

Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus

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ABSTRACT

Aim The Royal Dutch Society for Physical Therapy (KNGF) instructed a multidisciplinary group of Dutch anterior cruciate ligament (ACL) experts to develop an evidence statement for rehabilitation after ACL reconstruction.

Design Clinical practice guideline underpinned by systematic review and expert consensus.

Data sources A multidisciplinary working group and steering group systematically reviewed the literature and wrote the guideline. MEDLINE and the Cochrane Library were searched for meta-analyses, systematic reviews, randomised controlled trials and prospective cohort studies published between January 1990 and June 2015.

Eligibility criteria for selecting studies Included literature must have addressed 1 of 9 predetermined clinical topics: (1) preoperative predictors for postoperative outcome, (2) effectiveness of physical therapy, (3) open and closed kinetic chain quadriceps exercises, (4) strength and neuromuscular training, (5) electrostimulation and electromyographic feedback, (6) cryotherapy, (7) measurements of functional performance, (8) return to play and (9) risk for reinjury.

Summary Ninety studies were included as the basis for the evidence statement. Rehabilitation after ACL injury should include a prehabilitation phase and 3 criterion-based postoperative phases: (1) impairment-based, (2) sport-specific training and (3) return to play. A battery of strength and hop tests, quality of movement and psychological tests should be used to guide progression from one rehabilitation stage to the next. Postoperative rehabilitation should continue for 9–12 months. To assess readiness to return to play and the risk for reinjury, a test battery, including strength tests, hop tests and measurement of movement quality, should be used.

INTRODUCTION

Anterior cruciate ligament reconstruction (ACLR) is a common treatment for athletes after ACL injury. The incidence of non-contact ACL injuries appears to be the greatest in athletes who are between 15 and 40 years of age and participate in pivoting sports like soccer, handball, volleyball and alpine skiing.^{1,2} Every year, about 3% of amateur athletes injure their ACL; for elite athletes, this percentage could be as high as 15%.² Females are two to eight times more likely to sustain an ACL injury than their male counterparts, probably because male and

female neuromuscular patterns diverge during and following puberty.^{3–8}

Besides its mechanical function in maintaining knee stability, the ACL contains mechanoreceptors (2.5%) and therefore directly influences the neuromuscular control of the knee.⁹ ACL deficiency causes partial deafferentation and alters spinal and supraspinal motor control. The changes in motor control strategy can reveal changes in proprioception, postural control, muscle strength, movement and recruitment patterns.¹⁰ An ACL injury might therefore be regarded as a neurophysiological dysfunction and not a simple peripheral musculoskeletal injury.^{11,12} It is also not self-evident that an ACLR will automatically lead to a return to preinjury activity level.

Recent research shows that 35% of athletes after ACLR do not return to preinjury sport level within 2 years.^{13–15} Half of these athletes report their ACL injury as the primary reason for a lower activity level.^{13,14,16–18} Apart from the physical recovery, also the psychological response (eg, fear of reinjury) after ACLR has an influence on whether an athlete chooses to return to play.^{19–25} Return to play is defined as the ability to play a competitive match at the preinjury level. Moreover, recent research shows that 3–22% of athletes rerupture the reconstructed ligament and 3–24% rupture the contralateral ACL in the first 5 years after ACLR.^{17,26–30}

The difficulty with determining the moment of return to play is that it is unknown which measures should be used to predict a safe return to play with a low risk of a second ACL injury. Three recent systematic reviews show that the return-to-play decision by clinicians is hardly based on objective clinimetric criteria.^{27,31,32} Furthermore, these studies concluded that return to play is only connected to quantitative criteria, while it is known that qualitative criteria (eg, dynamic knee valgus, knee flexion angle and trunk control) play an important role in prevention and rehabilitation. Movement quality actually may affect the ACL (re) injury rate.^{33,34} The occurrence of dynamic knee valgus when landing from a jump, for instance, increases the risk of ACL (re)injury.^{35,36}

Return to play is the ultimate goal of rehabilitation programmes. So the above-mentioned factors are important topics to incorporate in the rehabilitation process after ACLR. However, currently, there is no consensus regarding the content of a



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rehabilitation programme. Therefore, the Royal Dutch Society for Physical Therapy (KNGF) instructed a multidisciplinary group of ACL experts in the Netherlands to develop an evidence statement for anterior cruciate ligament rehabilitation. The goal of this evidence statement was to describe the rehabilitation after ACLR and to encourage uniformity in physical therapy treatment and use of measurements of functional performance. The following three questions were formulated by a steering group of the KNGF to guide the realisation of the evidence statement:

1. What should be the content of the rehabilitation protocol after ACLR based on scientific evidence and, if not present, based on best practice?
2. Which measurements and assessments can be applied to monitor progression during the rehabilitation programme and to determine outcomes at the end of rehabilitation programme?
3. What criteria should be used to determine the moment of return to play?

METHODS

Expert participants

The process started with the formation of a multidisciplinary working group and steering group. The working group consisted of six Dutch ACL experts with 8–35 years of experience in ACL rehabilitation: five physical therapists specialised in sports injury rehabilitation and one orthopaedic surgeon specialised in knee surgery, ACL surgery in particular. The steering group consisted of ACL experts from different professions with 10–37 years of experience in ACL rehabilitation (three physical therapists, one sports physician, one orthopaedic surgeon and one trauma surgeon).

Procedure

The first author (NvM) chaired the working group and was responsible for the systematic review steps (literature search, methodological quality assessment, data extraction, data analysis, description of the results and translation into practice guidelines) and for writing the evidence statement. The working group monitored each step in the systematic review process and assisted in methodological quality assessment of the included studies, the writing process and the translation into practice guidelines. The steering group (chairman REHvC) validated all steps made by the first author and the working group. The KNGF assisted in the administrative processes.

The working group contacted each other by email and every 2 months a consensus meeting was organised. Every other meeting, the steering group joined the working group.

The first meeting of the working and steering group together, started with the formulation of nine clinical topics important for ACLR rehabilitation. These topics were used to guide the systematic review process. These nine topics were: (1) preoperative predictors for postoperative outcome, (2) effectiveness of physical therapy, (3) open kinetic chain (OKC) versus closed kinetic chain (CKC) quadriceps exercises, (4) strength training and neuromuscular training, (5) electrostimulation and electromyographic feedback, (6) cryotherapy, (7) measurements of functional performance, (8) return to play and (9) risk of reinjuries.

