Anterior cruciate ligament rehabilitation in the elite soccer player

Kees C.D. van Geel, 3244040, 17/07/2009, University Utrecht, Department Health sciences, Physical therapy sciences, the Netherlands

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1st Supervisor: dr. I.G.L van de Port, Utrecht University

1st Faculty supervisor: dr. T. Takken, Utrecht University

2nd Faculty supervisor: dr. M. van Brussel, Utrecht University

♦

University Medical Center Utrecht, Department of Rehabilitation and Sports Medicine

Content

Outcome measures after anterior cruciate ligament reconstruction.

A narrative review

Kees C.D. van Geel, 3244040, 17/07/2009, University Utrecht, Department Health sciences, Physical therapy sciences, the Netherlands

1st Supervisor: dr. I.G.L van de Port, Utrecht University
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University Medical Center Utrecht, Department of Rehabilitation and Sports Medicine

Kees C.D. van Geel

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Samenvatting

Het scheuren van de voorste kruisband (VKB) is een veelvoorkomend fenomeen onder voetballers. Na het scheuren van de VKB wordt veelal een reconstructie gedaan, waarna een lange revalidatie periode volgt. De doelen van de revalidatie zijn het verkrijgen van statische en dynamische stabiliteit, een volledige range of motion, het verbeteren van kracht en het functionele niveau en het voorkomen van een recidief. Om te kunnen controleren in welk stadium van de revalidatie de patiënt zich bevindt, zijn er verschillende meetinstrumenten ontwikkeld. Het feit is echter, dat niet een meetinstrument alle beschreven doelen kan meten. Een testbatterij dient daarom gebruikt te worden om een volledig profiel van de patiënt te kunnen maken. In deze literatuurstudie zijn 27 verschillende meetinstrumenten gevonden om het niveau van de patiënt in kaart te kunnen brengen. Zeven van deze meetinstrumenten maken gebruik van vragenlijsten om het herstel meer subjectief te kunnen meten terwijl de overige 20 objectieve testen omvatten. De vragenlijsten als de Lysholm score, de Tegner score en de Cincinnati knee rating system bleken valide vragenlijsten, waar de KOOS dat niet bleek te zijn. Ook kijkende naar betrouwbaarheid blijkt de KOOS de enige met negatieve resultaten te zijn. De Cincinnati knee rating system blijkt nauwelijks ene plafond effect te behalen en blijft significant verschillen bij de follow up metingen. De isokinetische testen als de Biodex en de Cybex worden in de literatuur veelal als gouden standaard weergegeven. De meer functionele testen, als de hop test wordt frequent beschreven, maar de resultaten varieren omtrent validiteit en betrouwbaarheid. Om een goede testbatterij te kunnen samenstellen zal er meer onderzoek gedaan moeten worden. Testen zoals de isokinetische tests en bepaalde hoptesten samen met bijvoorbeeld de Cincinnatit knee rating system, komen het beste naar voren.

Abstract

Anterior cruciate ligament (ACL) ruptures commonly occur in soccer players. Most likely an ACL reconstruction takes place which often leads to a long and intensive rehabilitation process. The aims of the entire rehabilitation process are to reach static and functional stability and a complete range of motion, to improve strength and functional level and to prevent the risk of recidivism. To identify an athlete's ability to tolerate the physical demands of a sport specific activity different outcome measures are developed. However, no currently known outcome measure is capable of measuring all aforementioned parameters in one test. Therefore a combination of tests is necessary to enable a more complete comprehensive evaluation of outcome. In this review, 27 outcome measures were found. Seven of these were subjective and twenty were objective measurements. Subjective outcome measures as the Lysholm, the Tegner and the Cincinnati knee rating system appeared to be highly valid were measurements as the KOOS did not. On reliability, the KOOS was the only one with negative results. The Cincinnati knee rating system has low ceiling effect and kept changing significantly over time. Different results on validity and reliability are presented for the objective measurements. The isokinetic tests as the Biodex or the Cybex are presented as golden standard. More active tests as the Hop tests are frequently described with varying results on validity but are highly reliable. More tests are necessary in order to make profound statements. Tests suggested in literature are several hop tests, strength test and a subjective questionnaire such as the CKRS.

Introduction

Soccer is worldwide one of the most popular sports with 200.000 professional players and about 240 million amateur players.[1] Beside the health aspects of sports, injuries can occur. Over the period 2000 till 2002, 930.000 injuries among soccer players were noted.[2] The majority of these injuries were located in the lower extremities (61% to 90%)[3] and about 20% is located at the knee.[4] One of those knee located injuries is the anterior cruciate ligament (ACL) tear. This is a severe disabling injury, which, after reconstruction, results in absence from soccer for approximately 6 months.[5] Before returning to sports, an intensive rehabilitation takes place. The main aims of this rehabilitation process are to reach static and functional stability and a complete range of motion, to improve strength and the player's functional level and to prevent the risk of recidivism. To identify an athlete's ability to tolerate the physical demands of a sport specific activity different outcome measures are developed.[6] No currently known outcome measure is capable of measuring all aforementioned parameters in one test. Therefore a combination of tests is necessary to enable a more complete comprehensive evaluation of outcome. So far, no consensus is reached on which measure or combination of measures is the most useful in assessing the amount of progress during rehabilitation or functional activity level following ACL reconstruction.[7] Important aspects when choosing a test is that it should be standardized, valid, reliable and responsive to change over time as well as being clinically relevant.[8]

In this review different outcome measures which assess functional capacity, determined as strength, speed, agility, coordination, flexibility, stability and endurance, are reviewed on reliability and validity. The following research questions will be considered: 1) What outcome measures are known in literature to assess functional capacity during rehabilitation after ACL reconstruction? 2) Are the outcome measures valid and reliable? 3) How sensitive are the outcome measures, during the rehabilitation phase?

Methods

With a predefined search string the search was conducted in the databases of PUBMED, the Cumulative Index to Nursing and Allied Health Literature (CINAHL), the Excerpta Medica Database (EMBASE) and Cochrane until 14 November 2008. The search string contained anterior cruciate ligament, the functional capacity terms (strength, speed, agility, coordination, flexibility, stability and endurance), pain, outcome measures, validity and reliability. All terms were used as Mesh headings or emtry tools when possible. If thesaurus suggested otherwise, other terms were used. The search strategy can be requested by the author.

The selection of the studies was done by two independent researchers (KG, IP). Screening was done by title, abstract and keywords. Included studies were analysed for full text. If the full text articles were not available, the authors were contacted. Each trial was independently assessed and the relevant data were extracted by the two independent reviewers (KG, IP). Any differences in selection or data extraction were resolved by discussion and if discussion remained a third independent researcher was asked to make a final decision. Articles were included conform the following inclusion criteria: 1) patients have undergone an ACL reconstructive surgery and are over the age of 16 years, 2) all sorts of prospective and retrospective studies will be included, 3) all studies should involve outcome measures, measured on functional capacity patients after ACL reconstruction, 4) articles should be written in Dutch, English or German. Articles were excluded if 1) (intra-)operative, anaesthesiology or in vitro based outcome measures were used, 2) if image techniques as MRI or CT scans were used in order to determine the outcomes and 3) if the first follow up was beyond 1 year post surgery.

Results

The search strategy yielded 143 articles. After the first screening on title, abstract and keywords 58 articles remained. The 58 articles were read full-text and screened on in- and exclusion criteria. Thirteen articles were left after screening

the full text. Out of the remaining thirteen articles, another fifteen articles appeared to be of interest by screening the references from the included articles. Out of these fifteen studies three studies met the inclusion criteria. A total of sixteen studies remained for the review. The flowchart is shown in figure 1.

The sixteen studies included a total of 847 patients after an ACL reconstruction. Seventy percent of the patients were male subjects and the average age of the patients was 27,7 years. A total of 27 knee related outcome measures were used in the studies. Appendix A shows information on the included studies. Seven of those were subjective and twenty were objective knee scoring instruments (see Appendix B). Table one shows the outcome measures evaluated on clinimetric properties according to Terwee et al. The norm values are presented in Appendix C.

Subjective outcome measures

The subjective measures were the knee injury and osteoarthritis outcome score (KOOS)[9], Tegner[10,11], Lysholm[11-13], Hughston clinic questionnaire score[14,15], Cincinnati knee rating system (CKRS)[13,16] the international knee documentation committee subjective knee form (IKDC)[13,17], and the knee self-efficacy scale (K-SES)[11].

One study described the KOOS.[9] The KOOS test-retest correlation, determined by Cronbach's α, ranged from 0.59 to 0.91. The KOOS appeared not to be valid in ACL reconstructed patients in this study. Only two out of the five domains, function in sports and recreation (p=0.516) and knee related QOL (p=0.940) fitted the Rasch model, and can therefore be used to measure changes in patients after ACL reconstruction.

The Hughston clinic questionnaire score was described in two studies. The first study[14] did not present reliability or validity outcomes solely for ACL reconstructed patients. The second study[15] showed high correlation with biomechanical testing. Biomechanical testing consisted of walking and walking up and down stairs. This study showed that significant changes were found in early stages after ACL reconstruction ($p< 0.001$) and implied that the assessment

becomes less challenging after 24 weeks and indicates that functional testing becomes more appropriate.

