة لا قدر الله، سوف يتم تقديم الإسعافات الأولية المتوفرة في قسم العلاج الطبيعي. ومع ذلك، هذه الدراسة سوف تتم في قسم العلاج الطبيعي، وبالتالي لا يوجد مخاطر محتملة لحدوث أي إصابة لا قدر الله.

القوائد المرجوة (مباشرة /غير مباشرة): تستطيع الاستفادة شخصيا من الدراسة عن طريق معرفة وضعك الطبي الحالي وهل بإمكانك العودة للممارسة الرياضة, بالإضافة للفائدة العامة من البحث وتحسين الحالة الوظيفية للمصابين بالرباط الصليبي.

وزارة الصحة
Ministry of Health

الرقم :..............................
التاريخ :....../......./ 1436 هـ
المشفوعات:.......................

- وصف لطرق العلاج البديلة المتوافرة خارج نطاق البحث ان وجدت: لا يوجد طرق بديلة سوى في المراكز الرياضية المتخصصة في تأهيل الرباط الصليبي للاعبين المحترفين وتقييمهم قبل عودتهم لممارسة الرياضة.
- كما أننا سنحافظ على سرية المعلومات الشخصية الخاصة بك ولن يتم ذكر أى بيانات شخصية أو عامة تدل على تحديد شخصيتك ولن يتم استخدام اسمك أو ذكر هويتك فى أى تقرير أو اصدار حول هذه الدراسة.
- لن تتحمل أى تكاليف متعلقة بهذه الدراسة ان وجدت ولكن الباحثين هم المسئولين عن تمويل هذه الدراسة.
- المشاركة في البحث أمر طوعي وان رفض المشاركة لن يترتب عليه أية عقوبة أو خسارة لمنفعة تستحقها بسبب اخر. كما أن لك الحق في الانسحاب من البحث في أية مرحلة من مراحله دون أن تتعرض لخسارة أو فوات منفعة تستحقها لأي سبب.
- توضيح المخاطر أو الأضرار التي يمكن أن تترتب على الانسحاب من البحث ان وجدت: لا يوجد
- أتعهد أنا الباحث الرئيسي بأنك ستحاط علما بجميع المعلومات التي قد تستجد خلال فترة اجراء البحث والتي يمكن أن تؤثر معرفتك لها في استمرار مشاركتك في البحث.
- في حال وقوع ضرر ناتج عن اجراء البحث عليك فان طريقة التعويض هي توفير العلاج لك من اي إصابة قد تحدث لك.
- اذا كان لديك أى استفسار أو شكوى حول هذه الدراسة الرجاء الاتصال برئيس قسم التأهيل الطبي:
- د/ عبدالرحمن التويجري جوال: 0555380401

ملاحظة:

من خلال توقيعكم على هذا النموذج تكون قد وافقت على المشاركة فى هذه الدراسة البحثية.
وتكون قد أعطيت الفرصة الكاملة لفهم ماسيتم وأعطيت الفرصة لأى سؤال يتعلق بهذه الدراسة كما أنه سيتم وضع صورة من هذا الاقرار فى ملفك الطبى.
(يتم التوقيع من قبل المريض أو ولى أمره)

( ) أوافق فى المشاركة فى هذه الدراسة	توقيع الشخص الذى حصل على الموافقة
الاسم :	الاسم : ....
التوقيع:.....................................	التوقيع :......................................
التاريخ:.....................................	التاريخ:......................................

8.9 Data Collection Sheet

ID	Sex	Age	Height	weight	Leg		Hand1	Hand2	Hand3	HandM	Hop1	Hop2	Hop3	hopM
					R	Flex								
						Ext								
					L	Flex								
						Ext								
ID	Sex	Age	Height	weight	Leg		Hand1	Hand2	Hand3	HandM.	Hop1	Hop2	Hop3	hopM
					R	Flex								
						Ext								
					L	Flex								
						Ext								
ID	Sex	Age	Height	weight	Leg		Hand1	Hand2	Hand3	HandM.	Hop1	Hop2	Hop3	hopM
					R	Flex								
						Ext								
					L	Flex								
						Ext								
ID	Sex	Age	Height	weight	Leg		Hand1	Hand2	Hand3	HandM.	Hop1	Hop2	Hop3	hopM
					R	Flex								
						Ext								
					L	Flex								
						Ext								
ID	Sex	Age	Height	weight	Leg		Hand1	Hand2	Hand3	HandM.	Hop1	Hop2	Hop3	hopM
					R	Flex								
						Ext								
					L	Flex								
						Ext								
ID	Sex	Age	Height	weight	Leg		Hand1	Hand2	Hand3	HandM.	Hop1	Hop2	Hop3	hopM
					R	Flex								
						Ext								
					L	Flex								
						Ext								
ID	Sex	Age	Height	weight	Leg		Hand1	Hand2	Hand3	HandM.	Hop1	Hop2	Hop3	hopM
					R	Flex								
						Ext								
					L	Flex								
						Ext								
ID	Sex	Age	Height	weight	Leg		Hand1	Hand2	Hand3	HandM.	Hop1	Hop2	Hop3	hopM
					R	Flex								
						Ext								
					L	Flex								
						Ext								
ID	Sex	Age	Height	weight	Leg		Hand1	Hand2	Hand3	HandM	Hop1	Hop2	Hop3	hopM
					R	Flex								
						Ext								
					L	Flex								
						Ext								

8.10 Information sheet

Appendix 2

Information To Participate In A Research Project

You are invited to take part in a research study which could provide important information about the functional status of anterior cruciate ligament reconstruction (ACLR) patients at discharge from rehabilitation.

