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Readiness for return to sport in non-surgically treated patients with anterior cruciate ligament injury following a public municipal rehabilitation program

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ABSTRACT

Objectives: To investigate the proportion of patients that pass a return to sport (RTS) test battery and assess changes in patient-reported outcomes and lower extremity muscle strength following three months of exericse-based rehabilitation in non-surgically treated patients with anterior cruciate ligament (ACL) injury.
Design: Prospective cohort study.
Setting: Clinical environment (public municipal).
Participants: Thirty-nine ACL injured patients (54% female, median age (IQR) 28 years (24–35).
Main outcome measures: The Knee Injury and Osteoarthritis Outcome Score, Knee Outcome Survey Activities of Daily Living Scale, single hop for distance, crossover hop for distance, side hop test, the Agility T-test, and quadriceps and hamstrings isometric maximal voluntary contraction (MVC).
Results: Following 3 months of rehabilitation, patients had statistically significant improvements in all patients-reported outcomes and in quadriceps and hamstring MVC. Of 28 patients who completed all RTS tests, 11% passed six RTS criteria, 14% five criteria, 11% four criteria, 4% three criteria, 18% two criteria, 21% one criterion, and 21% none of the criteria.
Conclusions: The results suggest that three months of public municipal rehabilitation improves patient-reported outcomes and lower extremity muscle strength in non-surgically treated patients with ACL injury. However, only one in every 10 patients passed all RTS criteria.

1. Introduction

Anterior cruciate ligament (ACL) injuries are common in athletes aged 15–40 years (Moses et al., 2012; Prodromos et al., 2007). Many ACL injuries are treated surgically followed by rehabilitation (Collins et al., 2013; Nordenvall et al., 2012), though data from the only two randomized controlled trials comparing structured rehabilitation plus early surgical ACL reconstruction and structured rehabilitation with optional delayed ACL reconstruction showed no clinically relevant differences in outcomes between the two different treatment strategies at two years follow-up (Frobell et al., 2010; Reijman et al., 2021). Similarly, previous studies have reported no difference in knee function and return to sport (RTS) rates between surgically and non-surgically treated ACL patients (1–20 years follow-up) (Grindem et al., 2012, 2014; Krause et al., 2018; van Yperen et al., 2018).

ACL injured athletes often have a strong motivation to RTS as quickly as possible following injury. To assess readiness for return

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to sport, it is recommended that athletes perform a battery of RTS tests (Filbay & Grindem, 2019). Such test batteries typically involve testing of muscle strength, jump performance, and questionnaires on readiness to start sporting activities. A systematic review and meta-analysis reported the passing rate of RTS testing to be 23% six month after ACL reconstruction (Webster & Hewett, 2019), whereas the passing rate have been reported to be 53% one year after ACL reconstruction (Logerstedt et al., 2014). Much less is known about readiness for RTS after a standard non-surgical rehabilitation program as it is delivered in clinical practice.

In several of the Nordic countries, many patients are first offered a period of rehabilitation following ACL injury to clarify if surgical treatment is wanted and needed. In this study, we aimed to investigate the proportion of patients that were able to pass a RTS test battery and assess changes in patient-reported outcomes and lower extremity muscle strength following a three-months exercise-based public, municipal rehabilitation program in patients with ACL injury who had not had ACL reconstruction.

2. Methods

2.1. Patients

We followed ACL injured patients who were referred to rehabilitation at a Danish municipality rehabilitation center (Hollufgård) in the period between December 2016 and August 2019. Patients were eligible for this study if they could speak and understand Danish and were referred to rehabilitation due to an ACL tear by an orthopedic surgeon from two hospitals in the region of Southern Denmark. Patients with previous knee injuries were also included in the study. There were no additional in- or exclusion criteria. All patients consulted a physiotherapist within two weeks of referral from the orthopedic department. All patients provided written informed consent. The Ethics committee of the Region of Southern Denmark waived the need for study approval.