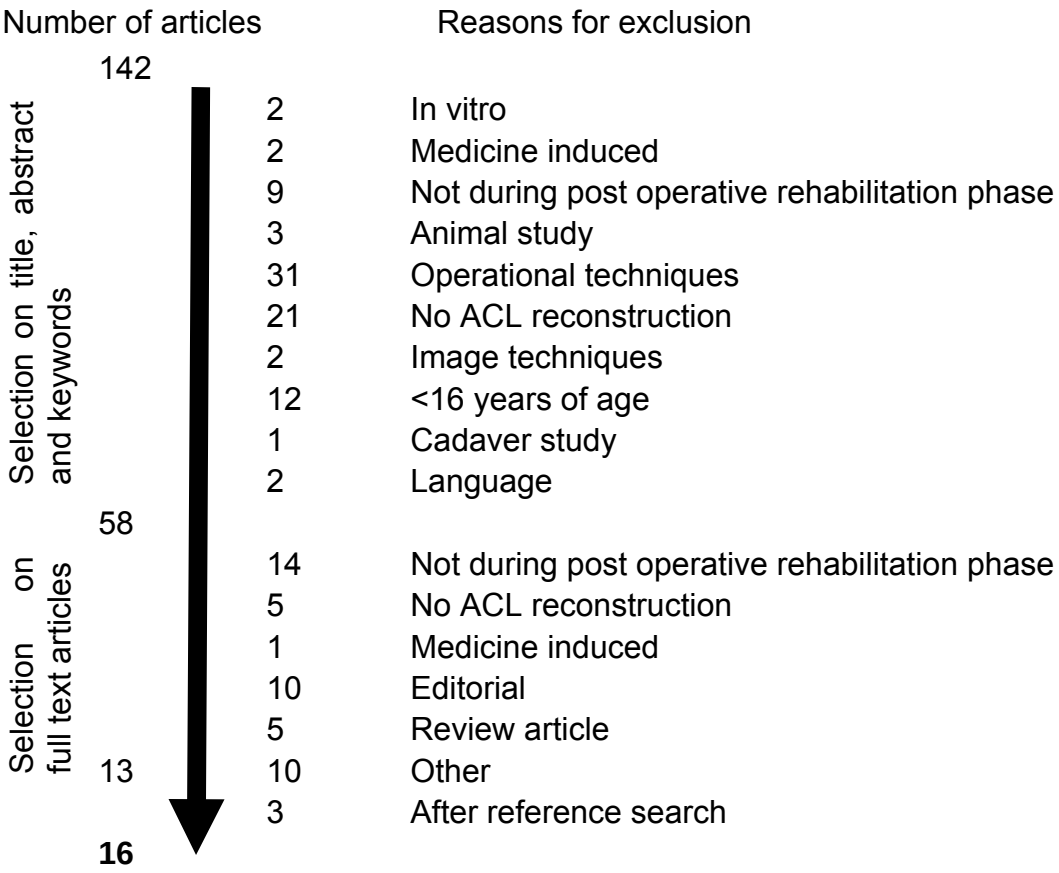

Figure 1 selection of literature

One study included the K-SES[11] but no data about validity or reliability were provided. According to Thomeé et al., the K-SES can pre-operatively be used as a predictive measurement for returning to sports.

The Italian version of the IKDC[17] showed good results on test-retest reliability with an ICC of 0.90. The internal consistency was expressed by a Cronbach's α of 0.91. Validity was measured in the study by Risberg et al..[13] High correlations were found between the Lysholm score and the CKRS (range 0.78 to 0.86) and between the IKDC 2 (symptoms) and the CKRS (range 0.69 to 0.76). The correlation between the Lysholm and the IKDC 2 ranged from 0.60 to 0.69 and

was therefore moderate. The final IKDC showed low correlations with the Lysholm and the CKRS. The scores ranged between 0.40 to 0.60 and 0.47 to 0.55 respectively within one year after surgery. IKDC validity was only shown in IKDC2, IKDC3 on extension deficit and IKDC 4 at all follow ups (range 0.72 to 0.85). IKDC 1 had lower criterion validity at 3 months after surgery 0.56, compared to 6 months or one year were the validity seemed high (0.75 and 0.77). For IKDC3, which involves knee flexion, correlation was high at 3 months (0.70), but low in 6 months (0.49) and at one year (0.37).

One study[16] showed a high ICC (0.97) on the Cincinnati knee rating system. No validity was measured.

Objective outcome measures

The objective outcome measures are divided in three categories. The first are the main strength tests, including the Biodex[19,20], Cybex[21,22] and three power tests[10], namely the knee-flexor-, knee-extensor-, and the leg-press power test. Second laxity tests, which includes the KT-1000 arthrometer[13,23] and the Stryker's laxity test[12]. The third group consists of the hop tests in which neuromuscular control, strength and confidence in the limb are measured.

Strength

No validation or reliability was measured in the studies using the Cybex[21,22] and the Biodex.[19,20] For the power tests no validity or reliability was measures in patients with an ACL reconstruction.[10]

Laxity

The KT-1000 is found to be reliable, showing high intra observer reliability with ICCs ranging from 0.98 to 1.0. The inter observer reliability however, was low ICC=0.53. The validity of the outcome measure was not provided.[11,13] The study in which the Stryker laxity tester was used[12], did not study reliability or validity.

Hop tests

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Three studies gave reliability results for the crossover hop. The intra observer reliability ranged from ICC 0.84 to 0.98.[16,18,19] The one legged hop for distance, the vertical jump and the six metre timed hop test were mentioned in two studies. The intra observer reliability (ICC) ranged respectively from 0.91 to 0.92[18,19], from 0.92 to 0.94[16,19] and from 0.82 to 0.96.[16,18] The intra observer reliability of the stair hop showed an ICC Of 0.96[16] and for the triple hop for distance an ICC of 0.93 was found.[18]

TAK

The consistency of the intra observer reliability was calculated by kappa coefficient (k) and showed moderate to good consistency. Kappa ranged from 0.43 to 0.65 except for test 4 which had a poor result with a kappa of 0.34. The correlation between the deficiency in functional capacity according to the TAK and the difference in isokinetic quadriceps muscle strength between right and left leg was moderate to good (r_s = 0.72 – 0.88) in all tests.[19]

Time line

The outcome measures used in the different studies placed in time are shown in table 1. This indicates the sensitivity of the outcome measures. Do the outcome measures reach their maximum scores early in the rehabilitation or are not the reached at all?

Before the third month of rehabilitation only the Hughston clinic questionnaire and the KT-1000 were used. From there on more physical tests, such as the different hop tests and the Cybex were used.

Patients with a reconstructed ACL scored 74 points on the Hughston clinical questionnaire prior to the surgery. At 2 weeks post surgery they scored 42, at 6 weeks 59, at 12 weeks 72, 80 at 6 months and 88 out of 100 at 9 months.[14] Another study measured the Hughston clinical score at 2,6 and 24 weeks post surgery. The mean scores were 46.2, 61 and 70 respectively.[15]

Table 1 Clinimetric properties of the outcome measures

Questionnaires	Content validity	Internal consistency	Criterion validity	Construct validity	Agreement	Reliability	Responsiveness	Floor or ceiling effect	interpretability
TAK1	+	0	0	+	0	+, -	0	0	0
KOOS	+	?	0	?	0	?	0	0	0
Hughston clinic questionnaire	+ ; ?	0; 0	?; ?	+; +	0; 0	+; 0	?; 0	0; 0	?; 0
CKRS6;11	?; +	0; 0	?; ?	+; ?	0	+; 0	0; 0	+; 0	?; ?
IKDC9;11	+; +	?; 0	?; ?	?; ?	0	+, 0	0; 0	+; 0	?; ?
Lysholm11	+	0	?	?	0	0	0	0	?
K-SES13	+	0	0	+	0	?	0	-	0
Knee extension power test	+	NR	0	0	0	+	0	+	?
Knee flexion power test	+	NR	0	0	0	+	0	+	?
Leg press power test	+	NR	0	0	0	+	0	+	?
Single hop for distance10;14;15	+	NR	0	?; 0;+	0	+; +	?;?;0	+	?
Square hop 15	+	NR	0	+	0	+	0	+	?
Side hop 15	+	NR	0	+	0	+	0	+	?
Drop jump double hop 15	+	NR	0	+	0	+,-	0	+	?
Vertical jump 15	+	NR	0	+	0	+	0	+	?
6 meter timed hop10	+	NR	0	?	0	+	?	+	?
Triple hop for distance10;11;14	+	NR	0	?;?; 0	0	+	?	+	?
Crossover hop for distance10	+	NR	0	?	0	+	?	+	?
Stairs hopple test11	+	NR	0	?	0	0	0	0	?
Side step test 14	+	NR	0	0	0	0	0	0	?
Carioca run 14	+	NR	0	0	0	0	0	0	?
Shuttle run 14	+	NR	0	0	0	0	0	0	?
KT-100011;12	+; +	NR	0; 0	?; ?	0; 0	0; +	0; 0	0; 0	?; ?
Stryker laxity tester	+	NR	0	?	0	?	0	0	?
Goniometer11	+	NR	0	?	0	0	0	0	?
Cybex	+	NR	0	0	0	0	0	0	?
Biodex	+	NR	0	0	0	0	0	0	?

TAK = Test for athletes with knee problems, KOOS = Knee injury and osteoarthritis outcome score, CKRS = Cincinnati knee rating system , IKDC = international knee documentation committee subjective knee form, K-SES = knee self-efficacy scale,
Rating: + = positive, 0 = intermediate, - = poor, ? = no information available, NR = not relevant

At 3, 6 and 12 months after surgery Risberg et al.,[13] tested 109 patients on 4 aspects of the IKDC, the CKRS, the Lysholm score, satisfaction using a VAS, KT-1000, ROM, triple jump test and a stairs hopple test.

Within one year no significant changes were found in IKDC 1, 2 and 4 which consider patient subjective assessment, symptoms and ligament examination.