Articles found during the systematic review process were subdivided into the nine topics and every topic was given a level of evidence according to the EBRO (Dutch evidence-based guideline development) criteria.³⁷ The recommendations were, if available, based on the latest scientific evidence, supplemented

with best practice when necessary. The results of the systematic review process (see online supplementary appendix 1) were used to formulate the evidence statement (see online supplementary appendix 2).

Search strategy

A systematic literature search was performed searching in MEDLINE (PubMed) and the Cochrane Library to identify relevant articles from January 1990 up to June 2015 using keywords specified for the database according to the nine topics mentioned above with PICO questions (table 1). An academic librarian composed a syntax based on all the keywords. Meta-analyses, systematic reviews, randomised controlled trials (RCTs) and prospective cohort studies were included for study selection.

Study selection

All eligible articles were screened first by title and abstract independently by two reviewers (NvM and REHvC). When the two reviewers did not reach consensus, a third reviewer (CN) made the final decision. After this first inclusion, the full-text article was screened using the inclusion and exclusion criteria as listed in table 2. In addition, a hand search was performed on the reference lists of meta-analysis and systematic reviews for RCTs and prospective cohort studies that were not included in the primary search. A flow chart of the search strategy is presented in figure 1.

Methodological quality assessment

Quality assessment of the included articles was independently performed by two reviewers (NvM and REHvC). When the reviewers did not reach consensus, a third reviewer made the final decision. All articles were individually graded for level of methodological quality (table 3 and online supplementary appendix 1).

Methodological quality of meta-analyses and systematic reviews was assessed with the AMSTAR checklist. The assessment of risk of bias of the RCTs was performed with the PEDro scale (<http://www.pedro.org.au>). The PEDro scale was scored on 10 items. Methodological quality was rated poor when an article had a score of ≤ 4 . Subsequently, the RCTs with poor quality were excluded.

The prospective cohort studies were assessed with an adapted Cochrane Library Checklist (table 4), also used before in the KNGF guideline for urinary incontinence.³⁸ This checklist has a maximum score of 5. Prospective cohort studies were only used when no higher level evidence was available or to support findings in the RCTs.

Data extraction

Data extraction was performed by one reviewer (NvM). See online supplementary appendix 1 for the data extraction table. Results from the included studies were synthesised descriptively for the evidence statement. Based on the results of all articles selected in one topic, a final conclusion was made with a corresponding level of evidence (table 5).^{37–39} To correct for double evidence, RCTs that were also included in a meta-analysis or systematic review were not used separately to determine the level of evidence of the final conclusion.

RESULTS

Study selection and methodological quality assessment

After removing doubles, the systematic literature search in MEDLINE and the Cochrane Library provided 3713 articles

Table 1 Search strategy 31 May 2015

	Citations MEDLINE	Citations Cochrane
1: anterior cruciate ligament [Mesh]	10 170	739
2: anterior cruciate ligament [tiab]	11 970	1359
3: anterior cruciate ligaments [tiab]	331	–
4: ACL [tiab]	10 402	853
5: 1–4 with OR	17 340	1596
6: anterior cruciate ligament reconstruction [Mesh]	1794	179
7: anterior cruciate ligament reconstruction [tiab]	3903	968
8: anterior cruciate ligament/surgery [Mesh]	6451	–
9: reconstructive surgical procedures [Mesh]	143 978	6051
10: reconstructive surgical procedures [tiab]	149	908
11: reconstructive surgical procedure [tiab]	32	–
12: reconstruction [tiab]	142 371	3348
13: reconstructed [tiab]	39 500	474
14: reconstructive [tiab]	25 421	1187
15: ligament surgery [tiab]	317	930
16: bone-patellar tendon-bone grafts [Mesh]	14	–
17: bone-patellar tendon-bone grafts [tiab]	67	–
18: bone-patellar tendon-bone graft [tiab]	212	94
19: tendon graft [tiab]	1357	247
20: tendon grafts [tiab]	699	–
21: tendon transfer [Mesh]	3540	62
22: tendon transfer [tiab]	1302	83
23: tendon transfers [tiab]	674	–
24: orthopedic procedures [Mesh]	213 556	9925
25: orthopedic procedures [tiab]	680	1350
26: orthopedic procedure [tiab]	124	–
27: orthopaedic procedures [tiab]	523	–
28: orthopaedic procedure [tiab]	107	–
29: 6–28 with OR	444 486	15 852
30: physical therapy modalities [Mesh]	129 118	16 446
31: physical therapy [tiab]	11 921	18 473
32: physiotherapy [tiab]	12 631	3939
33: kinesiotherapy [tiab]	114	850
34: exercise therapy [tiab]	2120	16 047
35: postoperative care [Mesh]	52 666	3903
36: postoperative care [tiab]	4852	13 295
37: rehabilitation [Mesh]	154 448	15 806
38: rehabilitation [tiab]	110 195	14 259
39: rehabilitation [subheading]	168 951	13 952
40: instruction [tiab]	20 681	3773
41: instructions [tiab]	21 227	–
42: resistance training [Mesh]	3752	1255
43: resistance training [tiab]	4168	4113
44: strength training [tiab]	3137	4966
45: neuromuscular training [tiab]	227	631
46: exercise [Mesh]	124 975	14 346
47: exercise [tiab]	188 673	42 289
48: exercises [tiab]	25 022	–
49: testing [tiab]	376 479	23 811
50: test [tiab]	1 057 291	101 340
51: tests [tiab]	484 232	–
52: 30–51 with OR	2 266 540	190 016
53: 5 and 29 and 54	4252	580
54: inclusion publication date 1990-01-01 until 2015-05-31	4051	544
55: inclusion language English	3619	529

ACL, anterior cruciate ligament.

Table 2 Inclusion and exclusion criteria for literature search

Inclusion	Exclusion
► Date of publication: January 1990–June 2015	► Narrative reviews, retrospective cohort studies, case studies
► English language	► Articles about non-operative treatment
► Meta-analyses, systematic reviews, RCTs and prospective cohort studies	► Articles about allograft, synthetic graft or other autograft than BPTB or HS
► Full text available	► Articles about ACL revision reconstruction
► Articles about brace-free rehabilitation after arthroscopic ACLR with BPTB or HS autograft	► Articles with follow-up measurement, but no description of the rehabilitation protocol
► Articles including information on one of the 9 clinical topics formulated by the experts	► Articles about operative techniques, timing of the operation or graft choice
	► Articles about bracing after ACLR
	► Articles about skeletally immature patients
	► Animal, cadaveric or in vivo studies

ACLR, anterior cruciate ligament reconstruction; BPTB, bone-patellar tendon-bone; HS, hamstring; RCT, randomised controlled trial.