2.2. Procedures

At the first visit to the rehabilitation center, one of four physiotherapists examined the patients. At the second session (baseline), patients filled out all questionnaires (patient-reported outcomes) followed by a 10 min bike warm-up and muscle strength testing. The rehabilitation was initiated at the third visit at the rehabilitation center. Participants started with a 20-min warm-up followed by a standardized exercise program based on lower extremity strength exercises including leg press, leg curl, leg extension, leg raise, kettlebell swings, and calf raises using machines and barbells performed in three sets of 6–15 repetitions with an estimated repetition maximum of 6–20. Patients also performed proprioceptive exercises tailored to the individual patients needs and level of rehabilitation. The exercise program was performed twice a week for three months as group-based exercise supervised by one of two physiotherapists (with at least 10 years of experience in treating ACL patients). Patients were allowed to exercise individually without supervision if they were not able to participate in the group-based exercise sessions. Patients were instructed in performing the same exercise program irrespective of exercise format (i.e., supervised group-based exercise or unsupervised individual exercise) and patients performing individual unsupervised exercise consulted one of the physiotherapists every two weeks to ensure progression. For a more detailed description please refer to Supplementary Table 1. At the last rehabilitation session (approximately three months after baseline testing) when the patient was discharged from the municipal program, collection of patient-reported outcomes and muscle strength data were repeated, and hop-tests and the agility *t*-test were performed.

2.3. Patient-reported outcomes

The Knee injury and Osteoarthritis Outcome Score (KOOS) is a patient-reported questionnaire intended for patients in the continuum from knee injury (including ACL injury) to osteoarthritis. The KOOS consists of five subscales: Pain, Symptoms, Function in activities of daily living (ADL), Function in sports and recreation (Sport/Rec), and knee-related Quality of life (QOL). KOOS subscale score were calculated according to the KOOS guidelines and range from 0 (extreme problems) to 100 (no problems) (Roos et al., 1998). The KOOS is a validated tool for various knee disorders including ACL, meniscus, and chondral injuries (Roos et al., 1998; Van De Graaf et al., 2014).

The Knee outcome Survey Activities of Daily Living Scale (KOS-ADLS) is a 14-item self-reported questionnaire, which assess function, symptoms and limitations in activities of daily living. It has been used as part RTS test criteria due to its relevance to ACL injured patients (Irrgang et al., 1998). The scale is scored from 0 to 100, whereas 0 is the worst (extreme symptoms) and 100 is best (no symptoms). KOS-ADLS is a reliable tool (intraclass correlation coefficient (ICC) 0.97) and has been validated for several knee disorders including meniscal tears, osteoarthritis and ACL tears (Irrgang et al., 1998).

2.4. Physical performance tests

All physical performance tests were carried out on both the ACL injured leg and the uninjured leg. Quadriceps and hamstrings isometric maximal voluntary contraction (MVC) was assessed at both baseline and follow-up. The force output (N) was collected using a fixed handheld dynamometer in a standardized setup with the patient's leg placed in 90° angle and multiplied by lower leg length (m) to report MVC in Nm. Before testing, the patients were given two submaximal trials at 50% and 75% of maximal force followed by two maximal trials. The trial with the highest force output was used for further analysis. Handheld dynamometry has moderate to good correlation with isokinetic dynamometry as well as acceptable inter-tester reliability and high test-retest reliability for quadriceps and hamstrings MVC (Almeida et al., 2019; Thorborg et al., 2013).

The Agility T-test was performed at follow-up to evaluate the ability to change directions rapidly (forward, sideways left-right, and backward). The test was performed as described by Semenick (Semenick, 1990). The patients received one test trial before testing, and thereafter completed three trials with a 3-min break between trials. The best trial was used for further analysis. The agility *t*-test has excellent test-retest reliability (Pauole et al., 2000). The Agility *t*-test was included due to the relevance of rapid changes in direction in various sports (e.g., handball and football). Additionally, it is recommended to include a sports-related agility test in a RTS test battery (Filbay & Grindem, 2019).