Patients' satisfaction did not change significantly and ranged from 73.1 to 74.6.

Laxity testing with the KT-1000 gave no significant differences and ranged from 0.92 to 1.9mm.

Table 2 Follow-up time after reconstruction per outcome measure

weeks	Hughston	KT-1000	IKDC	Lysholm	CKRS	Hop tests	Cybex	KOOS	Tegner	Power tests	Biodex
2	x										
5		x									
6	x										
12	x	x	x	x	x	x					
13						x	x				
16						x					
20								x			
22						x					
24	x										
26						x	x		x	x	
27											x
36	x										
52				x	x	x			x		

IKDC 3, considering ROM, showed significant changes. The ROM was divided in extension deficit and flexion deficit. The extension deficit ranged from 3.1 to 0.9 degrees and resulted in significant changes ($p < 0.001$) between the 3rd and 6th month. The same is found for the flexion deficit, which ranged from 126.7 to 135.5.

The Lysholm score ranged from 79.6 to 88 and showed significant changes ($p < 0.05$) between the 3rd and 6th month.

The CKRS ranged from 66.6 to 82.1 and showed significant changes ($p < 0.001$) between the 3rd and the 6th and the 6th and the 12th month.

Risberg et al.,[13] also included hop tests in their study. The two hop tests were done at 6 months and one year after surgery. The LSI changed significantly for

both hop tests ($p < 0.001$). The triple jump increased from 92.3 to 95.8 and the stairs hopple test from 82.4 to 90.5.

Reid et al.,[18] measured patients at 16 and 22 weeks after surgery on the single hop, the 6 metre timed hop, the triple hop and the crossover hop. Around the 16th week three tests were done in order to rule out training effects. The LSI at week 16 was 82.1% for the single leg hop, 82.4% for the 6 metre timed hop, 84% for the triple hop and 85.8% for the crossover hop. Six weeks later the LSI significantly changed ($p=0.01$) for all hop test except the timed hop ($p = 0.17$) to respectively 88.5%, 89.5%, 87.4% and 87.7%. On all hop tests an abnormal LSI (> 10% difference) was found.

Discussion

In this review 27 different outcome measures were found in the literature to determine functional capacity in the first year after ACL reconstruction. Seven were subjective and twenty were objective measures. The subjective measures were the KOOS, IKDC, Lysholm, Tegner, Hughston clinic questionnaire score, CKRS and the K-SES. Of all these measures the Lysholm, Tegner, Hughston clinic questionnaire and the CKRS were found to be valid. The Hughston clinic questionnaire however, showed to be used up to the 24th week after reconstruction because then its maximum score is achieved.[15] Given that the rehabilitation after ACL reconstruction lasts more closely up to 9 months, a more sensitive measurement could be preffered. This partially correlates with outcomes by Shaw et al.,[24] who stated that most outcome measures have not been adequately tested on reliability or validity. According to Shaw et al.,[24] the IKDC and the Lysholm are reliable and show construct, concurrent and criterion validity, where studies included in this review showed moderate to good results on the reliability of the IKDC and the KOOS, but scored low on validity. The Lysholm, Tegner and K-SES were not tested on reliability or validity in these studies. The CKRS showed good results on the reliability but validity was not explicitly tested in these studies.. Barber-Westin et al. {636} studied the validity aspects in 250 ACL reconstructed patients, 50 patients with other knee injuries

and 50 healthy subjects. There appeared to be very good construct validity were 8 out of 9 hypotheses were confirmed. Item-discriminant validity was found in 94% of the comparisons between the CKRS items and Muscle strength, age, anterior-posterior displacement, patellofemoral crepitus, flexion and extension.

Marx and co-workers [30] compared the Lysholm Knee Scale, the subjective components of the Cincinnati Knee Rating System, the American Academy of Orthopaedic Surgeons Sports Knee Rating scale, and the Activities of Daily Living scale of the Knee Outcome Survey. They found reliability was high for all scales, with ICC's ranging from 0.88 for the Cincinnati Knee Rating System to 0.95 for the Lysholm Knee Scale. With regard to validity testing, all four knee rating scales correlated well with both clinician and patient ratings of severity. Responsiveness, measured with the standardized response mean, ranged from 0.88 for the Cincinnati Knee Rating System, to 1.1 for the Activities of Daily Living Scale. They concluded that all four scales are acceptable for use in clinical practice and research. Currently, however, the only knee specific rating system to have undergone stringent validity and reliability evaluation is the Cincinnati Knee Rating System.[25] It is unique among knee-specific rating scales, in that it is the only subjective score that has been gone through rigorous statistical reliability, responsiveness and validity evaluation in a large population that included patients with uninvolved, ACL involved and ACL reconstructed knees.[13,25]

Objective knee scores

The 20 objective knee scores contain laxity (2), strength (5) and hop (13) testing. No validity was given for either the laxity or the strength tests. Reliability was proven to be good for the laxity test and for the power test. Both Cybex as Biodex have not been tested in these studies but are described often as the golden standard in isokinetic testing.

Functional tests are designed to imitate functional demands of sporting activities. However, functional tests are pre-determined, planned and task orientated, while sporting movements are unpredictable requiring automatic responses to changing environments.[26] Although functional test performance is often used as

a guide for returning an injured athlete to sport, there is little evidence that satisfactory performance during functional testing will translate into safe and competent return to the unpredictable and uncontrolled sporting environment.[6]

A variety of hop tests have been described including: Single leg hop for distance (7), triple jump test (5), vertical hop (3), stair hop (2), one leg one step leap test, 6 metre timed hop, cross over hop, drop jump followed by a double hop for distance, counter movement jump, 30s one leg side jump, side step test, side hop, square hop. Further functional tests were the Shuttle run and the Carioca test.[21]

Of these, the single and triple hop tests for distance have been thoroughly investigated in terms of reliability and validity. Additionally, a number of authors have highlighted that a single functional test may not be sensitive enough to detect performance limitations and that at least two functional tests should be used.[10,27]

This review also showed that outcome measures which require physical activity are not used before the twelfth week of the rehabilitation process. This makes sense according to the grafts recovery. The graft endings normally heal to the bone tunnels between the sixth and the tenth week, but the graft itself is at its weakest. In about thirteen weeks the graft is completely incorporated in the femur and tibial bone. The graft tissue now reacts to tensile stress and becomes more ligamentatious.[28]

Due to a strict in and exclusion criteria few studies remained and therefore several outcome measures are only mentioned once or twice. The statement on responsibility and validity might therefore be less conclusive. Another problem in comparing data is the differences in testing procedures mainly in hop testing. Some protocols did and some did not allow participants to use their upper limps to give more power and balance.

Conclusion

A large variety in outcome measures is used in the evaluation of patients after anterior cruciate ligament reconstruction. Up to now, no consensus has been

reached in order to select an appropriate set of outcome measures during the rehabilitation. Tests suggested in literature are several hop tests, strength test and a subjective questionnaire such as the CKRS, the Tegner and the Lysholm score. However, more research has to be done. Studies with large populations and appropriate statistics are needed in order to establish a core set of outcome measures which can be used during the rehabilitation after anterior cruciate ligament reconstruction.

Acknowledgements

There are no conflicts of interest and no funding was received. Special thanks to dr. I van de Port for the guidance throughout the project.

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Correspondence: Kees C.D. van Geel, Department Health sciences, Physical therapy sciences, University Utrecht, the Netherlands.
Email address: k.vangeel@umcutrecht.nl

Appendix A Included studies

Study	Design	Description of population	N (♂/♀)	Outcome	Outcome measure	Follow-up time	Main results
Björklund et al. (2006)	Prospective observational study	ACL injured age 32 (19-50) ACL reconstructed age 30 (18-50) healthy athletes 25 (15-38)	14 (8/6) 31 (24/7) 14 (8/6)	stability springiness strength endurance coordination muscle torque of the quadriceps inter and intra reliabilty	TAK Biodex		 The correlation between isokinetic quadriceps muscle strength and functional tests in TAK was moderate. This criterion-based test method for athletes with knee injuries showed good inter-rater reliability and acceptable intra-rater reliability for the physiotherapists' assessment. The consistency of the patients' ratings was low.
Comins et al. (2008)	Retrospective observational study	Patients after ACL reconstruction at 20 weeks. Mean age 29,4 years	200 (130/70)	pain knee symptoms function in ADL function in sports or recreation knee-related quality of life	KOOS	20 weeks post OK	KOOS in it's current form is not valid in ACL reconstructed patients Out of the five sub domains, pain, knee symptoms, function in ADL, function in sport/rec and knee related QOL, only the last two can be used to measure change in their respective constructs
Fischer-Rasmussen et al. (1999)	Observational study	ACL injured ACL reconstructed bone-patella-bone or semitendinosus tendon Healthy subjects	20 (11/9) 18 (9/9) 3 15 20 (11/9)	Performance Performance laxity load load proprioception	Tegner Lysholm Stryker's laxity tester One leg triple jump test One leg one-step leap test Proprioception bench		Patients with ACL reconstruction scored higher on performance Laxity measurement differed ($p<0.05$) between injured and non-injured joints Both test showed impairments at the injured side ($p<0.01$) The ability to detect passive movement was reduced ($p<0.01$) in reconstructed patients
Höher et al. (1995)	Observational study	Various knee disorders one group consisted out of patients with ACL reconstruction using bone patella bone technique Healthy controls	28 (2 weeks) 28 (6 weeks) 28 (12weeks) 26 (24 weeks) 20 (36 weeks) 25	pain swelling, locking instability Sports participation Activities of daily living	Hughston Clinic questionnaire score	2,6,12,24 and 36 weeks	the reliability in healthy persons was tested in 25 persons and had a correlation of 0.86; in the knee-handicapped group, 21 patients were tested and had a correlation of 0.92. Two and 6 weeks after surgery the VAS score was significantly lower than the preoperative value ($P < 0.001$). Six weeks after surgery there was no significant difference to the preoperative score. The VAS scores estimated 24 and 36 weeks after surgery were significantly higher in comparison with the preoperative value ($P < 0.05$ and $P < 0.01$, respectively)
Hopper et al. (2002)	Retrospective observational study	Patients after ACL reconstruction using semitendinosus graft Age 26.8 ± 8.4 (16-45)	19 (13/6)	Satisfaction and knee perception strength	Cincinnati knee rating system and VAS 6 metre timed hop Cross over hop	12 months	ICC s ranged from 0.82 to 0.98. No significant differences were found between the CKRS and the VAS between the testing occasions ($p=0.53$ and 0.88 respectively) Except for the vertical hop all test scored significant different