What is the project all about?

The main purpose of this study is to evaluate the functional status of anterior cruciate ligament reconstruction (ACLR) patients at discharge from rehabilitation.

Why have I been chosen?

You have been chosen to participate because you are:

1. Adult with unilateral ACL injury and had an ACL reconstruction.
2. Aged between 18 to 44 years old.
3. You are confident you will be able to hop without an adverse reaction.

Do I have to take part?

No, this is a completely voluntary study and it is up to you to decide if you wish to participate once you have read all the information. Take at least 24 hours to consider your involvement. If you do wish to participate you will complete a consent form but anytime during the study you will be able to withdraw (with no given reason) if you later decide you no longer wish to be involved.

If I participate in this study, can I also take part in other studies?

As the study is not including a treatment or long-term assessment, taking part should not affect any other studies that you are involved in. However, if you are taking part in other research or would like to do so, please discuss it with the researcher.

What will I have to do?

1) You will be asked to wear training clothes to allow the movement to become easier when testing lower limb muscles during the study.
2) The examiner will take your age, and measure your height and weight.
3) You will be asked to fill in four different questionnaires.

SHOPS ACLR study V.2.0 25 / January / 2017

4) You will be asked to do three trials of single-leg hop for distance.

5) Then the examiner will ask you to set on a chair to allow testing your knee muscles power, you will then be required to undertake a number of tests, which include knee flexion and extension tests, all of these tests will be carried out in a physiotherapy department at the hospital.

4) The testing procedure will be familiar by having the chance to practice the tests before collecting them, and warming up 5 minutes on a stationary bike.

5) The test will be conducted within 60 minutes.

6) All the collected data will be coded with a specific number, so your information will remain anonymous and confidential, and these data will be stored on a computer accessed by a researcher.

Expenses and payments?

The research will be entirely voluntary so you will not be paid for your participation in the study.

What are the possible benefits of taking part?

You may not personally benefit from the study but it is hoped that the knowledge generated will ultimately help to improve the functional status of anterior cruciate ligament reconstruction (ACLR) patients at discharge from rehabilitation.

Is there any risk involved?

There is an inherent risk with any type of muscle testing or hop. However, health and safety issues will be overcome be ensuring that the project supervisor or a qualified member of staff is always be present during data collection. In addition, the risk present will be minimized by giving you all enough time for training, warming up and formularization before the task. Additionally, in unlikely event of injury, first aid is present at all sessions in physiotherapy department. However, this study will be done in a physiotherapy department and therefore any risks are minimal.

Who will see my details and results?

All your information will be strictly kept confidential. The final results of this study will be available for you, and this study may be published.

What if something goes wrong?

If you wish to complain, or if you have any concerns about any aspect of the way you have been treated during the study, you can contact:

- the researcher ------------- (contact details at the bottom)
- Or if this is not suitable then contact his main supervisor -------. Email: -----. Telephone: ------.
- Or you can contact the Research Centres Manager at the University of Salford Anish Kurien, Email: a.kurien@salford.ac.uk. Telephone: 0161 295 5276. G.08 Joule House Acton Square, University of Salford, M5 4WT.
- Additionally, If through discussing sensitive experiences you feel upset about this you could enquire about counselling services by contacting your GP, or contacting the NHS helpline on free telephone number 111 for further advice (or your equivalent doctor/health service, if not based in the UK).

What if I want to leave the study earlier?

You are free to not participate in this study as well as drop out of the study at any time. If you want to withdraw or if you have any further questions about the project, you can contact the researcher.

What will happen to the results of the research study?

The results will be disseminated through my PhD thesis which this study forms part of, along with publications and/or presentations in academic journal articles and conferences. These outputs will contain a pseudonym so that your identity will remain confidential.

Who is organising or sponsoring the research?

The research is being organised by the Centre for Health Sciences Research, University of Salford, Salford M6 6PU. The research is being conducted as part of a PhD project funded by the University of Salford.

Further information and contact details:

- If you would like to participate in the study or enquire about any additional information please contact ------- at ---------.

- Supervised by ---------. Email: ------. Telephone: ---------.

Please note that:

- You are free to decide whether or not to take part in this study. Moreover, you will be also free to withdraw from this study at any time without giving any reason.
- Your participation would involve one session for approximately 60 minutes at physiotherapy department at the hospital.
- At least a minimum period of 48 hours will be set, between giving you the information sheet and signing the consent form.
- Please feel free to ask any further questions in the future about the project at any time.
- For any complaint regarding this study please do not hesitate to contact:
  Mr. Anish Kurien
  Research Centres Manager
  0161-295-5276
  a.kurien@salford.ac.uk

Many Thanks for Your Participation

وزارة الصحة
Ministry of Health

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التاريخ :....../....... / 1436هـ
المشفوعات:.........................