Three different jump tests were performed at the follow-up assessment: the single-leg hop for distance test; the crossover hop for distance test; and the side hop test. These tests have good to excellent test-retest reliability and has been associated with patient reported outcomes (functional status and global rating of change) after ACL injury (Noyes et al., 1991; Reid et al., 2007). For the first two hop tests, the hop distance was measured in centimeters with a standard tape measure from the toe in the starting position to the heel in the landing position. The longest jump was recorded and used for further analysis. The tests were considered successful if no body parts, other than the jumping foot, touched the ground and the foot remained still after landing. All patients performed one test trial followed by two successful trials with a 30 s break between

trials. For the side hop test, a stopwatch was used to record time and a physiotherapist counted the total number of successful hops in 30 s. The side hop test was considered successful if the patient did not touch the tape or landed within the 40-cm lines. Participants performed only one full trial of the side hop test to avoid fatigue. The patients' hands were placed behind their backs when performing all hop tests. The uninvolved leg was always tested first. Patients were asked to wear footwear that enabled safe jumping.

2.5. Return to sport (RTS) test battery

The RTS test battery in this study consisted of one patient-reported outcome (KOS-ADLS) and five physical tests: quadriceps MVC; single hop for distance; crossover hop test; side hop test; and the agility *t*-test. To pass the individual RTS tests patients were required to achieve a score of 90% or greater in the Limb Symmetry Index (LSI) of the functional tests (quadriceps MVC, single hop test, crossover hop test, and side hop test) (Grindem et al., 2016; Kyritsis et al., 2016). For the KOS-ADLS a score of 90 or greater was required to pass. As the Agility T-test is performed using both legs we used normative data from college aged men and women (mixed level of sports) to define a cut off to pass the Agility T-test. The cut off for men was defined as >10.5 s and for women >12.5 s, corresponding approximately to the mean scores (Pauole et al., 2000).

2.6. Statistics

Descriptive statistics were reported as mean and standard deviation (SD) or median and interquartile range (IQR) for continuous variables as appropriate and as frequency and percentage distribution for categorical variables. The LSI was calculated as the score of injured leg divided by score of uninjured leg multiplied by 100. Changes in KOOS, KOS-ADLS, and quadriceps and hamstring peak torque from baseline to follow-up was assessed using paired *t*-test. Only participants with full data available in all six RTS tests were included in the RTS analysis. Statistical significance level was set at $P \leq 0.05$. Stata 17.0 (College Station, Texas USA) was used for the statistical analysis.

3. Results

A total of 79 participants were included in the study, of which 39 (49%) underwent both baseline and follow-up assessments, and 28 (35%) completed all six RTS tests. Decision to undergo ACL reconstructive surgery prior to finishing the rehabilitation program and not showing up for the follow-up assessment accounted for the majority of loss to follow-up (Fig. 1). Patients lost to follow-up had significantly worse scores in KOOS QOL at baseline. We observed no other significant differences in descriptive variables or patient-reported outcomes between patients included in the analysis and patients lost to follow-up at baseline (Supplementary Table 2). The participants included in the analysis had a median (IQR) age of 28 (24–35) years and 54% were female. The most frequent preinjury sports were running (46%), football (41%), and cycling (25%). Mean (SD) rehabilitation time was 113 (37) days and mean (SD) number of attended supervised exercise session was 16 (8.9) (Table 1).

3.1. Patient reported outcomes

From baseline to three months follow-up, statistically significant improvements were observed in all subscales of the KOOS. Participants reported less knee pain (10 points), less knee symptoms (12 points), improved function in activities of daily living (5 points), improved function in sport/recreation (20 points), and improved knee-related quality of life (10 points). Likewise, a statistically significant mean improvement of 10 points was observed in the KOS-ADLS (Table 2).

3.2. Muscle strength

Changes from baseline to three months follow-up for quadriceps and hamstring muscle strength is shown in Table 3. Within the injured leg, quadriceps and hamstrings peak torque increased by 25% and 50% from baseline to three months follow-up, respectively. Within the uninjured leg, quadriceps and hamstrings peak torque increased by 17% and 29%, respectively.