					Stair hop Vertical hop		between the test occasions. An improvement was noted in the second test occasion. LSI scores for the hop tests ranged from 88.8 to 96.6%
Hooper et al. (2000)	Observational study	ACL2 reconstructed assessed 2 wk after reconstruction of the ACL (19 having bone-patellar tendon-bone grafts, 11 bone patellar tendon-bone grafts in combination with a ligament augmentation device). ACL6 had 4 weeks physical therapy ACL24 Healthy controls	37 (29/8) 37 (29/8) 8 5/3) 8(6/2)	walking ascent and descent stairs	The original Hughston Clinic questionnaire was modified from its American English form to British English Biomechanical testing	2,6,24 weeks post surgery	In stair descent and descent, the peak flexion moment, peak power and energy variables were highly correlated to the Hughston questionnaire at week 2 and 6. The amount of change in the Hughston questionnaire from 2 to 6 weeks post OK was able to significantly predict the amount of change in knee flexion at toe of and the peak concentric power during stance. In the ACL24 group the Hughston questionnaire was significantly correlated to the amount of knee flexion at heel strike and terminal stance while walking. Similar findings were there for descending stairs. Knee flexion at initial toe contact while ascending stairs was also significantly correlated. There were no significant relationships between the Hughston questionnaire score and knee kinetics in the ACL 24 group.
Neeter et al. (2006)	Observational study	Three groups of patients ACL injured ACL reconstructed Healthy subjects	 23 (14/9) 44(30/14) 13 (7/6)	Physical activity Physical activity Muscle power Muscle power Muscle power reliability	Physical activity scale Modified Tegner scale Knee-extension power test Knee-flexion power test Leg-press power test Test retest	6 months after injury or surgery 10.5 ± 7.9 days	The reliability of the test battery showed ICC ranged from 0.94 to 0.98 CI from 0.86 to 0.99 and SEM from 6 to 10%. Patients who had undergone ACL reconstruction were significantly stronger on the uninjured side in the knee extension and leg press test. For the knee extension test 86% had an abnormal LSI, for the knee flexion test the LSI was 42% and in the leg press test 61%. 95% of the patients had an abnormal LSI after 6 months.
Padua et al. (2004)	Observational study	All patients with ACL reconstruction 24 years range 18 to 42	50 (41/9)	Reproducibility Content validity	IKDC subjective knee form SF-36	5 day interval	10 minutes duration, patients considered clear and relevant towards their knee conditions. IKDC item responses were 59.38; SD 22.88 Test-test reliability showed good results ICC 0.90
Reid et al. (2007)	Prospective observational study with repeated measures	All patients were reconstructed with a semitendinosus and gracilistendon autograft 25.6 years ± 9.2 (15-42)	42 (23/19)	Neuromuscular control, strength and confidence in the limb	Single hop for distance 6-m timed hop Triple hop for distance Crossover hop for distance Lower extremity functional scale (LEFS)	3 tests within 16th week Final 4th test at week 22	All hop test scores showed a significant effect ($p<0.001$) in time between operated and non-operated leg. Hop tests with the operated leg showed significantly different values in favour of the second test ($p<0.01$). No differences were measured between the 2nd and the 3rd measure and with exception of the timed hop significance was measured between the 2nd and the 4th test ($p<0.001$) In the non operated leg no significance was found between the 1st and the 2nd measure, but no difference was found between the 2nd and the 4th test in exception for the crossover hop ($p<0.035$) Reliability in all the hop tests was excellent and the ICC ranged from 0.82 up to 0.93. Longitudinal validity showed significant differences in the limb symmetry index between the operated and the non-

							operated leg. Correlations between performance-based and self report measures ranged from 0.26 to 0.58.
Risberg et al. (1998)	Observational study	Patients with bone-patella-bone reconstruction. 27.8 years (14-50)	109	patient subjective assessment symptoms Range of motion ligament examination patients' satisfaction range of motion laxity strength strength	IKDC 1 IKDC2 IKDC3 IKDC 4 IKDC final Lysholm Cincinnati knee score VAS Handheld goniometer KT-1000 knee arthrometer Triple hop test Stairs hopple test	3,6,12 and 24 months	IKDC 1 and 2 did not differ significantly during the first years post surgery. IKDC improved significantly from 3 to 6 months ($p<0.05$) and remained unchanged thereafter. The Cincinnati knee scores changed significant during all follow-up moments (3-6 $p<0.001$; 6-12 $p<0.001$). Lysholm and the ROM only differed within 3 to 6 months ($p< 0.05$;$p<0.001$) Patient's satisfaction and laxity did not change at each follow-up. The triple jump and stairs hopple test increased significantly from 6 months to 1 year ($p<0.001$) High correlation were measured between the Lysholm and the Cincinnati score (0.78-0.86) and between Cincinnati and IKDC2 (0.69-0.76). Moderate correlations were found between Lysholm and IKDC2 (0.60-0.69). The correlations between the IKDC1 and the Lysholm and Cincinnati score respectively increased during follow-up. Criterion validity was high for IKDC2 and 4 but low for IKDC 1 and 3.
Thomeé et al. (2007)	Observational study	Patients received bone patella bone or hamstring tendon autograft reconstructions. Mean age 29.7 (16-55)	38 (25/13)	Pre injury physical activity Self-efficacy of knee function Physical activity Symptoms Muscle function lower limb symmetry index (LSI)	Tegner K-SES Tegner, PAS Lysholm One-leg counter movement jump (CMJ) one-leg hop for distance 30-s one-leg side jump	pre OK and 1 year after	The K-SES could be of predictive value for the return of sports one year after reconstruction.
Holcomb et al. (1993)	Observational study	All patients received bone-patella-bone age 27.6	19 (13/6)	Laxity	KT-1000	5 weeks post OK	Intra tester ICC ranged from 0.98 to 1.0. and the standard error of measurement differed from 0.0 up to 0.28mm. The arthrometer however was not removed between measures. Intertester ICC and SEM were 0.53 and 1.2mm, which is a poor result
Keays et al. (2000)	Longitudinal prospective study	All patients received bone-patella-bone age 27 (19-38) No professional athletes	32 (22/9)	strength agility strength, confidence and dynamic muscle co-activation	Cybex 2 isokinetic dynamometer shuttle run carioca side step test single hop for distance triple hop for distance	1 week pre OK and 6 months post OK	Before surgery significant differences were noticed between the injured and the uninjured leg. Quadriceps at 60° per second deficits 12% and 9% at 120° per second in the injured leg. No differences between sides for hamstring strength. After surgery quadriceps deficits 28% at 60° per second and 22% at 120° per second in the injured leg. There was a significant difference between the hamstring strength of the injured and the uninjured

							leg, but that was due to strength gaining in the non-injured leg. Strength compared before and after surgery showed no significant differences in the uninjured leg, however the hamstrings at the uninjured leg had gained unexpected more strength. In the injured leg quadriceps strength showed significant lower values on strength at both speeds. 18 and 14%. All the agility tests showed significant improvement after surgery. Shuttle run 10%, side step 17% and carioca 23%. Hop tests had no significant changes for the injured leg. Single hop increased 5% triple hop made no difference.
Gustavsson et al. (2006)	Longitudinal prospective study	Healthy controls age 28 ± 4 ACL injured age 31 ± 9 ACL reconstructed age 27 ± 7 Tegner score 8.0 (2.0)	15 (9/6) 30 (18/12) 35 (25/10)	strength, confidence and dynamic muscle co-activation	single hop test vertical jump hop for distance drop jump followed by a double hop for distance square hop side hop	3-13 days between test 1 and 2. 3-19 days between test 2 and 3. ACL r was tested 6 months post OK	The test retest reliability of the 5 hoptest showed an ICC from 0.85 to 0.97 an d had a methodological error ranged from 3 to 6%. A significant difference was found on all hop tests between the injured and the non-injured leg in ACLr patients. Patients with an ACL reconstruction had an significant different side to side difference compared to healthy controls. The lower limb symmetry index for the five hop tests ranged from 14 to 49% in patients with ACL reconstructions. Factor analysis showed two factors: maximal hop tests (vertical jump, hop for distance and drop jump followed by a double hop) and endurance hop test (square hop and side hop)
Petschnig et al. (1998)	Longitudinal prospective study	Healthy controls age 28.2 ± 6.4 ACL reconstructed with bone patella bone age 27.8 ± 9	50 (50/0) 30 (30/0)	Strength	Vertical jump Single hop for distance Triple hop for distance Cybex 6000	13 weeks post OK	Significant difference existed between the operated and the non-operated leg on all functional performance and isokinetic tests. The correlation between the one legged and the two legged vertical jump tests was r=0.7149 LSI was in the vertical jump 46%, single hop 73%, triple hop 71% and the peak torque showed 54.7%
Østerås et al. (1998)	Retrospective observational study	All patients underwent Clancy plastique, contralateral bone-patella-bone reconstruction High level athletes age 24.1 (15-48)	90 (0/90)	Strength	Biodex	27 ± 6 weeks post OK	Testing 240°/s showed 49.6 Nm in the operated leg hamstring muscle, which gives 0.1% deficit. 13.3% of the subjects showed more than 10%. During 60°/s hamstring strength was 74.9Nm which corresponded with a 3.1% deficit. Now 17.8% had more than 10% deficit. Testing 240°/s showed 65.9 Nm in the operated leg on quadriceps strength, this sows a 21% deficit and a significant difference between the operated and the non-operated leg. 60% had more than 15% deficit. During 60°/s quadriceps strength was 117.7Nm which represented 28.7% and was a significant difference . Here, 12.2% had more than 15% deficit.
ACL = anterior cruciate ligament, TAK = Tests for athletes with knee injuries; VAS = Visual analogue scale; IKDC = international knee documentation committee subjective knee form							