عنوان الدراسة الحالة الوظيفية للمصاب بقطع في الرباط الصليبي بعد إنتهاء من برنامج التأهيل

الباحث الرئيس حسام عبدالله المالكي

العنوان جامعة سالفورد– بريطانيا

رقم الهاتف 0503303339

سيشرح لك عضو من فريق البحث محتويات هذه الدراسة وتأثيرها عليك. و يصف هذا الإقرار إجراءات الدراسة ، والمخاطر والفوائد من المشاركة ، وكيفية الحفاظ على سرية المعلومات. الرجاء اخذ الوقت الكافي في طرح الأسئلة لكي تتخذ قرارك ما إذا كنت ستشارك أم لا. وهذه الموافقة تسمى الموافقة المستنيرة. إذا قررت المشاركة في هذه الدراسة ، سيطلب منك التوقيع على هذا الإقرار وستعطي نسخة لسجلاتك. وطوال هذا الإقرار اللفظ "أنت" سوف يشير إليك أو إلى طفلك ، حسب الاقتضاء.

لماذا تُجرى هذه الدراسة؟ معرفة الحالة العامة للمريض بعد الإنتهاء من برنامج التأهيل ومقارنة حالته مع أشخاص سليمين

كم عدد المشاركين في هذه الدراسة ؟ 50

ماذا سيحدث إذا شاركت في هذه الدراسة ؟

سيتم تقييم حالتك الوظيفية وقوة العضلات وتقييم وظائف الركبة والجاهزية النفسية للعودة للرياضة بعد الإنتهاء من التأهيل

موقع الدراسة؟

قسم العلاج الطبيعي – مستشفى التأهيل الطبي بالمدينة المنورة

ما هو المتوقع مني خلال هذه الدراسة (ما هي مسؤولياتي)؟

1- يتم قياس قوة العضلة الرباعية الأمامية في الفخذ وقوة العضلة الخلفية للفخذ في الرجلين باستخدام جهاز يدوي محمول

2- يتم تقييم الوظائف الحركية بالقفز على قدم واحده لأبعد مسافة ممكن ثلاث مرات.

3- سيتم تقييم وظائف الركبة بتعبئة استبانتين:

أ- إستبانة الالتهاب المفصلي العظمي وإصابات الركبة (KOOS)

ب- إستبانة اللجنة الدولية لتوثيق وظائف الركبة (IKDC)

4- سيتم تقييم العوامل النفسية المؤثرة في عودة اللاعب لممارسة الرياضة بعد الإصابة بالرباط الصليبي بتعبئة إستبانتين: -

أ- إستبانة الخوف من الحركة وعودة الإصابة (TAMPA)

ب- إستبانة مقياس العودة للرياضة بعد الرباط الصليبي (ACL-RSI)

تصميم : صقر عرب

وزارة الصحة
Ministry of Health

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التاريخ :...../...... / 1436هـ
المشفوعات:.........................

ما هي مدة مشاركتي في هذه الدراسة؟ 30 دقيقة

هل أستطيع إنهاء مشاركتي في هذه الدراسة ؟

نعم. يمكنك أن تقرر التوقف في أي وقت. فقط اخبر الطبيب إذا قررت التوقف. ليوضح لك كيفية إنهاء مشاركتك بأمان. لا أحد سيجملك علي تغيير رأيك.

هل هناك مخاطر متوقعة إذا أنهيت مشاركتي في هذه الدراسة ؟ لا

ما هي المخاطر أو الآثار الجانبية التي يمكن حدوثها من جراء مشاركتي في هذه الدراسة ؟

لا يوجد مخاطر محتملة خلال اختبار قوة العضلات أو اختبار القفز على قدم واحدة

هل هناك فوائد من مشاركتي في هذه الدراسة ؟
تستطيع الاستفادة شخصيا من الدراسة عن طريق معرفة وضعك الطبي الحالي وهل بإمكانك العودة للممارسة الرياضة, بالإضافة للفائدة العامة من البحث وتحسين الحالة الوظيفية للمصابين بالرباط الصليبي.

ما هي الخيارات الأخرى؟

لديك خيارات أخرى بدلا عن المشاركة في الدراسة:
لا يوجد طرق بديلة سوى في المراكز الرياضية المتخصصة في تأهيل الرباط الصليبي للاعبين المحترفين وتقييمهم قبل عودتهم لممارسة الرياضة.

ماذا يحدث لو أنني تعرضت للإصابة بسبب مشاركتي في هذه الدراسة ؟

من المهم أن تبلغ الدكتورعبدالرحمن التويجري رئيس قسم التأهيل إذا كنت تظن انك قد تعرضت للإصابة بسبب مشاركتك في هذه الدراسة. يمكنك أن تبلغ الطبيب شخصيا أو الاتصال به علي 0555380401 . و في حال تعرضك للإصابة سيكون العلاج متاحا. سيقدم لك مستشفى التأهيل الطبي تكاليف العلاج، ويتوقف ذلك على عدد من العوامل. عادة لا تقدم مستشفى التأهيل الطبي أو ممول الدراسة أي شكل آخر من أشكال التعويض عن الضرر. وللحصول على مزيد من المعلومات عن هذا الموضوع، يمكنك الاتصال بمستشفى التأهيل الطبي علي الرقم 8490016.

وما هي تكاليف المشاركة في الدراسة ؟

لن تتحمل تكاليف أي من أنشطة الدراسة.

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هل سأتقاضى اجر نظير المشاركة في هذه الدراسة ؟

لن يكون هناك اجر.