(figure 1). After the first exclusion based on title and abstract, 101 articles were included for full-text assessment. After reading, no study was excluded. After the hand search in the reference lists of meta-analyses and systematic reviews, eight articles were included additionally. After quality assessment, 19 RCTs were excluded based on a PEDro score of ≤ 4 . The most common flaws were no blinding of participants, therapists or outcome assessors and an inadequate percentage of participants eligible for follow-up.

All final included (n=90) articles were arranged by topic: 10 for preoperative predictors for postoperative outcome,^{40–49} 10 for effectiveness of physical therapy,^{50–59} 11 for OKC versus CKC quadriceps exercises,^{60–70} 21 for strength training and neuromuscular training,^{71–91} 11 for electrostimulation and electromyographic feedback,^{63 93–102} 5 for cryotherapy,^{103–107} 8 for measurements of functional performance,^{27 31 32 108–112} 10 for return to play^{13 14 17 22 113–118} and 5 for risk of reinjuries^{29 35 36 119 120} (topics ‘open vs closed kinetic chain quadriceps exercises’ and ‘electrostimulation’ share one systematic review).

Data extraction

Evidence for clinical practice at all nine topics is summarised below, according to table 5. See also online supplementary appendix 1 for the data extraction table. Final recommendations were made according to the EBRO criteria in table 5.

Preoperative predictors for postoperative outcome

Ten articles were found about preoperative predictors for postoperative outcome. These were one systematic review,⁴⁰ one RCT⁴¹ and eight prospective cohort studies.^{42–49}

The prospective cohort studies of Eitzen *et al*,⁴² Heijne *et al*,⁴⁴ McHugh *et al*⁴⁷ and McHugh *et al*⁴⁸ were included in the systematic review of de Valk *et al*.⁴⁰ This level A2 systematic review documented that (1) better functional outcomes after ACLR were achieved for men than for women at a minimum follow-up of 1 year after ACLR, no matter the graft choice; (2)

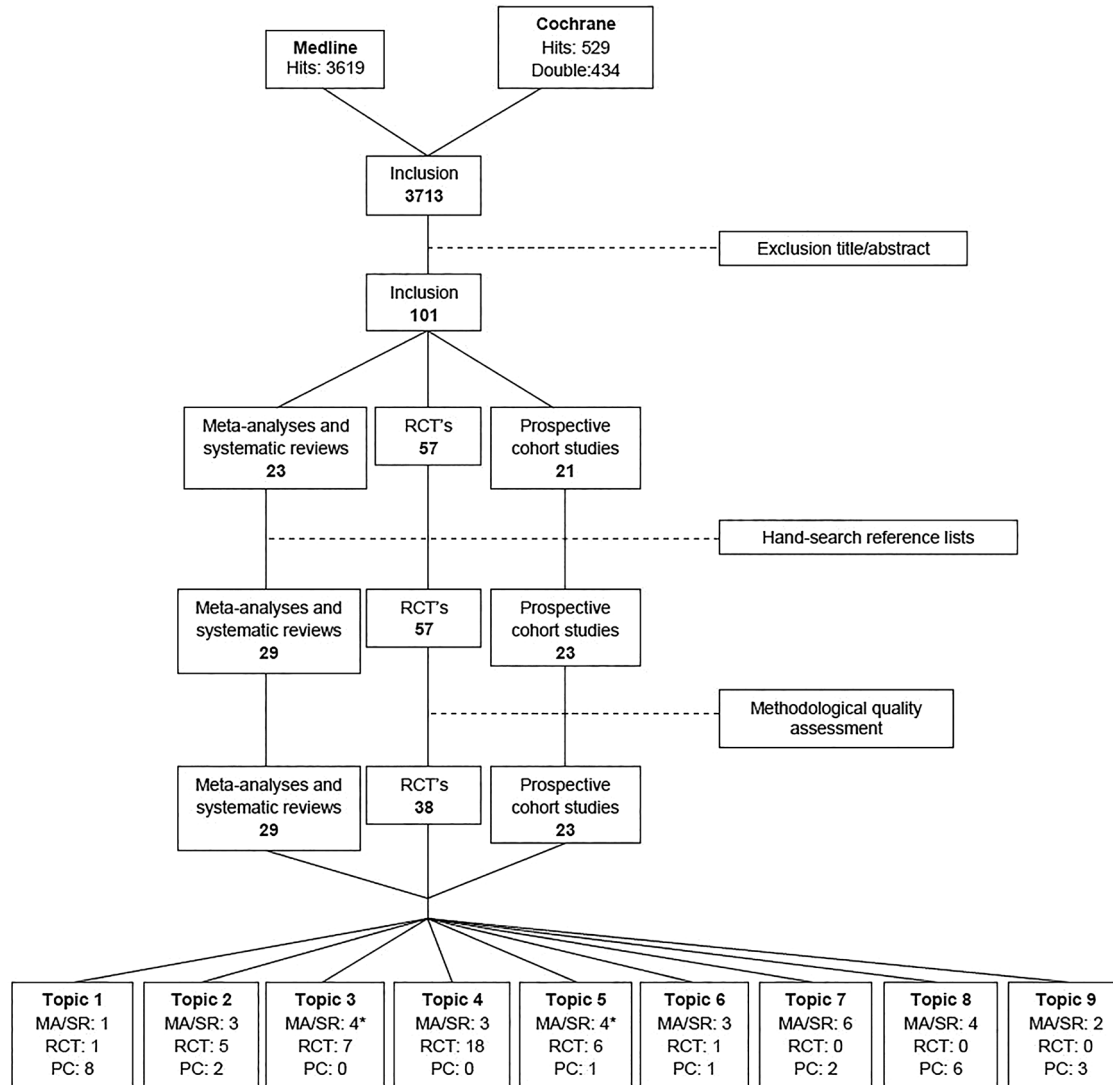


Figure 1 Flow chart of search strategy on 31 May 2015. *Topics 3 and 5 share one SR. MA, meta-analysis; PC, prospective cohort study; RCT, randomised controlled trial; SR, systematic review.