Appendix B Outcome measures

Subjective measurements

KOOS (Knee Injury and Osteoarthritis Outcome Score)

The Knee Injury and Osteoarthritis Outcome Score (KOOS) was constructed on the basis of a literature review, expert panel, and pilot study. The KOOS covers five dimensions that are reported separately: pain, symptoms, activities of daily living, sport and recreation function, and knee-related quality of life.[9]

Tegner

The Tegner covers activities in daily life and recreational and competitive sports graded from 0 to 10 (Table 3). Activity levels 5-10 can be achieved only if the patient takes part in recreational or competitive sports.[10,11] Interrater reliability is 0.97.[29]

The modified Lysholm scale

The modified Lysholm scale, as described by Tegner and Lysholm, is an eight-item questionnaire that was originally designed to evaluate patients following knee ligament surgery. It is scored on a 100-point scale, with 25 points for knee stability, 25 points for pain, 15 points for locking, 10 points each for swelling and stair-climbing, and 5 points each for limp, use of a support, and squatting.[10] ICC is 0.95.[30]

The Hughston Clinic Questionnaire

The Hughston Clinic Questionnaire12 was used to evaluate the subjects' self-assessment of their knee condition. This questionnaire consists of 28 questions in which people are asked to respond by marking a horizontally orientated 10-cm-long visual analogue scale (VAS)

The test retest reliability is 0.86 in 25 sports students.(5) In knee handicapped the reliability 6 weeks after surgery was 0.92. The VAS score was assessed in 21 patients with knee disorders such as medial and lateral meniscal lesions, chronic anterior cruciate ligament insufficiency, degenerative joint disease with second and third degree lesions of cartilage (Outerbridge classification) and anterior knee pain syndrome (chondropathia patellae).[14,15]

The Cincinnati Knee ligament rating system

The Cincinnati Knee ligament rating system includes physical examination and instrumented testing as well as a four-part evaluation format to assess symptoms and functions. This includes 1) a symptom rating scale assessing pain, swelling and partial and full giving way, depending on six specifically defined activity levels; 2) assessment of function by determining how each patient performs certain activities (including walking, climbing stairs, squats, running, jumping an pivoting); 3) a sports activity rating scale that stratifies function depending on four levels of sport type and level and frequency of participation; 4) a final rating system that provides an overall grade defined by the lowest score in any individual category. A pre- and post injury occupational rating scale is also used to categorize lower extremity activity according to defined functional gradients.[31]
ICC is 0.88.[30]

The IKDC Subjective Knee Form

The IKDC Subjective Knee Form was designed as an evaluative measure to detect improvement or deterioration in symptoms, function, and sports activity experienced by patients with a variety of knee conditions, including ligament and meniscal injuries, articular cartilage lesions, and patellofemoral pain.[13,32] The IKDC form consists of eight variables: patient subjective assessment (IKDC1), symptoms (IKDC2), range of motion (ROM) (IKDC3), ligament examination (IKDC4), compartmental findings (crepitus patellofemoral), harvest site pathology, X-ray findings, and the one-leg-hop test (a functional knee test). Only the first four variables (IKDC1–4) are graded as: normal (1), nearly normal (2),

abnormal (3), or severely abnormal (4). The worst grade from each of the four IKDC variables (IKDC1–4) is used to determine the final evaluation (IKDC-final). In this study, the IKDC1–4 and the IKDC-final were evaluated because these are the reported variables in the IKDC form.[33]

The K-SES

The K-SES consists of 22 items in four sections and is a self administered instrument. In sections A – daily activities (seven items), B – sports activities (five items) and C – knee functions tasks (six items), the patients report how confident they are about being able to perform the task right now, despite knee pain/discomfort. In section D – knee function in the future (four items), the patients report how confident they feel about their future capabilities. Patients gave their response to the 22 items using an 11-grade Likert scale, ranging from 5 not at all certain about the task to 105 very certain about the task. The sum of item scores was calculated and divided by the number of items.[11,34]

Objective knee scores

Instability

The Stryker Knee Laxity Tester

The Stryker Knee Laxity Tester employing maximum manual effort was used to measure laxity and recorded as the difference in anterior–posterior (AP) translation between the symptomatic and asymptomatic knees, at 90 degrees of flexion.[23,35]

KT-1000 Knee Ligament Arthrometer

The KT-1000 Knee Ligament Arthrometer (KT-1000; MEDmetric Corp, San Diego, California) has emerged as the most commonly used and frequently studied knee ligament–testing device. Over time, it has retained its original design and provides objective measurement of the sagittal plane motions of the

tibia relative to the femur, thereby providing information useful for the clinical assessment of anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) integrity.[35]

Strength

Biodex

With the isokinetic dynamometer Biodex it is possible to practice both testing and training, with different angular velocities, in order to measure maximal or endurance muscular function.[20] Intraclass correlation coefficients (ICCs) ranged from 0.88 for both extension and flexion peak torque to 0.97 for extension peak torque and 0.98 for flexion peak torque.[37].

Cybex isokinetic dynamometer

The Cybex isokinetic dynamometer has been described as an equipment in determining strength.[21] The ICC values of the Cybex 6000 range from 0.82 to 0.91 for peak torque, from 0.76 to 0.89 for total work and from 0.71 to 0.88 for average power.[36]

Power tests

The three power test were performed on isotonic weight training machines in order to measure muscular power. A linear encoder is connected to the weight allowing for measurements of time and displacement. So velocity, acceleration and average power can be calculated. When tested in healthy subjects, ICC ranged from 0.94 to 0.98.[10]

Single leg hop for distance

Subjects are required to stand on the involved leg and then hop as far as possible. The landing must be controlled and balanced. This means that no extra hops are allowed and the position must be hold for at least three seconds. Distance is measured from the toe at the starting point to the heel at landing.[25,27]

Triple jump test

In the triple jump test the subjects are required to make three continuous hops as far as possible.[18]

Vertical hop

Subjects start in upright position with hands placed behind the back. Subjects quickly bent the knee as much as desired and then immediately jump upwards.[16,22,25,27]

Counter movement jump

Same as the vertical jump only now the subject is allowed to use the arms.[11]

Stair hop

Subjects are required to hop up and down three steps on a three step platform. Then the subjects turn around at a fixed marker 1 meter from the platform and hop back over the platform through the finish line. Time is recorded in seconds.[16]

One leg one step leap test

The subjects are required to jump with the involved leg up and down a 14 centimetre height step until exhausted.[12]

6 metre timed hop

Subjects are required to hop as fast as possible between timing gates placed 6 meters apart. Time is recorded in seconds.[16,25]

Cross over hop

Subjects are required to perform three hops for maximum distance, while crossing a 15 cm wide line between each hop. The involved leg is at the homolateral side of the line. Distance from the start line to the toe of the test leg following the third hop is measured.[16,25]

Drop jump followed by a double hop for distance

Subject starts standing with the leg to be tested on top of a 30 cm height box with the hands behind the back. At 45 centimetres from the box a starting line is marked. The subject jumps of the box, not landing over or on the starting line, and then immediately hops two times as far as possible. The landing must be controlled and balanced.[27]

Side step test

The side stepping test required the patient to move laterally without crossover. At the end of each length, the patient touches a line on the floor with the foot and changed direction.[21]

Side hop

For the side hop the subjects are required to hop on the leg to be tested over two lines, 40 centimetres apart. Within 30 seconds, as many jumps as possible have to be made.[27]

Square hop

The subjects stand on the leg to be tested, with their hands behind their back, outside a 40·40 cm square marked with tape on the floor. A 10 cm frame is marked around the square. For the right leg, the subjects are required to jump clockwise in and out of the square as many times as possible during a period of 30 s. The number of successful jumps performed, without touching the taped frame, is recorded. Touching the taped frame is recorded as an error and, if more than 25% of the jumps have errors, a second trial of 30 s is performed after a 3-min rest period. For the left leg, the subject performs the test in a counter-clockwise mode.[27]

Shuttle run

The shuttle run test requires the patient to run forward to the end of the test area. At the end of each length, the patient touches a line on the floor with the foot of

the involved leg then turns on that leg, changing direction toward the uninvolved side.[21]

Carioca

The carioca test requires the patient to move laterally with a crossover step. The patient begins by moving from left to right and then in reversed direction covering the distance in the shortest possible time.[21]

Tests for athletes with knee injuries (TAK)

The TAK includes eight different demanding functional activities of increasing difficulty, rated on a ten-point scale, according to five criteria. Three of the tests are two-leg tests, and five are one-leg tests. Functional stability, springiness, strength, endurance and coordination influence the results of the two running test and the three one-leg hop tests. The patient runs in a figure of eight and runs straight forward accelerating for 25 metres and brakes within 5 metres twice (test 1 and 2). The patients jumps one-leg hop for distance, 10 hops in rapid succession as far as possible (Test 6). The patient jumps five vertical hops in rapid succession as high as possible with springiness (Test 7). The patient jumps one-leg crossover hops in rapid succession using steps as wide and long as possible on a track of 8 m (Test 8). Functional active range of motion and balance influences the results of the three squatting tests. The patient stands on one leg, flexing the knee or rising from a seated position and squats down to the floor with equal weight on both legs (Tests III, IV and V).