هل سيتم الحفاظ علي سرية المعلومات الطبية الخاصة بي ؟

ستبذل قصارى جهدنا للتأكد من أن المعلومات الشخصية في سجلك الطبي تحظى بالسرية. ومع ذلك ، لا يمكننا أن نضمن الخصوصية التامة. قد يفصح عن معلوماتك الشخصية إذا اقتضى الأمر ذلك بموجب القانون. لن يتم الإفصاح عن اسمك أو معلوماتك الشخصية إذا تم نشر أو عرض نتائج هذه الدراسة.

ما هي حقوقي إذا وافقت على المشاركة في هذه الدراسة ؟

قرار المشاركة في هذه الدراسة من اختيارك. لك حرية اختيار المشاركة في هذه الدراسة أو لا .كما يمكنك إنهاء المشاركة في أي وقت. مهما كان قرارك ، لن يكون هناك أي عقوبة و لن تفقد أي من الفوائد العادية الخاصة بك. ترك الدراسة لن يؤثر علي الرعاية الطبية المقدمة لك من جامعة الملك سعود. حسام المالكي قد يستخدم المعلومات التي تم جمعها قبل أن تترك لدراسة.

ونحن سوف نبلغك بكل المعلومات والمستجدات أو التغييرات في الدراسة التي يمكن أن تؤثر على صحتك أو على استعدادك لمواصلة الدراسة .

وفي حالة الإصابة الناتجة عن هذه الدراسة، بتوقيع هذا الإقرار. لن تفقد أيا من الحقوق القانونية في طلب التعويض.

بمن يمكنني الاتصال إذا كانت لدي أي أسئلة أو مشاكل؟

قبل أن توافق على المشاركة هذه الدراسة ستتحدث إلى احد أعضاء فريق الدراسة المؤهلين ليخبرك عن هذه الدراسة . يمكنك أن تطرح الأسئلة حول أي جانب من جوانب البحث. إذا كان لديك المزيد من الأسئلة عن الدراسة يمكنك السؤال في أي وقت. يمكنك الاتصال الباحث الرئيس علي الرقم:0503303339

التصميم : صقر حرب

8.11 Biodex System 4 PRO dynamometer pilot measurements

Mean and Mean differences of peak torque between Biodex System 4 PRO dynamometer with hand-held in session 1 and Biodex System 4 PRO dynamometer alone in session 2.

Test n=3	Session 1	Session 2	Mean differences
Right Flexor (Nm)	78.1	80	1.9
Right Extensor (Nm)	159.7	157.5	2.2
Left Flexor (Nm)	82	83.5	1.5
Left Extensor (Nm)	166.4	168.7	2.3

8.12 Using HHD when measuring quadriceps and hamstring muscles strength

8.13 Results in details

Healthy group

Mean (SD) and p-value, Comparison of Significant (P = 0.05) between right and left leg single-hop test in healthy age groups

Test	Right leg (SD)	Left leg (SD)
Men (18-24) n=35		
Single hop (cm)	159.14 (13.71)	154.98 (15.72)
Single hop (%)	170.160 (12.13)	165.80 (15.64)
Men (25-34) n=35		
Single hop (cm)	132.97 (16.85)	132.83 (13.10)
Single hop (%)	148.06 (21.88)	147.74 (16.78)
Men (35-44) n=35		
Single hop (cm)	121.4 (15.39)	114.63 (20.29)
Single hop (%)	137.85 (32.05)	131.14 (37.93)

Mean (SD) and p-value, Comparison of Significant (P = 0.05) between right and left leg peak force test in healthy age groups

Test	Right leg (SD)	Left leg (SD)
Men (18-24) n=35		
Quadriceps peak force (N)	430.18 (64.96)	437.56 (88.42)
Quadriceps peak force (Nm)	178.43 (28.37)	181.63 (37.73)
Quadriceps / body mass (Nm/kg)	2.84 (0.57)	2.83 (0.71)
Hamstring peak force (N)	230.73 (26.28)	238.21 (32.5)
Hamstring peak force (Nm)	95.74 (12.57)	99.41 (15.52)
Hamstring peak force (Nm/kg)	1.50 (0.35)	1.55 (0.37)
Hamstring / Quadriceps ratio (%)	54.87 (0.10)	56.66 (0.13)
Men (25-34) n=35		
Quadriceps peak force (N)	413.92 (56.74)	415.94 (79.91)

Quadriceps peak force (Nm)	167.04 (27.91)	168.69 (36.41)
Quadriceps / body mass (Nm/kg)	2.39 (0.43)	2.41 (0.60)
Hamstring peak force (N)	221.86 (40.17)	224.06 (46.71)
Hamstring peak force (Nm)	89.89 (18.21)	90.70 (20.08)
Hamstring peak force (Nm/kg)	1.28 (0.27)	1.30 (0.30)
Hamstring / Quadriceps ratio (%)	53.97 (0.9)	54.85 (0.11)
Men (35-44) n=35		
Quadriceps peak force (N)	400.86 (71.50)	394.63 (38.26)
Quadriceps peak force (Nm)	165.21 (31.29)	162.12 (17.53)
Quadriceps / body mass (Nm/kg)	2.26 (0.28)	2.26 (0.30)
Hamstring peak force (N)	205.57 (34.76)	207.71 (27.64)
Hamstring peak force (Nm)	84.71 (15.04)	85.84 (11.38)
Hamstring peak force (Nm/kg)	1.17 (0.18)	1.20 (0.26)
Hamstring / Quadriceps ratio (%)	52.01 (0.80)	52.66 (0.65)