Table 3 Grading of the level of methodological quality of individual studies (EBRO)

Level of evidence	Interventional studies	Diagnostic accuracy studies	Harm, side effects, aetiology, prognosis
A1	Systematic review/meta-analysis of at least two independently conducted studies of A2 level		
A2	Randomised, double blind trial with good study quality and an adequate number of study participants	Index test compared to reference test (reference standard); cut-offs were defined a priori; independent interpretation of test results; an adequate number of consecutive patients were enrolled; all patients received both tests	Prospective cohort study of sufficient magnitude and follow-up, adequately controlled for 'confounding' and no selective follow-up
B	Clinical trial, but without all the features mentioned for level A2 (including case-control study, cohort study)	Index test compared to reference test, but without all the features mentioned for level A2	Prospective cohort study, but without all the features mentioned for level A2 or retrospective cohort study or case-control study
C	Non-comparative studies		
D	Expert opinion		

patients younger than 30 years of age had a higher postoperative Tegner activity level than older patients at a minimal follow-up of 22 months after ACLR; (3) patients with ACLR within 3 months after injury and patients with a high preoperative Tegner activity level have a higher Tegner activity level at a minimal follow-up of 2 years after ACLR; (4) smoking, high

BMI (>30), quadriceps strength deficits and range of motion (ROM) deficits resulted in worse functional outcomes at a minimum of 1 year after ACLR.⁴⁰ The steering group found some prospective cohort studies that supported the conclusions of de Valk *et al.* Lepley and Palmieri-Smith⁴⁵ (level B) showed that preoperative quadriceps strength is positively related to

Table 4 Adapted Cochrane library checklist

Item	Score: + or –
1. Are inclusion and exclusion criteria reproducible?	
2. Are the applied measurements reproducible?	
3. Follow-up of participants is at least 80%?	
4. Is the analysis corrected for confounders?	
5. Is outcome measure description reproducible?	
Level of methodological quality	
A2: all five items are scored positive	
B: four of five items are scored positive	
C: three or less items are scored positive	

Table 5 Level of evidence of the conclusion (EBRO)

Level	Conclusion based on
1	A1 study or at least two independent studies of level A2
2	One study of level A2 or at least two independent studies of level B
3	One study of level B or C
4	Expert opinion

postoperative quadriceps strength at the moment of return to play. Månsson *et al*⁴⁶ (level C) found that a higher preoperative Tegner activity level predicts a better outcome at a minimal follow-up of 22 months. Quelard *et al*⁴⁹ (level B) described that a limited preoperative ROM and female sex account for a limited ROM 3 months postoperative.

Grindem *et al*⁴³ (level C prospective cohort study) and Shaarani *et al*⁴¹ (level B RCT) investigated the effect of preoperative rehabilitation, so-called prehabilitation, on the outcome after ACLR. Grindem *et al*⁴³ described that combined prehabilitation and postoperative rehabilitation had better self-reported knee function at 2-year follow-up compared to postoperative rehabilitation only. Shaarani *et al*⁴¹ had a follow-up of only 12 weeks after ACLR. They found no differences in quadriceps and hamstring (HS) strength between a prehabilitation group and a group with no prehabilitation, but the prehabilitation group scored better on self-reported knee function.⁴¹

From the above-mentioned predictive factors, the non-modifiable factors could be taken into account by the physical therapist to predict the outcome of treatment.

The conclusions about modifiable factors in this topic were as follows:

- ▶ **Level 2:** a preoperative extension deficit (lack of full extension) is a major risk factor for an extension deficit after ACLR.^{40 49}
- ▶ **Level 2:** a preoperative deficit in quadriceps strength of >20% has a significant negative consequence for the self-reported outcome 2 years after ACLR.^{40 45}
- ▶ **Level 3:** prehabilitation ensures better self-reported knee function up to 2 years after ACLR.^{41 43}

Effectiveness of physical therapy

Ten articles were found about the effectiveness of postoperative physical therapy. These were three systematic reviews,^{50–52} five RCTs^{53–57} and two prospective cohort studies.^{58 59}

The systematic review of van Grinsven *et al*⁵¹ (level B) described a time-based rehabilitation protocol based on the available evidence supplemented with expert opinion.

The level A1 systematic review of Coppola and Collins⁵⁰ investigated the effect of physical therapy after knee surgery. Based on

10 RCTs, they concluded that physical therapy is not more effective than a home exercise programme in a young and healthy population following relatively simple knee surgery as arthroscopic meniscectomy. However, for rehabilitation after complicated knee surgery as ACLR, there is a lack of evidence.⁵⁰ The systematic review of Wright *et al*⁵² (level A1) concluded that it is reasonable that a minimally supervised rehabilitation can result in successful ACLR rehabilitation. In their study, Coppola and Collins⁵⁰ included three RCTs about rehabilitation after ACLR. Wright *et al*⁵² included the same three RCTs plus the RCT of Beard and Dodd.⁵³ The level B RCT of Beard and Dodd⁵³ showed that physical therapy had minimal extra benefit in a, not explicitly described, young athletic population after ACLR. Their rehabilitation programme was only administered from weeks 4 to 16 after ACLR. They found no differences in self-reported knee function and quadriceps and HS strength 24 weeks after ACLR.⁵³ Hohmann *et al*⁵⁷ and Grant and Mohtadi⁵⁶ (both level B) also investigated the difference between supervised physical therapy (Hohmann: 19 sessions, Grant and Mohtadi: 17 sessions) versus home-based rehabilitation (4 sessions). They both found no between-group differences in ROM, quadriceps and HS strength and hop tests at >1 year follow-up,^{56 57} but Grant and Mohtadi⁵⁶ found a better self-reported knee function in the home-based group. The level C prospective cohort study of Dragicevic-Cvjetkovic *et al*⁵⁸ found a better self-reported knee function and greater improvement in thigh muscle circumference in a rehabilitation group (20 weeks) compared to a group with no rehabilitation at all at a 1 year follow-up.

Both studies of Beynnon *et al*^{54 55} (levels B and A2) studied the difference between a 19-week and a 32-week rehabilitation programme after ACLR. They concluded that there were no differences in self-reported knee function, laxity, ROM, strength and hop tests at a 2-year follow-up.^{54 55} The rehabilitation programme of Muneta *et al*⁵⁹ (level B) comprised a 6-month rehabilitation. Their results are comparable to both studies of Beynnon *et al*.^{54 55 59}

The conclusions in this topic were as follows:

- ▶ **Level 2:** owing to a lack of high-quality studies and contradictory results, it is unclear whether there is a benefit of supervised rehabilitation compared to home-based rehabilitation or no rehabilitation at all. A minimally supervised rehabilitation programme may result in successful rehabilitation in specific groups of patients that are highly motivated and live far from a physical therapist.^{50 52 56 57}
- ▶ **Level 2:** when comparing a 19-week with a 32-week rehabilitation programme, there are no differences in terms of laxity, ROM, self-reported knee function, single-leg hop test for distance or isokinetic concentric quadriceps and HS strength.^{54 55 59}

OKC versus CKC quadriceps exercises

Concerning the OKC and CKC quadriceps exercises, 11 articles were traced. These were four systematic reviews^{60–63} and seven RCTs.^{64–70}

Andersson *et al*⁶⁰ conclude in their systematic review (level A1) that after ACLR with BTPB, CKC quadriceps exercises produce less pain, less risk of increased laxity and better self-reported knee function compared to OKC quadriceps exercises. They included the RCTs of Bynum *et al*,⁶⁴ Mikkelsen *et al*,⁶⁷ Morrissey *et al*⁶⁸ and Perry *et al*.⁶⁹ The recent RCT of Uçar *et al*⁷⁰ found no differences between CKC and OKC exercises, but they investigated a group of patients after ACLR with a HS graft.