3.3. RTS passing rate

A total of 28 participants were included in the RTS analysis. At three months follow-up, 40% of the participants had a KOS-ADLS score of ≥90. A total of 32%, 43%, and 39% achieved ≥90% in the LSI for the side hop test, crossover hop test, and single hop for distance, respectively. Hop test performance at follow-up is shown in Table 4. Eighteen participants (64%) had quadriceps MVC LSI of ≥90%. In the Agility T-Test, 38% of males performed the test in >10.5 s, while 13% of females performed the test in >12.5 s. The proportion of patients passing RTS criteria are shown in Fig. 2.

4. Discussion

This study investigated the proportion of patients that were able to pass a RTS test battery and assessed changes in patient-reported outcomes and lower extremity muscle strength following three months of exericse-based municipal rehabilitation in patients with a non-surgically treated ACL injury. At 3 months follow-up, all patients-reported outcomes and quadriceps and hamstring strength improved significantly. Only one in every 10 patients passed all RTS criteria, while nearly half of the patients passed none or one of the RTS criteria.

Patients with ACL tears demonstrated meaningful improvements in four out of five KOOS subscales after the three months rehabilitation program. Pain, symptoms, function in sport/recreation, and knee-related quality of life improved by 10–20 points, which is greater than the suggested minimal important change (MIC) of 8–10 points (Roos & Lohmander, 2003). Although participants demonstrated statistically significant improvements in function in activities of daily living as measured using the KOOS, it did not exceed the threshold for meaningful change. On the contrary, participants had meaningful improvements in self-reported function as measured with the KOS-ADLS. Participants on average improved by 10 points, reaching the suggested MIC threshold of 10 points (Irgang et al., 1998). Even though the ADL subscale of the KOOS and the KOS-ADLS both measure constructs related to function in activities of daily living, the participants had high baseline scores in the KOOS ADL subscale compared to the KOS-ADLS, possibly leaving less room for meaningful improvement. Eitzen et al. (Eitzen et al., 2010) reported a 5-point improvement in the KOS-ADLS following five weeks of progressive exercise therapy in patients with ACL injury, suggesting that longer rehabilitation programs may be needed to reach clinically relevant changes in self-reported function in patients with a non-surgically treated ACL injury.

Knowledge of the clinical course following public, non-surgical rehabilitation of ACL injuries is needed to guide evidence-based recommendations for treatment and safe return to sport. Several observational studies comparing surgical and non-surgical treatment in patients with ACL injury have reported no significant differences in RTS outcomes including quadriceps strength, self-reported knee function, hop tests, and rate of RTS (Ageberg et al.,