ACLR group

Mean (SD) and p-value, Comparison of Significant (P = 0.05) between injured and non-injured in leg single-hop test in ACLR men age groups

Test	Injured leg (SD)	Non-injured leg (SD)	p-value	Effect size	Single hop LSI (%)
Men (18-24) n=9					
Single hop (cm)	116.22 (25.58)	153.11 (10.94)	0.00*	1.64	75.91
Single hop (%)	127.10 (28.47)	167.19 (10.74)	0.00*	1.66	76.02
Men (25-34) n=26					
Single hop (cm)	103.88 (38.88)	123.48 (24.36)	0.00*	0.84	84.13
Single hop (%)	116.43 (45.08)	133.54 (26.96)	0.00*	0.82	87.19
Men (35-44) n=12					
Single hop (cm)	89.92 (44.92)	104.50 (32.34)	0.01*	0.88	86.05
Single hop (%)	98.66 (49.34)	114.52 (35.21)	0.02*	0.78	86.15

Mean (SD) and p-value, Comparison of Significant (P = 0.05) between injured and non-injured leg peak force test in ACLR patients age groups

Test	Injured leg (SD)	Non-injured leg (SD)	p-value	Effect size	LSI (%)
Men (18-24) n=9					
Quadriceps peak force (N)	328.00 (108.72)	395.22 (126.19)	0.04*	0.81	83.13 (18.21)
Quadriceps / body mass (N/kg)	5.04 (1.40)	6.08 (1.62)	0.03*	0.83	
Quadriceps peak force (Nm)	134.54 (45.89)	162.02 (51.64)	0.04*	0.65	
Quadriceps / body mass (Nm/kg)	2.07 (0.59)	2.49 (0.66)	0.03*	0.84	
Hamstring peak force (N)	200.22 (19.21)	238.11 (18.44)	0.00*	1.73	
Hamstring / body mass (N/kg)	3.12 (0.23)	3.71 (0.24)	0.00*	1.72	
Hamstring peak force (Nm)	82.04 (8.46)	97.84 (11.04)	0.00*	1.66	
Hamstring peak force (Nm/kg)	1.28 (0.10)	1.52 (0.16)	0.00*	1.72	84.20 (8.41)
Hamstring / Quadriceps ratio (%)	65.95 (16.43)	65.94 (19.15)	0.99	0.00	
Men (25-34) n=26					
Quadriceps peak force (N)	326.27 (85.86)	374.88 (86.62)	0.00*	1.38	
Quadriceps / body mass (N/kg)	4.22 (1.09)	4.86 (1.18)	0.00*	1.31	
Quadriceps peak force (Nm)	133.64 (36.35)	153.58 (36.94)	0.00*	1.37	
Quadriceps / body mass (Nm/kg)	1.72 (0.43)	1.98 (0.45)	0.00*	1.35	86.87 (9.06)
Hamstring peak force (N)	199.27 (47.18)	239.35 (64.61)	0.00*	0.82	
Hamstring / body mass (N/kg)	2.58 (0.59)	3.10 (0.82)	0.00*	0.78	
Hamstring peak force (Nm)	82.37 (23.37)	99.09 (31.23)	0.00 *	0.81	
Hamstring peak force (Nm/kg)	1.06 (0.26)	1.27 (0.37)	0.00*	0.78	83.46 (17.79)
Hamstring / Quadriceps ratio (%)	64.61 (19.88)	65.72 (19.37)	0.74	0.07	
Men (35-44) n=12					
Quadriceps peak force (N)	295.08 (61.03)	340.83 (51.98)	0.00*	1.41	
Quadriceps / body mass (N/kg)	3.53 (0.56)	4.08 (0.32)	0.00*	1.36	
Quadriceps peak force (Nm)	120.20 (26.66)	138.97 (24.92)	0.00*	1.38	
Quadriceps / body mass (Nm/kg)	1.43 (0.20)	1.66 (0.09)	0.00*	1.34	86.18 (10.10)
Hamstring peak force (N)	192.67 (36.08)	229.42 (40.77)	0.00*	2.13	

Hamstring / body mass (N/kg)	2.32 (0.43)	2.77 (0.47)	0.00*	2.11	
Hamstring peak force (Nm)	78.65 (16.58)	93.74 (19.75)	0.00*	2.00	
Hamstring peak force (Nm/kg)	0.95 (0.17)	1.13 (0.20)	0.00*	2.11	84.07 (6.70)
Hamstring / Quadriceps ratio (%)	66.31 (10.05)	67.97 (11.21)	0.38	0.26	

8.14 Rehabilitation Protocol

KINGDOM OF SAUDI ARABIA
General Directorate for Health Affairs
Medina region
Medical Rehabilitation Hospital
Department of Physiotherapy

وزارة الصحة
Ministry of Health

المملكة العربية السعودية
المديرية العامة للشئون الصحية بمنطقة المدينة المنورة
مستشفى التأهيل الطبي
القسم (العلاج الطبيعي)

Title:	**ACL Protocol**	**Pages:**	**6**
Policy:	**RH 15.5**	**Applies To:**	**Dept of Physiotherapy**
Effective Date:			

Preoperative Phase:

Rehabilitation for the injured knee begins immediately following ACL injury. The clinical goals for preoperative period include restoring full range of motion (ROM) and normal strength and control swelling prior to surgery. Patients are also to completely understand the basic principles of accelerated rehabilitation including full terminal knee extension, early weight bearing, and closed and open chain strengthening. The time needed to accomplish these goals can be as little as 1 week or as long as 2 months, depending on how the knee responds to the initial injury.