The systematic reviews of Glass *et al*⁶¹ (level A1) and Wright *et al*⁶³ (level A1) conclude that OKC quadriceps exercises

should not be used in the first 6 weeks of rehabilitation after ACLR. Herewith, they confirmed the results of Andersson *et al.*⁶⁰ The RCT of Heijne and Werner⁶⁶ (level B) investigated early (4 weeks) versus late (12 weeks) start of OKC quadriceps exercises and compared ACLR with bone-patellar tendon-bone (BPTB) and HS. They concluded that the HS group with an early start had more laxity after a follow-up period of 7 months than the other groups. Besides, an early start of OKC quadriceps exercises had no beneficial effect on quadriceps strength.⁶⁶ Fukuda *et al.*⁶⁵ (level B RCT) described that OKC quadriceps exercises can be started from week 4 after ACLR with HS, but in a limited ROM between 45° and 90°.

The systematic review of Lobb *et al.*⁶² concluded that there is limited evidence that a combination of OKC and CKC quadriceps exercises results in better strength and return to play than CKC exercises alone. They also included the systematic review of Andersson *et al.*^{60 61}

The overall conclusions were as follows:

- ▶ **Level 1:** CKC and OKC training can be used for regaining quadriceps strength.^{61 62 70}
- ▶ **Level 2:** after ACLR, OKC exercises can be performed from week 4 postoperative in a restricted ROM of 90–45°.^{61 63 65 66}

Strength training and neuromuscular training

Concerning strength training and/or neuromuscular training, 21 articles were found. Among them were 3 systematic reviews^{71–73} and 18 RCTs.^{74–91}

Systematic reviews of Gokeler *et al.*⁷² (level A1) and Kruse *et al.*⁷³ (level A1) concluded that eccentric quadriceps training can be safely incorporated 3 weeks after ACLR and may be the most effective way of restoring quadriceps strength. However, the level A1 systematic review of Augustsson⁷¹ concluded that the strength training programmes after ACLR should be further developed because it is still unclear what is the best way to train the quadriceps. To optimise outcome after rehabilitation, neuromuscular training should be added to strength training according to Gokeler *et al.*⁷² and Kruse *et al.*⁷³ Neuromuscular training is defined as training enhancing unconscious motor responses by stimulating afferent signals and central mechanisms responsible for dynamic joint control.⁹² These exercises are designed to induce compensatory changes in muscle activation patterns and facilitate dynamic joint stability.⁹² Nine RCTs were included in the above-mentioned systematic reviews: Cooper *et al.*,⁷⁸ Gerber *et al.*,⁸⁰ Gerber *et al.*,⁸² Risberg *et al.*,⁸⁷ Risberg and Holm,⁸⁸ Sekir *et al.*⁸⁹ and Shaw *et al.*⁹⁰ The level B RCTs of Berschin *et al.*,⁷⁵ Bieler *et al.*,⁷⁶ Fu *et al.*,⁷⁹ Gerber *et al.*⁸¹ and Kinikli *et al.*⁸⁴ support the findings in those systematic reviews.

The level B RCTs of Isberg *et al.*⁸³ and Shaw *et al.*⁹⁰ concluded that isometric quadriceps exercises are safe in the first postoperative weeks, because there are no differences in laxity up to 2 years of follow-up.

Baltaci *et al.*⁷⁴ (level B RCT) and Cappellino *et al.*⁷⁷ (level B RCT) demonstrated that the use of Wii Fit, respectively, neurocognitive rehabilitation have no beneficial effect to a combined strength and neuromuscular rehabilitation at a short-term follow-up.

Tyler *et al.*⁹¹ (level B RCT) concluded that immediate weight bearing had no detrimental effects for laxity and a positive effect on anterior knee pain at a 1-year follow-up.

The main conclusions were as follows:

- ▶ **Level 1:** starting eccentric quadriceps training (in CKC) from 3 weeks after ACLR is safe and contributes to a bigger

improvement in quadriceps strength than concentric training.^{72 73 76 81 84}

- ▶ **Level 1:** neuromuscular training should be added to strength training to optimise self-reported outcome measurements.^{72 73 75 79}
- ▶ **Level 2:** isometric quadriceps exercises are safe from the first postoperative week.^{83 90}
- ▶ **Level 3:** immediate weight bearing does not affect knee laxity and results in decreased incidence of anterior knee pain.⁹¹

Electrostimulation and electromyographic feedback

Eleven articles about electrostimulation and electromyographic feedback were found. These were four systematic reviews,^{63 93–95} six RCTs^{96–101} and one prospective cohort study.¹⁰²

Imoto *et al.*⁹³ and Kim *et al.*⁹⁴ (level A1 systematic reviews) concluded that the addition of electrostimulation to conventional rehabilitation might be more effective in improving quadriceps strength up to 2 months after ACLR. The level A2 RCT of Paternostro-Sluga *et al.*¹⁰⁰ and the level B RCT of Fitzgerald *et al.*⁹⁹ were included in both systematic reviews. Ediz *et al.*⁹⁷ (level B RCT) and Lepley *et al.*¹⁰² (level C prospective cohort study) found no differences in effusion, pain, ROM and knee extension and flexion moments when electrostimulation was added to conventional rehabilitation. Feil *et al.*⁹⁸ and Taradaj *et al.*¹⁰¹ (both level B RCTs) did examine quadriceps strength and found a higher increase in quadriceps strength when electrostimulation was added to conventional rehabilitation at a 6-month follow-up. Wright *et al.*⁶³ (level A1 systematic review) summarised that electrostimulation may help improve quadriceps strength in the early postoperative period, but that it is not a prerequisite for successful rehabilitation. All authors did not distinguish between regaining quadriceps motor control and increasing quadriceps strength.