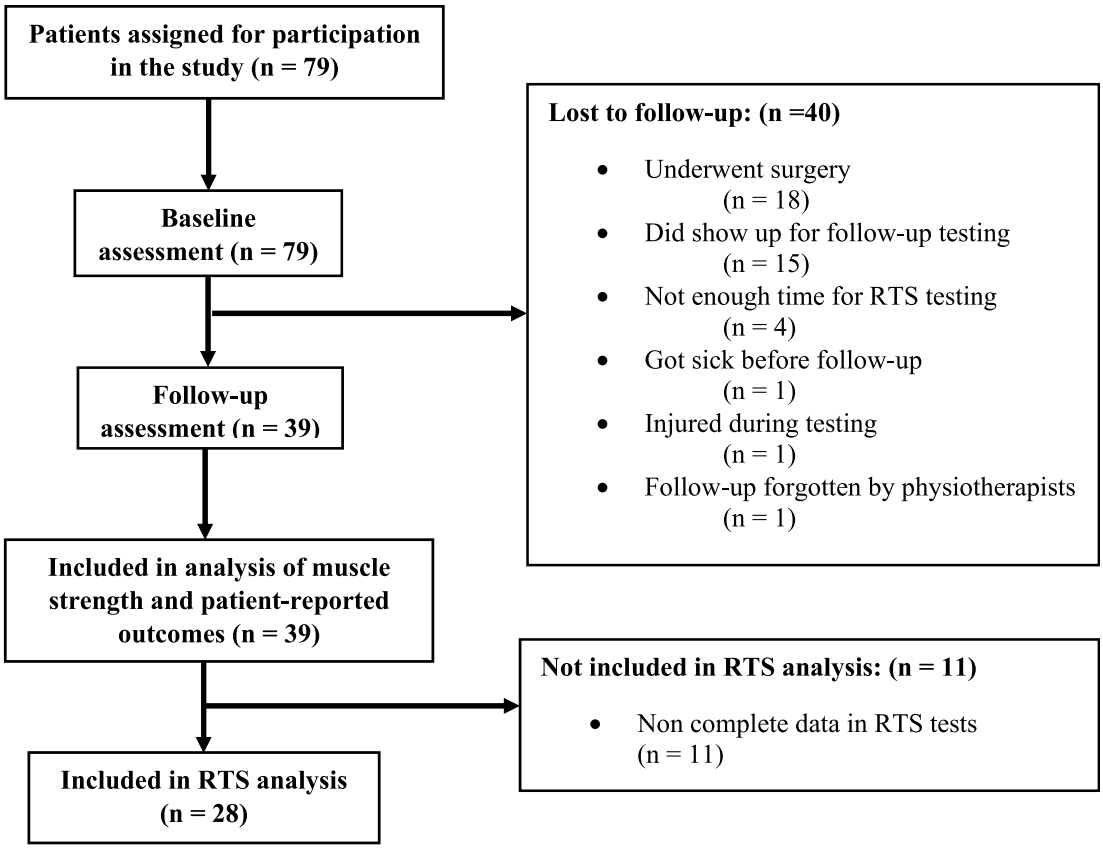

Fig. 1. Flow-chart.

Table 1
Baseline characteristics.

Female, no. (%)	21 (54)
Age, years; median (IQR)	28 (24–35)
BMI, mean (SD)	24.1 (2.9)
ACL injured leg, left/right (%)	22/17 (56/44)
Preinjury sports participation, no. (%)*	
Football (soccer)	16 (41)
Handball	8 (21)
Cycling	10 (25)
Running	18 (46)
Swimming	4 (10)
Gymnastics	3 (8)

*Some participants reported participating in more than one sport.

Table 2
Changes from baseline to follow-up for patient-reported outcomes.

	Baseline mean (SD)	Follow-up mean (SD)	Change (95% CI; P)
KOS-ADLS[a]	74 (14)	84 (11)	10 (5–15; <0.01)
KOOS[a]:			
Pain	73 (16)	83 (14)	10 (5–16; <0.01)
Symptoms	70 (16)	82 (16)	12 (6–18; 0.01)
ADL	88 (8)	93 (10)	5 (1–9; 0.01)
Sport/Rec	50 (26)	70 (23)	20 (11–29; <0.01)
QOL	54 (12)	64 (16)	10 (5–15; <0.01)

KOS-ADLS= Knee Outcome Survey Activities of Daily Living Scale; KOOS= Knee Injury and Osteoarthritis Outcome Score; ADL = Function in activities of daily living; Sport/rec = Function in sport and recreation; QOL = Knee-related quality of life, [a] Missing n = 5.

2008; Grindem et al., 2014; Meuffels et al., 2009; Myklebust et al., 2003). Consequently, the current evidence may suggest that patients who choose rehabilitation only should not expect inferior knee function compared to those who choose reconstructive surgery. However, as RTS outcomes and the duration and type of non-operative treatment courses vary between countries and settings, direct comparisons and interpretation of implications for clinical practice may be challenging. In addition, in several of the Nordic countries, surgical and non-surgical treatment courses differ not only with regard to whether or not patients undergo surgical reconstruction, but also the duration of rehabilitation. The duration of rehabilitation following surgical treatment may more than twice that of rehabilitation offered to non-surgically treated patients (i.e., 3 vs. 6–12 months) (Grindem et al., 2014; Amager og Hvidovre Hospital 5,). While this reflects differences in expected progression rate, our findings suggest that three months of public municipal rehabilitation using the current protocol is insufficient if the goal is to pass a RTS test battery after an ACL injury.