The inter observer reliability of the TAK was measured by a kappa coefficient between two therapists in 45 patients with ACL reconstruction and 14 healthy subjects. The study showed a good consistency (κ = 0.62 – 0.78) in all tests, except for test 1 (κ = 0.54). Good correlation was shown in all tests (r_s = 0.83 – 0.92) except for tests 1 and 4 (r_s = 0.64 and 0.68) which were moderate.

A moderate correlation was shown between the isokinetic quadriceps test (120°/s) and the therapists' assessment for all tests (r_s = 0.61 – 0.73) except in

tests 1 and 2 which showed poor correlation (r_s = 0.34 and 0.52) Correlation was slightly lower when the isokinetic test was done with 180°/s.[19]

Appendix C Quality criteria according to Terwee et al.

Property	Definition	Quality Criteria[a, b]
1 Content validity	The extent to which the domain of interest is comprehensively sampled by the items in the questionnaire	+ A clear description is provided of the measurement aim, the target population, the concepts that are being measured, and the item selection AND target population and (investigators OR experts) were involved in item selection ? A clear description of aforementioned aspects is lacking OR only target population involved OR doubtful design or method - No target population involvement 0 No information found on target population involvement
2 Internal consistency	The extent to which items in a subscale are intercorrelated, thus measuring the same construct	+ Factor analyses performed on adequate sample size (7 x no. of items and ≥ 100) AND Cronbach's α calculated per dimension and Cronbach's α values between 0.70 and 0.95 ? No factor analysis OR doubtful design or method – Cronbach's α less than 0.70 or greater than 0.95, despite adequate design and method 0 No information found on internal consistency
3 Criterion validity	The extent to which scores on a particular questionnaire relate to a criterion standard	+ Convincing arguments that gold standard is "gold" and correlation with gold standard ≥ 0.70 ? No convincing arguments that gold standard is "gold" or doubtful design or method – Correlation with gold standard < 0.70, despite adequate design and method 0 No information found on criterion validity
4 Construct validity	The extent to which scores on a particular questionnaire relate to other measures in a manner that is consistent with theoretically derived hypotheses concerning the concepts that are being measured	+ Specific hypotheses were formulated and at least 75% of the results are in accordance with these hypotheses ? Doubtful design or method (i.e., no hypotheses) – Less than 75% of hypotheses were confirmed, despite adequate design and methods 0 No information found on construct validity
5 Reproducibility		
5.1 Agreement	The extent to which the scores on repeated measures are close to each other (absolute measurement error)	+ SDC less than MIC or MIC outside the limits of agreement or convincing arguments that agreement is acceptable ? Doubtful design or method or (MIC not defined and no convincing arguments that agreement is acceptable) – SDC greater than or equal to MIC or MIC inside limits of agreement, despite adequate design and method
5.2 Reliability	The extent to which patients can be distinguished from each other, despite measurement errors (relative measurement error)	+ ICC or κ ≥ 0.70 ? Doubtful design or method (i.e., time interval not mentioned) – ICC or κ < 0.70, despite adequate design and method 0 No information found on reliability
6 Responsiveness	The ability of a questionnaire to detect clinically important changes	+ Individual SDC or group SDC less than MIC or MIC outside the LOA OR RR >1.96 OR AUC ≥0.70

	over time	? Doubtful design or method or sample size less than 50 or methodological flaws — Individual SDC or group SDC ≥ MIC or MIC equals or inside LOA OR RR ≤ 1.96 OR AUC <0.70, despite adequate design and methods 0 No information found on responsiveness
7 Floor and ceiling effects	The number of respondents who achieved the lowest or highest possible score	+ ≤15% of the respondents achieved the highest or lowest possible scores; ?Doubtful design or method; — >15% of the respondents achieved the highest or lowest possible scores, despite adequate design and methods; 0 No information found on floor and ceiling effects.
8. Interpretatability	The degree to which one can assign qualitative meaning to quantitative scores	+ Mean and SD scores presented of at least four relevant subgroups of patients and MIC defined; ? Doubtful design or method OR less than four subgroups OR no MIC defined; 0 No information found on interpretation.
MIC = minimal important change; SDC = smallest detectable change; LOA = limits of agreement; ICC = Intraclass correlation; SD = standard deviation. a + = positive rating; ? = indeterminate rating; — = negative rating; 0 = no information available. b Doubtful design or method = lacking of a clear description of the design or methods of the study, sample size smaller than 50 subjects (should be at least 50 in every (subgroup) analysis), or any important methodological weakness in the design or execution of the study.		

Isokinetic and functional testing in elite soccer players during rehabilitation after anterior cruciate ligament reconstruction

Kees C.D. van Geel, 3244040, 17/07/2009, University Utrecht, Department Health sciences, Physical therapy sciences, the Netherlands

1st Supervisor: dr. I.G.L van de Port, Utrecht University
1st Faculty supervisor: dr. T. Takken, Utrecht University
2nd Faculty supervisor: dr. M. van Brussel, Utrecht University

University Medical Center Utrecht, Department of Rehabilitation and Sports Medicine

C.D. van Geel

Bevestigt hierbij dat de onderhavige verhandeling mag worden geraadpleegd en vrij mag worden gefotokopieerd. Bij het citeren moet steeds de titel en de auteur van de verhandeling worden vermeld”

Samenvatting

Doel: Het bepalen van de kracht door middel van isokinetische en functionele tests bij professionele voetballers welke een voorste kruisband reconstructie hebben ondergaan.

Design: Retrospectieve studie

Methode: Achttien professionele voetballers uit de Nederlandse eredivisie werden gemeten op vier maanden na reconstructie en op het eind van de revalidatie. Voor het isokinetisch testen is de Cybex 6000 gebruikt. Voor de functionele tests is gebruik gemaakt van de single leg hop test, de triple leg hop test en de six meter timed hop test.

Results: De verschillen tussen de metingen op vier maanden en de metingen om het eind van de revalidatie waren allen significant ($p < 0,05$). Op het eind van de revalidatie was de gemeten kracht minder dan 10% verschillend in het aangedane been vergeleken met het niet aangedane been. Dit verschil wordt als normaal gezien. Vergeleken met gezonde professionele voetballers, bleek de quadriceps significant minder en de hamstringkracht significant groter te zijn in de patiëntengroep.

Conclusie: Op het einde van het revalidatieproces, 41 weken na reconstructie, is er nog een duidelijk krachtdeficit te zien bij professionele voetballers na reconstructie van de voorste kruisband. Het verschillen tussen het aangedane en het niet aangedane been, zijn echter kleiner dan 10% en daarmee normaal. Een duidelijke relatie tussen isokinetische tests en functionele test is niet bewezen.

.

Abstract

Objective: To determine strength through isokinetic and functional testing in elite soccer players who underwent anterior cruciate ligament (ACL) reconstruction and to determine the relation between isokinetic and functional testing.

Design: Retrospective study.

Method: Eighteen elite soccer players from the Dutch soccer league were measured at four months and at the end of their rehabilitation for isokinetic testing. Functional test were solely done at the end of rehabilitation. For the isokinetic tests a Cybex 6000 was used. Functional testing consisted out the one legged hop test for distance, the triple hop test for distance and the six meter timed hop test.

Results: Significant differences are seen between all tests at four months and at the end of the rehabilitation ($p \leq 0,05$). Strength in the ACL reconstructed leg was within ten percent range on the leg symmetry score and therefore indicated to be normal. Compared to healthy elite soccer players the patients after ACL reconstruction had significantly less quadriceps strength and the hamstring strength was significantly more.

Conclusions: At the end of the rehabilitation, 41 weeks after ACL reconstruction, the knee strength of elite soccer players do not level up to those of elite soccer players without ACL reconstruction. The limb symmetry indices, however, are above 90%. This counts both for the isokinetic as the functional testing. The relationship between these tests was not proven.

Introduction

Soccer is worldwide one of the most popular sports with 200.000 professional players and about 240 million amateur players.[1] Beside the positive health aspects of sports, injuries can occur. In the Netherlands, during the period 2000 until 2002, 930.000 injuries among soccer players were noted.[2] The majority of these injuries were located in the lower extremities (61% to 90%)[3] and about 20% was located at the knee.[4] One of those knee injuries is the anterior cruciate ligament (ACL) tear. This is a severe disabling injury, which, after reconstruction, results in absence from soccer for at least 6 months.[5]

The ACL provides 86% of the primary restraint to anterior tibial excursion. Problems stemming from extensive damage to this ligament could be chronic instability, meniscal tears, articular degeneration, and arthritic changes.[6] The aims of the treatment in patients with ACL injuries is to prevent this detrimental progression and return individuals to their pre-injury functional status. Surgical reconstruction of a damaged ACL attempts to structurally compensate for decreased knee stability. After surgery a long rehabilitation program follows consisting of reducing swelling, increasing mobility (both knee range of motion as patellofemoral glide) and strengthening exercises. Also proprioceptive and neuromuscular control drills are used in order to provide a neurologic stimulus so that the athlete can regain the dynamic stability needed in athletic competition.[7]

Increasing muscle strength is one of the main aims in ACL rehabilitation after surgery.[7-9] Follow-up studies on patients after ACL reconstruction have shown that increased muscle strength on the operated leg is associated with a satisfactory return to pre-injury activities.[6] In addition, post surgical evaluations of the quadriceps muscle have shown that increased strength in the surgically treated knee is positively associated with improved functional return.[10] Arvidsson et al.[11] found that 7.9 years after ACL reconstruction the maximum torque produced by the quadriceps was significantly less in the involved leg than the uninvolved leg for fair ($P < 0.001$) and poor ($P < 0.05$) functional groups. Maximum quadriceps torque was not significantly different in the good or excellent groups. Odensten et al.[12] found that successful return to pre injury

functional status was positively correlated (r = 0.62) with increased quadriceps strength.