Studies concerning electromyographic feedback are contradictory. The systematic review of Wasielewski *et al.*⁹⁵ (level A1) showed that electromyographic feedback improves short-term postsurgical pain after ACLR, but Christanell *et al.*⁹⁶ (level B RCT) described no differences in pain during the first six postoperative weeks with or without biofeedback.

The conclusions on this topic were as follows:

- ▶ **Level 1:** electrostimulation, in combination with conventional rehabilitation, might be more effective for improving muscle strength for up to 2 months after ACLR than conventional rehabilitation alone. However, its effect on long-term functional performance and self-reported knee function is inconclusive.^{63 93 94 98 101}
- ▶ **Level 2:** electromyographic feedback might improve short-term postsurgical pain after ACLR.^{95 96}

Cryotherapy

Five articles were found about cryotherapy: two meta-analyses,^{103 104} one systematic review,¹⁰⁵ one RCT¹⁰⁶ and one prospective cohort study.¹⁰⁷

All three level A1 articles shared the conclusion that cryotherapy is effective in reducing postoperative pain until about 1 week postsurgery, but it has no effect on drainage or ROM.^{103–105} The level A2 RCT of Edwards *et al.*¹⁰⁶ was included in the meta-analyses of Martimbianco *et al.*¹⁰³ The prospective cohort study of Glenn *et al.*¹⁰⁷ (level C) supports these findings.

The conclusion on this topic was as follows:

- ▶ **Level 1:** cryotherapy is effective in decreasing pain immediately after application up to 1 week postsurgery after

ACLR, but has no effect on postoperative drainage or ROM.^{103–105 107}

Measurements of functional performance

Eight articles about measurements of functional performance were traced: six systematic reviews^{23 27 28 108–110} and two prospective cohort studies.^{111 112}

Five systematic reviews (all level B) concluded that there is a lack of objective criteria to determine return to play.^{23 27 28 109 110} Extensive test batteries for determining quantity and quality of movement are recommended, including strength tests, hop tests and video analysis for measuring quality of movement.^{27 28}

There is weak evidence from a level A2 systematic review for factors that could be associated with a higher chance of return to play: less effusion, less pain, higher quadriceps strength, greater tibial rotation, higher Marx Scale score, higher athletic confidence, higher preoperative knee self-efficacy, lower kinesiophobia and higher preoperative self-motivation.¹⁰⁸ Müller *et al*¹¹¹ (level B prospective cohort study) added better self-reported knee function and better hop test performance to this list.

Thoméé *et al*¹¹² (level B prospective cohort study) described that there were poor results at 2 years after ACLR when testing leg muscle power and hop performance and applying an Limb Symmetry Index (LSI) of >90% to all six tests. Only 23% of patients passed when using these criteria and only 10% passed when an LSI of 95% was used.¹¹²

The overall conclusions were as follows:

- ▶ **Level 2:** an extensive test battery should be used for determining the moment for return to play, but there are no tests or test batteries that have been tested for construct or predictive validity for return to play.^{23 27 28 108–111}
- ▶ **Level 3:** It is not clear which cut-off point of the LSI should be used for strength and hop tests.¹¹²

Return to play

Ten articles were traced about return to play: two meta-analyses,^{13 14} two systematic reviews^{113 114} and six prospective cohort studies.^{17 22 115–118}

The meta-analysis of Ardern *et al*¹³ (level A2) included their earlier meta-analysis¹⁴ and the prospective cohort studies of Brophy *et al*,¹⁷ Gobbi and Francisco¹¹⁵ and Langford *et al*.²² They found that 65% of patients after ACLR returned to preinjury competitive sport level within 2 years, but only 38% remained at the same level >2 years after ACLR. Men were 1.4 times more likely to return to their preinjury sport level than women, and BPTB was 1.2 times more likely than HS.^{13 14 17 22 115} Laboute *et al*¹¹⁶ (level C prospective cohort study) reported 65.7% of athletes returning to preinjury sport level, while Zaffagnini *et al*¹¹⁸ reported a higher return to preinjury sport level of 71% in a group of professional soccer players 4 years after ACLR.

Several psychological factors have influence on the rehabilitation process and return to play. According to the systematic reviews of Everhart *et al*¹¹³ (level A2) and te Wierike *et al*¹¹⁴ (level B), a high self-efficacy, a high internal locus of control and a low level of fear are associated with a higher chance of return to play. They included the prospective cohort studies of Gobbi and Francisco,¹¹⁵ Langford *et al*²² and Thoméé *et al*.¹¹⁷

The literature concluded that:

- ▶ **Level 1:** the rate of return to preinjury play level for (non-professional) pivoting athletes after ACLR is 65%.^{13 116}

- ▶ **Level 2:** Psychological factors as self-efficacy, locus of control and fear of reinjury have influence on the rehabilitation process and return to play after ACLR.^{113 114}

Risk of reinjuries

Five articles about risk of reinjuries were found. These were two systematic reviews^{119 120} and three prospective cohort studies.^{29 35 36}

The systematic reviews of Swärd *et al*¹¹⁹ and Wright *et al*¹²⁰ (both level B) concluded that the risk of a contralateral ACL injury is higher than the risk of a first-time ACL rupture or an ACL graft rerupture. The level B prospective cohort study of Wright *et al*²⁹ was included in both systematic reviews.

The level B prospective cohort studies of Hewett *et al*³⁵ and Paterno *et al*³⁶ support the conclusions of the systematic review of Swärd *et al*¹¹⁹ that altered neuromuscular function and biomechanics could be responsible for the risk of second ACL rupture (graft rerupture and contralateral ACL). Factors contributing could be greater hip internal rotation, the occurrence of dynamic knee valgus or less knee flexion when landing from a jump.^{35 36 119}

Their conclusions were as follows:

- ▶ **Level 2:** the risk of a contralateral ACL rupture (>10%) is higher than the risk of graft rerupture (about 5%) (up to 10 years after ACLR) or first-time ACL rupture.^{119 120}
- ▶ **Level 2:** altered neuromuscular function and biomechanics (greater hip internal rotation, the occurrence of dynamic knee valgus or less knee flexion during landing) after ACLR could be a risk factor for second ACL injury (graft rerupture or contralateral rupture).^{35 36 119}

CONSENSUS CONCLUSION

Although there are many articles published about ACL rehabilitation, there is limited evidence for parameters that influence or predict the final result of ACLR rehabilitation and return to play. The aim of this study was to describe the process in which the KNGF evidence statement for ACL rehabilitation was developed and to present this practice guideline (see online supplementary appendix 2). The goal of the evidence statement was to describe the rehabilitation after ACLR with BPTB or HS autograft and to encourage uniformity in physical therapy treatment and the use of measurements of functional performance. The evidence statement is aimed to fill a gap between evidence and clinical practice and describes a complete protocol to rehabilitate an athlete after ACLR. The multidisciplinary approval of this evidence statement underlines the importance of a close collaboration between different professions.