Currently, a clear consensus on exercise selection for non-surgical rehabilitation of ACL injuries does not exist. The three months exercise program was mainly based on lower extremity strength exercises progressing from light loads focusing on slow and controlled movement to high loads focusing on rate of force development. While there has been growing attention towards the importance of more aggressive strength training of the quadriceps muscle after ACL injury (Bruhn et al., 2006; Hartigan et al., 2009), approaches combining different exercise therapy programs may be

Table 3
Changes from baseline to follow-up in quadriceps and hamstrings muscle strength,[a] missing n = 1,[b] missing n = 2.

	Baseline Mean (SD)	Follow-up Mean (SD)	Change, baseline to follow-up, Mean (95% CI; P)	Difference in change between injured and uninjured leg, Mean (95% CI; P)
Knee extensor strength				
Injured[a] (Nm)	153 (61)	192 (63)	38 (27–49; <0.01)	8 (−0.88 to 18; 0.07)
Uninjured (Nm)	178 (63)	208 (60)	30 (20–39; <0.01)	
LSI (%)	86 (19)	92 (13)		
Knee flexor strength				
Injured[b] (Nm)	75 (30)	113 (40)	37 (27–46; <0.01)	12 (4–19; <0.01)
Uninjured[b] (Nm)	90 (28)	116 (39)	25 (15–35; <0.01)	
LSI (%)	83 (25)	97 (11)		

Table 4
Hop test performance at follow-up.

	Injured leg mean (SD)	Contralateral leg mean (SD)	LSI % (SD)
Single leg hop for distance, cm	116 (42)	129 (38)	88 (15)
Cross over hop for distance, cm	314 (117)	333 (123)	92 (23)
30 s side hop test, no.	27 (18)	35 (16)	77 (27)

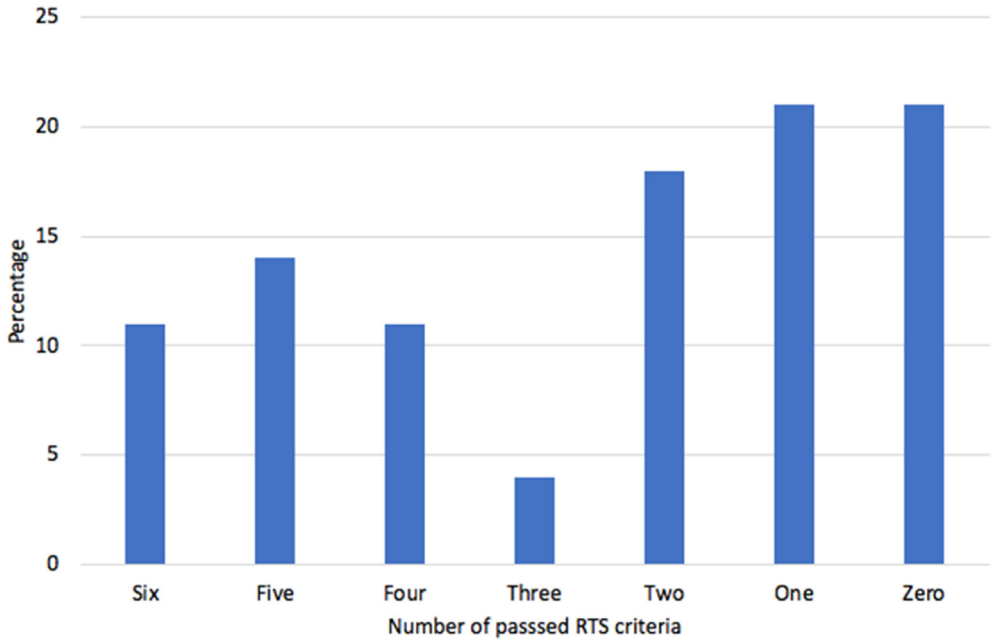

Fig. 2. Proportion of patients passing RTS criteria.