Since muscle strength is an important outcome after ACL reconstruction and focus of the rehabilitation period, monitoring this outcome is relevant. In order to keep track of the progression and to evaluate a patients physical capacity concerning strength, different outcome measures are used. To determine strength an isokinetic dynamometer is useful to test muscles in an open kinetic chain.[13] Besides isokinetic muscle testing, functional tests are also used in rehabilitation after ACL reconstruction. The hop test, designed by Daniel et al.[14], was designed to assess both strength and confidence in the involved leg. Patients with inadequate hop test indices were considered at an increased risk for giving way during functional activities.[15,16] The one-legged hop tests for distance have been established as valid and reliable measurements [17-20]

So far, no consensus has been reached on the relationship between isokinetic and functional strength testing.[21,22] In addition, the author is unaware of available reference values are available for elite soccer payers during their ACL rehabilitation.

The purposes of this study were: 1) to determine strength in elite soccer players after anterior cruciate ligament reconstruction at four months and at the end of the rehabilitation, 2) to determine whether patients after ACL reconstruction had the same strength as healthy elite soccer players and 3) to examine the relationship between isokinetic knee strength and three functional performance tests in elite soccer players.

Method section

Participants

Elite male soccer players who had undergone ACL reconstruction between October 2001 and April 2009 and who had followed their rehabilitation at the Medical Department of the Royal Dutch Soccer Association, Zeist, The Netherlands were included in this study. Patients were excluded if the ACL tear was a recurrent ACL injury.

Procedure

Four months after ACL reconstruction and at the end of the rehabilitation, isokinetic testing took place. Whether the patients' knee was ready for isokinetic testing was judged by an experienced physical therapist from the Medical Department of the Royal Dutch Soccer Association. Prior to isokinetic testing each patient performed a 10 min warm-up period by aerobic ergometer cycling. Patients cycled at 70 to 80 rounds per minute with intensity equal to the patients' body weight. The patient was then seated in the testing apparatus (Cybex 6000, Lumex Inc., Ronkonkoma, New York) with a seat belt and additional straps around the pelvis, the thigh, and malleoli. The axis of the knee was placed in line with the axis of rotation of the dynamometer.

Before testing, the patient was instructed to perform a sufficient number of sub maximal repetitions of knee extension and flexion in order to become familiar with the system. The range of movement during extension and flexion was 90 degrees (approximately 5 to 95 degrees of flexion). The quadriceps and hamstring torques were measured at 30, 60, 180 and 300°/sec. Speeds up to 120°/sec are used for strength and speeds exceeding 240°/sec measure endurance. In this study only the 60 and 300°/sec were used.

Normative data for elite healthy soccer players were presented by Rahnama et al. for 60 and 300°/sec.[23] Each patient completed, under verbal encouragement, five (at 60°/sec) or twenty (at 300°/sec) maximal voluntary repetitions of alternating knee extension and flexion. The non-operated limb was tested first. At the end of testing the patient performs a cooling down session for ten minutes by aerobic ergometer cycling.

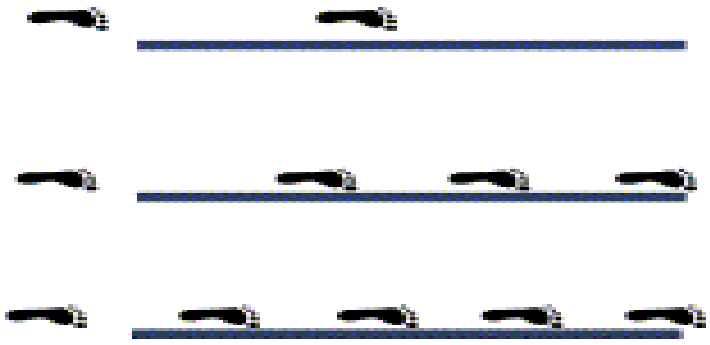
During the same week as the final isokinetic test, the functional testing took place. Prior to functional testing each patient completed a 10 min warm-up period by aerobic ergometer cycling. Patients cycled at 70 to 80 rounds per minute and the intensity was equal to the patients' body weight. The patients were then asked to maximally perform on three hop tests: the one legged hop for distance, the one legged triple hop for distance and the one legged 6 meter timed hop. For

the one legged hop for distance, the patients were instructed to stand on one leg with their hands behind their backs. The patients then jumped as far as possible and landed on the same leg and stood still for at least 2 seconds. The total distance in centimeters was measured. The triple hop for distance followed the same procedure, but instead of one hop the patients performed three consecutive maximal hops. For the six meter timed hop, two cones were placed six meters apart. The patients started also on one leg with the hands behind their backs and hopped as fast as possible from one cone to the other cone. Time was measured in seconds. All the hop tests were done twice and the mean score was noted.

A = One legged hop for distance

B = One legged triple hop for distance

C = 6 meter hop test



Outcomes

The isokinetic strength data

The isokinetic strength data were generated through a Cybex 6000. The Cybex has been shown to have good retest reliability following ACL reconstruction. The intraclass correlation coefficient (ICC) values of the Cybex 6000 range from 0.82 to 0.91 for peak torque, from 0.76 to 0.89 for total work and from 0.71 to 0.88 for average power.[24]

Functional testing

Functional testing consisted of the six meter timed hop test, the one leg hop for distance and the triple hop for distance. The ICC's for the single hop for distance test, the six meter timed hop for distance test and the triple hop for distance are respectively 0.92, 0.96 and 0.88. [19]

Limb symmetry indices

A limb symmetry indices (LSI) score was calculated for each test. The mean, of the involved limb, was divided by the mean, of the uninvolved limb, and the result was multiplied by 100. A limb symmetry index of less than 85% was considered inadequate for the hop tests[16] and a limb symmetry index of less than 90% was considered inadequate for peak torque.[21]

Normative data.

The normative data consist of twenty-eight soccer players (14 elite and 14 sub-elite). Elite players are signed for a professional club and played international soccer (full-time professional players from the English Premier League). Sub-elite players are not signed for a professional club but had played regularly for various local and University teams.

Data analysis

Due to the central limit theorem[25] all data were analyzed through non-parametric testing. Wilcoxon signed rank test was used in order to measure the progression between 4 months and at the end of the rehabilitation. Statistical significance was determined at the $p < 0.05$ level. Spearman's rank correlation coefficient (r_s) was used to calculate the relation between isokinetic testing and the functional tests. Values of Spearman's rho above 0.80 indicate a good correlation where values between 0.60 and 0.79 indicate a moderate relation.[20] Because matching on an individual basis was not possible the following formula was used:

$$Z\text{patient} = \frac{(\text{Strength (Nm) observed patient} - \text{Strength (Nm) expected group})}{\text{SDgroup}}$$

To test whether patients after ACL reconstruction had the same strength as their healthy controls, a one sample *t* test with a two sided alpha of 0.05 was done. All data were analyzed with the Statistical Package for the Social Sciences (SPSS for Windows, release 15.0; SPSS Inc. Chicago Illinois, USA).

Results

Table one shows the characteristics of the included participants. All participants were men, aged between 18 and 30 years (mean age 23,0 (SD 3,5)). eight patients received a bone-patella-bone graft and ten a hamstring graft in which the gracilis and semitendinosus tendons.

Tabel 1 Characteristics study group

	ACL reconstructed (N=18)	Elite (N=14)	Sub-elite (N=14)
age (years)	23,00 ± 3,543 (18 – 30)	23,7 ± 4,3	23,1 ± 3,1
weigth (kg)	80,06 ± 5,023 (71 – 90)	85,5 ± 9,2 *	75,2 ± 8,1 *
T1 Cybex (weeks)	17,88 ± 3,871 (15 – 31)	..	..
End of rehabailitation (weeks)	41,00 ± 10,218 (30 – 68)	..	..
Days between hop tests and end measure Cybex	3,3 ± 5,125 (0 – 13)	..	..
Bone patella bone	8	..	..
Semitendinosus hamstring graph	10	..	..
ACL = anterior cruciate ligament; kg = kilograms Values are mean, SD (and range) * p ≤ 0.05			

Table two shows isokinetic testing data for the Cybex test at 60 degrees per second. At four months, significant differences were found for quadriceps strength, total work in the hamstring and the hamstring to quadriceps (HQ) ratio. These results correspond to the LSI at four months.