Despite the fact that our evidence statement is based on information from RCTs and systematic reviews from the two most important databases, the evidence is inconclusive. Owing to this lack of scientific evidence, available background literature and a steering group consisting of ACL experts were used to develop a multidisciplinary consensus statement for an ACLR rehabilitation protocol. This consensus statement was based on three formulated questions with the following conclusions.

What should be the content of the rehabilitation protocol after ACLR?

The description of the rehabilitation protocol is divided into preoperative and postoperative rehabilitation.

Preoperative rehabilitation

Preoperative rehabilitation, also known as prehabilitation, is not usually prescribed by orthopaedic surgeons (or trauma surgeons) in the Netherlands. Previous studies showed that a preoperative

full extension ROM reduces the chance for postoperative complications as arthrofibrosis.^{46–48} Moreover, a deficit in quadriceps strength of 20% or more predicts a significant strength deficit until 2 years after ACLR (level 2).^{41–121} Therefore, the steering group recommends to measure the preoperative ROM and quadriceps strength as part of the preoperative rehabilitation protocol. The steering group also advises to measure HS strength, although there is no recommendation for HS measurement in literature. Yet, there are studies that conclude that HS strength in the operated leg is still reduced compared to the non-operated leg until 2 years after ACLR.¹²¹ For this examination and possible treatment, the patient could be referred to a physical therapist to prevent a complicated or prolonged rehabilitation.

Preoperative information about walking with crutches, the early postoperative exercises and the rehabilitation process may improve a patients' self-efficacy; thus, the steering group advises to discuss these topics with patients (level 4). See also [table 6](#) for a summary of conclusions and recommendations.

Postoperative rehabilitation

Good communication between the surgeon and physical therapist is of great importance. While the orthopaedic surgeon is responsible for the surgery results and techniques, the physical therapist should be leading in decision-making in rehabilitation. Therefore, the steering group advises that the orthopaedic surgeon (or trauma surgeon) informs the physical therapist about perioperative findings: graft type, meniscectomy or

Table 6 Summary of conclusions and recommendations

Conclusions and recommendations	Level of evidence
Preoperative rehabilitation	
A preoperative extension deficit (lack of full extension) is a major risk factor for an extension deficit after ACLR <i>Recommendation: measure the preoperative ROM</i>	2
A preoperative deficit in quadriceps strength of >20% has a significant negative consequence for the self-reported outcome 2 years after ACLR <i>Recommendation: measure quadriceps strength and also HS strength</i>	2
Prehabilitation ensures better self-reported knee function up to 2 years after ACLR <i>Recommendation: refer the patient to a physical therapist when necessary</i>	3
Postoperative rehabilitation	
It is unclear whether there is a benefit of supervised rehabilitation compared to home-based rehabilitation or no rehabilitation at all. A minimally supervised rehabilitation programme may result in successful rehabilitation in specific groups of patients that are highly motivated and live far from a physical therapist	2
When comparing a 19-week with a 32-week rehabilitation programme, there are no differences in terms of laxity, ROM, self-reported knee function, single-leg hop test for distance or isokinetic concentric quadriceps and HS strength <i>Recommendation: continue rehabilitation for 9–12 months, depending on the final return-to-work or play goals of the patient</i>	2
Immediate weight bearing does not affect knee laxity and results in decreased incidence of anterior knee pain <i>Recommendation: immediate weight bearing should only be tolerated if there is a correct gait pattern (if necessary with crutches) and no pain, effusion or increase in temperature when walking or shortly after walking</i>	2
Cryotherapy is effective in decreasing pain immediately after application up to 1 week postsurgery after ACLR, but has no effect on postoperative drainage or ROM <i>Recommendation: cryotherapy could eventually be applied in the first postoperative week to reduce pain</i>	1
Isometric quadriceps exercises are safe from the first postoperative week <i>Recommendation: start isometric quadriceps exercises in this first week for reactivating the quadriceps muscles when they provoke no pain</i>	2
Electrostimulation, in combination with conventional rehabilitation, might be more effective for improving muscle strength for up to 2 months after ACLR than conventional rehabilitation alone. However, its effect on long-term functional performance and self-reported knee function is inconclusive. <i>Recommendation: electrostimulation can be useful as an addition to isometric strength training for re-educating voluntary contraction of the quadriceps muscles during the first postoperative weeks</i>	1
CKC and OKC training can be used for regaining quadriceps strength After ACLR, OKC exercises can be performed from week 4 postoperative in a restricted ROM of 90–45° <i>Recommendation: When the quadriceps is reactivated, concentric and eccentric exercises should be used to replace the isometric exercises, provided that the knee does not react with effusion or (an increase in) pain. CKC exercises can be performed from week 2 postoperative. For BPTB, OKC exercises can be started from 4 weeks postoperative in a restricted ROM of 90–45° and extra resistance is allowed, for example, at a leg extension machine. For HS, OKC exercises also can be started from 4 weeks postoperative in a restricted ROM of 90–45°, but no extra weight should be added in the first 12 weeks to prevent graft elongation. ROM can be increased to 90–30° in week 5, to 90–20° in week 6, to 90–10° in week 7 and to full ROM in week 8 for both graft types</i>	1
Neuromuscular training should be added to strength training to optimise self-reported outcome measurements	1
Altered neuromuscular function and biomechanics after ACLR could be a risk factor for second ACL injury (graft rerupture or contralateral rupture) <i>Recommendation: neuromuscular training should be added to strength training. Pay attention to a correct quality of movement for prevention of reinjuries</i>	2
Psychological factors as self-efficacy, locus of control and fear of reinjury have influence on the rehabilitation process and return to play after ACLR <i>Recommendation: evaluate psychological changes during rehabilitation with an objective instrument</i>	2
Criteria for return to play	2
An extensive test battery should be used to determine the return-to-play moment, but there are no tests or test batteries that have been tested for construct or predictive validity for return to play	2
It is not clear which cut-off point of the LSI should be used for strength and hop tests <i>Recommendation: perform an extensive test battery for quantity and quality of movement. This test battery should include at least a strength test battery and a hop test battery and measurement of quality of movement. An LSI of >90% could be used as a cut-off point. For pivoting/contact sports, an LSI of ≥100% is recommended</i>	3