of benefit for patients undergoing exercise-based rehabilitation for ACL injury. Previous systematic reviews concluded that exercises for proprioception and balance may improve dynamic knee stability and functional abilities in ACL deficient patients (Cooper et al., 2005; Risberg et al., 2004). In addition, there is evidence suggesting that rehabilitation programs including perturbation exercises may lead to beneficial neuromuscular adaptations (Fitzgerald et al., 2000; Hartigan et al., 2009) and that plyometric exercises may improve athletic performance and enhance muscle strength (Chmielewski et al., 2006; Lewek et al., 2003; Villarreal et al., 2010). Eitzen et al. (Eitzen et al., 2010) applied plyometric exercises (variations of single-leg hops and drills focusing on maintaining the knee-over-toe position with soft landings) in non-surgically treated patients whose initial impairments (effusion, range of motion deficits) had resolved. Only 4% of patients experienced pain or swelling after performing these exercises for five weeks, which suggests early controlled plyometric exercises are tolerated well in a non-surgical rehabilitation program. In our study, 64% of patients had a quadriceps MVC LSI of ≥90% at follow-up, while only between 25 and 43% had a LSI of ≥90% in the three hop tests and the agility *t*-test, which might partly be explained by the heavy emphasis on strength exercises applied in the exercise program.

We used an LSI ≥90 as an indicator of normal limb symmetry for strength measurements and hop tests. However, the use of LSI alone may be ambiguous if the main purpose is to evaluate improvements in knee function in the injured limb. Using the uninjured limb as control has the methodological advantage that biological differences between participants is avoided. One possible disadvantage is that the status of the uninjured site may lead to misinterpretation of results (Patterson et al., 2020; Wellsandt et al., 2017) due to possible bilateral neuromuscular changes after injury (Ageberg, 2002; Palmiera-Smith & Thomas, 2009). In addition to

evaluating quadriceps and hamstring strength LSI, we performed evaluations of the quadriceps and hamstring MVC absolute values for the injured and uninjured side and examined changes in percent from baseline to follow-up. These analyses revealed that within the injured leg, quadriceps and hamstring MVC increased by 25% and 50%, suggesting that patients with ACL tears have potential for substantial improvements in muscle strength with three months of rehabilitation. When comparing our isometric quadriceps strength data with normative data as presented by Danneskiold-Samsøe et al. (Danneskiold-Samsøe et al., 2009), the mean follow-up quadriceps peak torque for females was equivalent to normative values of healthy age-matched females (153 Nm vs. 154 Nm), while it was slightly lower for males in this cohort compared to the values of healthy age-matched males (206 Nm vs. 230 Nm).

5. Limitations

This study has some limitations. Fifty-one percent of the included participants were lost to follow-up. Even though only minimal differences were observed in baseline characteristics between patients lost to follow-up and patients retained in the study, patients lost to follow-up may differ in other unmeasured characteristics and the direction of any resulting selection bias is unknown. A total of 45% of participants lost to follow-up were due to deciding to undergo reconstructive surgery. International treatment guidelines recommend early anatomical ACL reconstruction in highly active patients engaged in jumping, cutting and pivoting sports (Diermeier et al., 2020). The rationale behind this treatment algorithm is that an ACL reconstruction will improve passive knee stability and decrease the risk of secondary knee injuries (Beaufils et al., 2009; Diermeier et al., 2020; Roos & Karlsson, 1998). In this study, 24 participants reported engaging in high-risk sports (i.e., handball and football) prior to sustaining their ACL injury. However, the participants' motivation for resuming to high-risk sports, an important indication for undergoing ACL reconstruction, was not assessed.

The RTS test battery in this study consisted of one patient-reported outcome (KOS-ADLS) and five physical tests: quadriceps MVC; single hop for distance; crossover hop test; side hop test; and the agility *t*-test. While the athlete's decision to RTS has significant implications for their safety and health, the optimal set of RTS criteria to guide clinical decision-making remains to be established. As a result, the evidence for and validity of the current RTS test battery is unknown.

6. Conclusion

Following three months of progressive exercise-based rehabilitation in a public municipal setting, non-surgically treated patients with an ACL injury demonstrated statistically significant and meaningful improvements in pain, symptoms, function in ADL, function in sport/rec and knee related QOL, as well as increased quadriceps and hamstrings strength. However, only one in every ten patients passed all RTS criteria.

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Ethical approval

The Ethics committee of the Region of Southern Denmark waived the need for study approval. All patients provided written informed consent to participate in the study.

Declaration of competing interest

None declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2021.10.016.

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