To reduce swelling, a cold compression (Cold packs) is applied to the knee. The patient can use cold application at home also for a duration of 20 to 30 minutes. Swelling reduction eases the return of normal range of motion.

Returning full knee range of motion equal to the uninvolved knee prior to surgery decreases complications such as post-operative knee stiffness. To restore full range of motion, the patient is instructed in several exercises including heel props (Fig. 1), prone hangs (Fig. 2), and towel extensions for extension and wall slides and heel slides for flexion.

Fig 1

Fig 2.

Immediate Postoperative:

The clinical goals include decreasing swelling, obtaining full passive knee extension, and obtaining 110 degrees of flexion.

Additional variables include performing an independent straight leg raise and restoring normal walk.

Post-Operative Positioning:

1. Compression dressing, ice to knee
2. Immobilizer with knee in straight (0 degrees) extension (the struts for the immobilizer should be bent out into a position of relative knee recurvation which generally keeps a knee with a post-op dressing in full extension).
3. Proper knee elevation
4. Immediate quad sets; ankle pumps encouraged

Postoperative Day One to Six (1 to 6 days):

Exercises for regaining full ROM are begun the day of surgery. Hyperextension is maintained with 10 minutes of heel

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prop exercises every waking hour. Flexion exercises are performed six times daily. This can easily done by slowly increasing flexion of the Continuous Passive Motion(CPM) machine from 35 to 90 degrees and holding the position for 10 minutes two to four times a day depending on availability of CPM. Once maximal flexion has been attained in the CPM machine, patients can continue to increase bend beyond 90 degrees by pulling leg further to buttocks with their hands.

Leg-control exercise is started on the day of surgery and consists of quadriceps contraction exercises and independent straight leg raises. Active heel height exercises (Figure 3) are performed to promote leg control and to minimize the potential for a patellar contracture. During the first week patients are to remain lying down as much as possible. However, when getting up to go to the bathroom patients is encouraged to be weight bearing as tolerated. Crutches may be used for the first few days to facilitate a normal walking pattern.

The patient will report to physical therapy out patient department one week after surgery and should have full terminal extension and flexion to 110 degrees, minimal swelling and soft tissue healing, and normal walking.

Figure 3

1. No pillow under knee at any time for first six weeks. Pillows should always support foot/ankle while in bed.
2. Out of bed
3. Quad sets - 30 reps, 3-5 times daily. Five quads hard for 6 seconds. Relax for 3 seconds. Repeat.
4. Ankle pumps every hour.
5. Protected weight bearing with crutches to tolerance
6. Dressing changes prior to hospital discharge
7. Obtain full passive extension (0 degrees) out of immobilizer (essential)
8. Achieve 90 degrees of flexion on Continuous Passive Movement machine, or actively if the patient can do by himself as tolerated. CPM Given for 30minutes to 1-hour duration starting from 35 degrees knee flexion and if tolerated by the patient attain 90 degree flexion within Painful limits. Usually an auto increase in flexion is set in the machine ranging from 2 degrees to 5 degrees.
9. Protected weight bearing as tolerated (WBAT) with crutches
10. Exercises (out of immobilizer):

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a. Quad sets

b. Active assisted knee flexion (sitting)

c. Hamstring stretches

d. Passive extension to 0 degrees

e. Standing hamstring curls

Discharge Protocol (From In-patient department to be done by Patient at home until he/she reports to out-patient Department):

1. Gait-weight bear as tolerated with crutches

2. Exercises (out-of-brace):

Flexion Exercises (4 times daily):

- Active assisted knee flexion (sitting) to > 90 degrees (as tolerated)
- Sitting/standing hip flexion
- Standing hamstring curls

Extension exercises:

- Quadriceps stretch to achieve full passive extension (frequently)
- Quad sets (10 sets of 30 daily)
- Straight leg raises (obtain full extension)

(10 sets of 30 daily). No sag of the knee should be present.

- Hamstring stretches (hourly)

Crutch Ambulation Protocol (verify with surgeon for each case):

1. Weight bear as tolerated (protected) with crutches for 2 weeks.

2. After two weeks, may progress to one crutch (on opposite side) once quadriceps function and gait mechanics are normal.

3. Discontinue one crutch once gait mechanics are normal (no limping).

Postoperative Two to Six Weeks:

Goals:

1. Top priority - obtain full (0 degrees) knee extension.

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2. Increase knee range of motion.

3. Increase quadriceps strength in preparation for progression to ambulation without use of crutches.

Exercise Program:

1. Continue knee immobilizer at full extension. Decrease use as comfortable (important - verify with surgeon). May ambulate without knee brace (with crutches) once quadriceps able to fire well to support operative knee.

2. Flexion Exercises:

- Active assisted knee flexion (with overpressure - goal is 130 degrees). Patient applies pressure on the operated leg using his sound leg.

- Biking as tolerated to 30 minutes (low resistance).

- First two weeks of exercise bike backwards (no resistance).