Tabel 2 cybex 60

	T1 (N=18)			T2 (N=16)		
	Involved	Uninvolved	LSI (%)	Involved	Uninvolved	LSI (%)
Hamstring pt	150 (129-169)	161 (144-175)	97 (58,5 - 122,3)	176 (152-179) ¥	176 (167-182) ¥	98 (81,6 - 114,8)
Hamstring tw	177 (166-195)	203 (189-219) *	85 (50,5 - 122,6)	212 (202-225) ¥	212 (202-233) ¥	97 (83,9 - 111,0)
Quadriceps pt	189 (143-207)	233 (204-255) *	77 (39,6 - 110,2)	235 (216-255) ¥	250 (240-259) ¥	96 (84,9 - 105,4) ₸
Quadriceps tw	221 (163-234)	235 (220-278) *	81 (53,3 - 109,2)	237 (221-293) ¥	262 (231-315) * ¥	94 (83,8 - 111,8) ₸
HQ ratio pt	79 (70-106)	67 (61-74) *	121 (61,4 - 233,3)	70 (64-82)	70 (60-74)	103 (93,2 - 119,7) ₸
HQ ratio tw	89 (73-107)	80 (73-88)	106 (70,1 - 230,9)	87 (78-93)	89 (73-91)	98 (86,2 - 129,9) ₸
Significance is set at p ≤ 0.05; all values are presented as median and interquartile range * p ≤ 0.05; between involved and the uninvolved leg ¥ p ≤ 0.05; within differences ₸ p ≤ 0.05; between the leg symmetry indices (LSI) pt = peak torque; tw = total work; HQ = hamstring quadriceps						

At the end of the rehabilitation period no differences between the involved and the uninvolved knee remained except in total work of the quadriceps. All LSI remained within the 10% range of 100%. Except for the HQ ratio all measures

differ significantly (p≤0.05) over time. This counts for both the involved and the uninvolved knee.

Tabel 3 cybex 300

	T1 (N=18)			T2 (N=16)		
	Involved	Uninvolved	LSI (%)	Involved	Uninvolved	LSI (%)
Hamstring pt	114 (104-131)	112 (99-134)	102 (76,0 - 115,3)	123 (115-126) ¥	129 (118-133) ¥	95 (85,4 - 113,6)
Hamstring tw	138 (118-146)	143 (132-169) *	96 (63,2 - 107,5)	145 (138-157) ¥	163 141-179) ¥	92 (76,1 - 111,5)
Quadriceps pt	127 (96-153)	131 (120-148)	92 (67,6 - 124,0)	138 (121-155) ¥	133 (126-151)	102 (80,6 - 109,6) ₸
Quadriceps tw	124 (106-146)	138 (124-154) *	89 (67,4 - 126,4)	144 (119-159) ¥	140 (115-157)	97 (74,4 - 108,6) ₸
HQ ratio pt	94 (83-110)	85 (79-92) *	116 (87,4 - 154,7)	82 (77-104) ¥	89 (84-100)	93 (78,8 - 112,0) ₸
HQ ratio tw	105 (97-120)	102 (94-118)	103 (75,2 - 154,9)	110 (97-127)	117 (100-122)	93 (84,0 - 118,9) ₸

Significance is set at p ≤ 0.05; all values are presented as median and interquartile range
* p ≤ 0.05; between involved and the uninvolved leg
¥ p ≤ 0.05; within differences
₸ p ≤ 0.05; between the leg symmetry indices (LSI)
pt = peak torque; tw = total work; HQ = hamstring quadriceps

Cybex test data at 300 degrees per second are given in table three. At four months, significant differences were found for quadriceps and hamstring total work and for the peak torque in the HQ ratio.

At the end of the rehabilitation period no differences between the involved and the uninvolved knee remained. All LSI remained within the 10% range of 100%. Over time, the involved knee progressed significantly on all factors except on the total work in the HQ ratio. The uninvolved leg solely progressed significantly on hamstring strength.

At the end of the rehabilitation, quadriceps strength was significantly less at all angular velocities for the patients with ACL reconstruction compared to the healthy elite soccer players. Their hamstring strength, however, was significantly more. Compared to the healthy Sub elite soccer players, the patients scored significantly higher on the 60°/s hamstring and quadriceps strength and on the 300°/s hamstring strength. For the strength at 300°/s in the quadriceps, the patients scored also higher but not significant. These results are presented in table four.

Table 4 ACL-R to normative data

			ACL-R (N=16)	Elite (N=14)	Sub Elite (N=14)
60	Hamstring	Involved	171,0 ± 20,6	148,4 ± 32,1 *	126,2 ± 19,3 *
		Uninvolved	172,6 ± 18,0		
	Quadriceps	Involved	239,7 ± 30,1	269,8 ± 39,4 *	231,0 ± 35,8 *
		Uninvolved	250,2 ± 26,2		
300	Hamstring	Involved	119,6 ± 11,0	111,6 ± 17,1 *	100,6 ± 16,6 *
		Uninvolved	126,1 ± 14,9		
	Quadriceps	Involved	139,3 ± 26,1	165,4 ± 23,5 *	130,9 ± 26,7
		Uninvolved	138,4 ± 20,5		
* significance at p ≤ 0.05					

Table 5 describes the relationship between hop testing and Cybex testing at the end of the rehabilitation period. The only significant correlations (r=0,943 and -0,829) are seen between the triple hop for distance and the peak torque in quadriceps muscle at 60 degrees per second and between the six meter timed hop and the total work in hamstring at 300 degrees per second. While the Cybex values at 60°/s show a mainly positive correlation with the hop tests, the 300°/s values tend to show more negative correlations.

Table 5 Relationship between hop testing and Cybex at the end of the rehabilitation

Deg/sec	LSI		Six meter hop (N=6)	Single hop (N=6)	Triple hop (N=6)
60	Hamstring	Peak torque	,029	-,543	,600
		Total work	,200	-,714	-,257
	Quadriceps	Peak torque	,371	-,200	,943(**)
		Total work	,600	,257	,429
	Hamstring Quadriceps Ratio	Peak torque	-,486	-,714	-,486
		Total work	,086	-,657	-,486
300	Hamstring	Peak torque	-,771	-,771	-,371
		Total work	-,829*	-,714	-,086
	Quadriceps	Peak torque	-,200	-,771	-,086
		Total work	-,600	-,714	-,200
	Hamstring Quadriceps ratio	Peak torque	-,429	,371	-,143
		Total work	-,486	-,486	-,086
* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).					

Discussion

The purposes of this study were to determine 1) the strength of the involved and uninvolved leg in elite soccer players after anterior cruciate ligament reconstruction at four months and at the end of the rehabilitation, and 2) the

relationship between isokinetic knee strength testing and three functional performance tests

At four months large differences are found between the involved and the uninvolved leg. At 60°/s the differences are more obvious. This is to be expected since lower angular velocities are more related to maximal strength, were higher angular velocities, such as 300°/s, measure more the muscle stamina. The differences between the involved and the uninvolved leg exist no longer at the end of the rehabilitation, except for the total work of the quadriceps at 60°/s.

Looked at the LSI between four months and the end of the rehabilitation significance was found for the quadriceps and the HQ ratio's. An explanation could be the reflex atrophy of the quadriceps muscle which is caused by the swelling in the early phases of the recovery. Another explanation could be caused by hamstring deficit in the early phases of recovery. If hamstrings are limited by weakness (peak torque output), quadriceps activation must be reduced, since a net external flexor moment is required to flex the knee. Hence, deficits in strength and activation of the hamstrings limit the potential for muscular co-contraction to protect ligaments. If hamstrings strength and recruitment is high, the quadriceps can be activated more while still producing a net external knee extensor moment (internal knee flexor or predominating hamstrings torque).

Although all patients are elite soccer players, at the end of the rehabilitation they did not reach the same strength as their controls. Large differences are also there between the elite and the sub elite players. So a possible explanation could be that the intensity of soccer training and the match play at high level improves the strength[23], which can not be trained in rehabilitation. The significant weight difference between the patients and the controls could be related to their increased muscle mass and thereby not influence the increased strength results.

The second hypothesis concerning the relationship between isokinetic knee strength and three functional performance tests showed no proper relationship. Where the 60°/s Cybex values did correlate more positive towards hop testing the 300°/s tend to correlate more negatively. This makes sense were the 300°/s

more stamina tests and the 60°/s are more maximal tests and thereby more related towards the hop tests. However, the correlations are, except for the triple hop for distance with the 60°/s, not significant and therefore the hop tests can not replace the Cybex testing or vice versa.

Results by Hamilton et al.[26] showed that the triple hop for distance predicted 56,7% of the variance in hamstrings strength at 60°/s ($p < .01$) and 49,0% of the variance in quadriceps strength at 60°/s ($p < .01$). Findings by Petschnig et al.[21] were quite equal on the results reported in this study. Also no strong correlations were found. Outcomes by Wilk et al.[22] are contradictionary towards the outcomes in this study. Wilk et al. found strong correlations between hop testing and isokinetic testing by the Cybex.[22] All these studies, studied the effect mentioned in patients after ACL reconstruction.

Several study limitations could interfere with the outcomes found. It is not recorded whether the patients could perform maximally. Diminished results could be caused by training effects from exercises done in the preceding days that week (i.e. lactic training which causes muscle soreness and stiffness). The patient could also lack confidence concerning the knee. The hop tests should be performed in the same week as the Cybex. Table one showed an average of ten days between the tests. A reason for the delay could be a reaction of the knee following preceding trainings (i.e. apexitis). Last, the number of patients was very low. It should be kept in mind however, that all participants are elite soccer players measured during their rehabilitation and therefore data are quite unique.

Conclusion

At the end of the rehabilitation, 41 weeks after ACL reconstruction, the knee strength of elite soccer players do not level up to those of elite soccer players without ACL reconstruction. The limb symmetry indices, however, are above 90%. This counts both for the isokinetic as the functional testing. The relationship between these tests was not proven.

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