3. Progressive Resistance Exercises: (30-50 repetitions, 0-5 pounds, 3 times/day) or as tolerated

- Straight leg raises (maintain full extension)

- Hamstring curls

- Hip flexion, extension, abduction

* If any of these exercises seem to aggravate the knee (swelling, pain, or tenderness), then that specific exercise which causes the difficulty should be postponed until the patient discusses the effects of the exercise with his or her treating therapist.

Postoperative Seven to Twelve Weeks:

Goals:

1. Achieve full extension to near full flexion.

2. Improve quadriceps tone.

Exercise Program:

1. Quadriceps - straight leg raises (10 sets of 30 repetitions each), and quads setting (10 sets of 30 repetitions each)

2. Hip muscle groups. May progress by adding weights above the knee. Hip abductors, flexors, abductors, extensors (10 repetitions, 4 sets daily). An isometric variation can be performed by pushing down on the hip being worked on and sustaining a contraction for 10 seconds.

3. Hamstrings curls - may add weights around the ankle (10 repetitions, 4 times daily).

4. Calf raises. 3 sets, 10 repetitions - fast and slow sets (each).

5. Swimming. Flutter kick only - gentle. No whip kick.

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6. May begin outdoor biking program - avoid hills. A good rule of thumb for those interested in returning to athletics is that you need three minutes of biking to substitute for one minute of running (verify with surgeon for each case)
7. Accelerated program - start with sand bags on tibial tubercle. Perform straight leg raises (10 sets, 10 repetitions each) and progress fulcrum distally one inch per week).
8. Walking (level ground). Build up pace gradually. Feel big toe of affected foot push off as you walk to ensure normal gait pattern. Start off at One mile at brisk pace, increase to three miles. No limping allowed.
9. Sissy squats. Stand facing the edge of a door and place hands on the door knobs on each side of the door. Feet should be shoulder width apart. Perform a half-squat (never past 90 degrees) and slowly raise to a starting position. Build up to 100 repetitions per day.

Postoperative 12-16 Weeks:

Goals:

1. Full knee range of motion. Refer back to surgeon for extension restriction of 5 degrees or if less than 110 degrees flexion.
2. Normal gait pattern.
3. Progressively increasing functional strengthening program.

Exercises:

1. Continue with exercise program from week 7-12.
2. Weight room activities:

- Leg press - press body weight as many times as possible on nonsurgical side (to fatigue). Follow same sequence on surgical side.
- Squat rack - half squats (not past 70 degrees) at one-half body weight, 10 repetitions; progress to full body weight as tolerated.

3. Continue biking and/or swimming on a daily basis. No whip kicks.
4. Agility workouts:

- Balancing on a teeter-totter board/balancing board or disc on a half-croquet ball
- Figure of 8's (20 to 30 yard diameter circles)
- Backward jog
- Half speed jog (level surfaces only). Initially alternate 100 yards walking/jogging over one mile. Build up to one mile by 16 weeks postoperative.

Postoperative Four Months - Six Months:

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Date:	Date:	Date:

Goals:

1. Improve quadriceps strength/function
2. Improve endurance
3. Improve coordination/proprioception

Exercises:

1. Jogging - (level surfaces) - 15 minutes at 8-10 minutes/mile pace. Add 5 minutes per week. Perform daily.
2. Biking - by now the amount of set resistance should be increasing. Perform daily at 20 minutes/day. Legs should feel drained once off the bike.
3. Step-ups - face the step. Put foot of operative knee on step and step up on the step. Repeat with gradual build up in repetitions until doing 100 step-ups/day. Try to lower from the step twice as long as it takes to raise up on the step.
4. Agility Drills:

- Figure 8's - daily - 5 minutes half-speed - tighten circle size down
- Shuttle runs daily - 5 minutes - half-speed - repeat 10-12 repetitions
- Zig-zag running - angle across a distance of 10-15 yards, then angle back across field to another boundary 10-15 yards apart. Continue for 100 yards. Tighten up as strength/endurance permits.

Postoperative Full Rehabilitation:

1. No competitive or pivot sports until cleared by surgeon.
2. Quadriceps/thigh circumference should be within 1 cm of non-operative (if normal) side.
3. Weekly strengthening program - independently (2-3 times/week):

- Full speed jog/run - 20-30 minutes - 6-7 minutes/mile or best pace.
- Exercise stationary bike - increasing resistance, set bike so low leg is flexed no more than 10-15 degrees, 20 minutes.
- Agility drills (figure 8's, shuttle runs, turns), teeter-totter balancing
- Continue quad sets, SLR's (300 repetitions/day)
- Hills/stairs - running up hills and up stairs can be utilized to help build muscle mass and strength. Care should be taken running downhill and down steps. This can irritate the knee and should be one of the last exercises added to the workout program.

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Date:	Date:	Date:

8.15 Prayer Kneeling

8.16 Prayer Bowing

8.17 Relationship between ACLR outcomes

Table 4.11 in details: [a]Pearson's and Spearman's correlation between the outcome measures, Bonferroni corrected *p*-value (**α** = 0.0009)

		Hop	Flexion Strength	Extension Strength	KOOS pain	KOOS Symptoms	KOOS ADL	KOOS Sport/ Rec	KOOS QoL	IKDC	ACL-RSI	TSK
Hop	Cor.		† **.53***	† **.50***	ǂ .16	ǂ .19	ǂ .16	ǂ .180	ǂ .18	ǂ .42	† .26	† -.02
	Sig.		**.0001**	**.0004**	.29	.21	.29	.23	.22	.003	.08	.89
Flexion Strength	Cor.	† **.53***		† .36	ǂ .18	ǂ .03	ǂ .20	ǂ .29	ǂ .19	ǂ .32	† .03	† -.06
	Sig.	**.0001**		.01	.23	.87	.19	.05	.19	0.03	.83	.70
Extension Strength	Cor.	† **.50***	† .36		ǂ .37	ǂ .14	ǂ .34	ǂ **.50***	ǂ .32	ǂ **.57***	† .13	† -.32
	Sig.	**.0004**	.01		.01	.34	.02	**.0001**	.03	**.0001**	.38	.05
KOOS Pain	Cor.	ǂ .16	ǂ .18	ǂ .37		ǂ .42	ǂ **.88***	ǂ **.81***	ǂ **.79***	ǂ **.70***	ǂ .22	ǂ -.32
	Sig.	.29	.23	0.01		.002	**.0001**	**.0001**	**.0001**	**.0001**	.14	.03
KOOS Symptoms	Cor.	ǂ .19	ǂ .03	ǂ .14	ǂ .42		ǂ .28	ǂ .31	ǂ .39	ǂ .33	ǂ .03	ǂ -.10
	Sig.	.21	.87	.34	.002		.06	.04	.007	.02	.83	.46
KOOS ADL	Cor.	ǂ .16	ǂ .20	ǂ .34	ǂ **.88***	ǂ .28		ǂ **.86***	ǂ **.65***	ǂ **.76***	ǂ .24	ǂ -.40
	Sig.	.29	.19	.02	**.0001**	.06		**.0001**	**.0001**	**.0001**	.11	.005
KOOS Sport/Rec	Cor.	ǂ .18	ǂ .29	ǂ **.50***	ǂ **.81***	ǂ .31	ǂ **.86***		ǂ **.63***	ǂ **.75***	ǂ .21	ǂ -.39
	Sig.	.23	.05	**.0001**	**.0001**	.04	**.0001**		**.0001**	**.0001**	.16	.007
KOOS QoL	Cor.	ǂ .18	ǂ .19	ǂ .31	ǂ **.79***	ǂ .39	ǂ **.65***	ǂ **.63***		ǂ **.66***	ǂ .46	ǂ -.35
	Sig.	.22	.19	.03	**.0001**	.007	**.0001**	**.0001**		**.0001**	.001	.02
IKDC	Cor.	ǂ .42	ǂ .32	ǂ **.57***	ǂ **.70***	ǂ .33	ǂ **.76***	ǂ **.75***	ǂ **.66***		ǂ .26	ǂ -.33
	Sig.	.003	.03	**.0001**	**.0001**	.02	**.0001**	**.0001**	**.0001**		.08	.02
ACL-RSI	Cor.	† .26	† .03	† .13	ǂ .22	ǂ .03	ǂ .24	ǂ .21	ǂ .46*	ǂ .26		† **-.53***
	Sig.	.08	.83	.38	.14	.83	.11	.16	.001	.08		**.0001**
TSK	Cor.	† -.02	† -.06	† -.32	ǂ -.32	ǂ .11	ǂ -.40	ǂ -.39	ǂ -.35	ǂ -.33	† **-.53***	
	Sig.	.89	.70	.05	.03	.46	.005	.007	.02	.02	**.0001**	

8.18 correlation between Arabic IKDC, ACL-RSI, TSK and KOOS, VAS, RAND-36 subscales

Outcome measure			IKDC	ACL-RSI	TSK
KOOS	KOOS Pain	Cor.	**0.69**	0.29	-0.39
		Sig.	0.0001	0.08	0.03
	KOOS Symptoms	Cor.	0.28	0.14	-0.18
		Sig.	0.08	0.21	0 29
	KOOS ADL	Cor.	**0.74**	0.30	-0.49
		Sig.	0.0001	0.03	0.002
	KOOS Sport/Rec	Cor.	**0.74**	0.28	-0.49
		Sig.	0.0001	0.07	0.002
	KOOS QoL	Cor.	**0.62**	**0.55**	-0.37
		Sig.	0.0001	0.0001	0.03
	KOOS Total	Cor.	**0.76**	0.39	-0.48
		Sig.	0.0001	0.04	0.002
Rand-36	Physical functioning	Cor.	**0.80**	**0.65**	-0.27
		Sig.	0.0001	0.0001	0.19
	Role limitations due to physical health	Cor.	**0.62**	**0.54**	-0.42
		Sig.	0.0001	0.0004	0.002
	Role limitations due to emotional problems	Cor.	0.34	**0.66**	-0.34
		Sig.	0.03	0.0001	0.01
	Vitality	Cor.	0.29	**0.75**	-0.25
		Sig.	0.03	0.0001	0.11
	Emotional well being	Cor.	0.46	**0.62**	-0.35
		Sig.	0.005	0.0001	0.005
	Social functioning	Cor.	0.46	0.47	-0.39
		Sig.	0.004	0.003	0.007
	Bodily pain	Cor.	**0.78**	**0.53**	-0.29
		Sig.	0.0001	0.0001	0.08
	General health	Cor.	0.48	0.47	-0.31
		Sig.	0.005	0.002	0.03
VAS		Cor.	**-0.64**	-0.41	0.41
		Sig.	0.0001	0.002	0.002