ACLR, anterior cruciate ligament reconstruction; BPTB, bone-patellar tendon-bone; CKC, closed kinetic chain; HS, hamstring; LSI, Limb Symmetry Index; OKC, open kinetic chain; ROM, range of motion.

meniscus repair, cartilage damage (location, size and grade), ligamentous injuries or complications during surgery. Also, when possible in his setting, the physical therapist should inform the surgeon about the current status of the patient preceding to every preoperative or postoperative outpatient appointment, to ensure that appropriate levels of stress are being applied to the healing tissues.¹²²

During the first meeting of the working and steering group, it was decided to define different phases during rehabilitation after ACLR. Current literature describes time-based rehabilitation protocols that are mainly based on the remodelling process of the graft.⁵¹ Since there is still uncertainty about the time schedule of the human remodelling process, it makes more sense to incorporate functional goal-based criteria to the rehabilitation protocol.^{123–126} Besides, there are individual differences in neuromotor learning and flexibility after ACLR. These underline the importance of a shift from time-based rehabilitation to goal-based rehabilitation with neuromuscular goals and criteria to manage the rehabilitation process. These goals for progression to the next phase and description of interventions during each phase are based on the International Classification of Functioning, Disability and Health (WHO 2001). Our evidence statement consists of three phases (see online supplementary appendix 2) with a goal-based progression: the so-called traffic-light method of progression through phases. This is relatively new in rehabilitation, but it assures a more patient-tailored rehabilitation.^{118 127} Patients can start with the next phase only if specific goals of the previous phase are achieved and these should be confirmed with objective tests (see online supplementary appendix 2 for criteria).

The steering group advises to start rehabilitation immediate after ACLR and continue rehabilitation for 9–12 months, depending on the final return-to-work or play goals of the patient.¹²⁸ This rehabilitation period is necessary to allow return to high-intensity sport or physically demanding work. This term differs from a previous ACLR rehabilitation protocol by van Grinsven *et al.*,⁵¹ who presented a 22-week rehabilitation with four time-based phases. Recent evidence suggests that longer rehabilitation periods are needed, because most patients are not able to reach the end-rehabilitation goals in 22 weeks.^{129 130} Herbst *et al.*¹³¹ presented a new functional performance test battery and concluded that most patients were not ready for return to play even at 8 months after ACLR. Others suggest that home-based rehabilitation is as effective as supervised rehabilitation.^{53 56 57} These home-based rehabilitation programmes are designed in countries where patients live too far from a physical therapist to schedule a visit a few times in a week. Important to mention is that these programmes are not designed for patients who perform high-intensity sports. Still, there is no evidence which rehabilitation period or how many appointments per week works best for return to play.

During postoperative rehabilitation, a physical therapist can use several treatment modalities, of which some are proven to be effective in literature and some are not (table 6). It is known that immediate weight bearing is safe (level 3).⁹¹ The steering group recommends that immediate weight bearing should only be tolerated if there is a correct gait pattern (if necessary with crutches) and no pain, effusion or increase in temperature when walking or shortly after walking. Cryotherapy could eventually be applied in the first postoperative week to reduce pain (level 1).^{103–107} The steering group suggests to start isometric quadriceps exercises in this first week for reactivating the quadriceps muscles when they provoke no pain (level 2).^{83 90} In addition,

electrostimulation can be useful for re-educating voluntary contraction of the quadriceps muscles during the first postoperative weeks (level 1).^{63 93 94 98–101} When the quadriceps is reactivated, concentric and subsequently eccentric exercises should be used to replace the isometric exercises, provided that the knee does not react with effusion or (an increase in) pain. Quadriceps strength training can be performed in CKC and OKC. Concentric CKC exercises can be performed from week 2 postoperative. For OKC exercises, there should be a distinction between ACLR with a BPTB graft or a HS graft. For BPTB, OKC exercises can be started from 4 weeks postoperative in a restricted ROM of 90–45° and extra resistance is allowed, for example, at a leg extension machine (level 2). For HS, OKC exercises can also be started from 4 weeks postoperative in a restricted ROM of 90–45°, but no extra weight should be added in the first 12 weeks to prevent graft elongation (level 2).^{65 66} ROM can be increased to 90–30° in week 5, to 90–20° in week 6, to 90–10° in week 7 and to full ROM in week 8 for both graft types.⁵¹ The steering group strongly advises that neuromuscular training should be added to strength training to optimise outcome measurements (level 1).^{72 73 75 78 79 85 87–90}

In literature about rehabilitation after ACLR, there is a lack of focus on the evaluation and training of the quality of movement as measurement of neuromuscular recovery. The relevance to focus more on the quality of movement is underlined by the fact that altered neuromuscular function and biomechanics after ACLR could be a risk factor for a second ACL injury (level 2).^{35 36 119} An improvement in quality of movement can be observed as an effect of motor learning. In the early phases of rehabilitation, mostly explicit motor learning is necessary, but we advocate that in the late phase of rehabilitation, more implicit motor learning strategies should be used.¹³² This is because implicit learning may produce more stable solutions under stress, anxiety-provoking conditions and fatigue states, especially necessary in sports.¹³⁰

Which measurements and assessments can be applied to monitor progression during the rehabilitation programme and to determine outcomes at the end of rehabilitation programme?

There are no clear recommendations regarding the use of measurements for quantity (eg, strength and hop performance) and quality of movement during the postoperative rehabilitation process. The criteria to progress from phase 1 to phase 2 or from phase 2 to phase 3 are based on expert opinion (see online supplementary appendix 2). Besides the quantity and quality of movement, it is important to evaluate psychological changes during rehabilitation with an objective instrument, for example, with the Marx Scale, the Psychovitality Scale or the Knee Self-Efficacy Scale (level 2).^{22 108 113–115 117}

What criteria should be used to determine the moment of return to play?

All included systematic reviews about measurements of functional performance have the same conclusion: studies are lacking objective physiological criteria at what time after ACLR return to play is allowed.^{27 31 32 108–110} There is also no conclusive evidence that any test or test battery can accurately identify athletes at high risk of reinjury. Therefore, the steering group recommends to perform an extensive test battery for quantity and quality of movement (level 2).^{27 31 32 108–111} This test battery should include at least a strength test battery and a hop test battery and measurement of quality of movement for

determining the moment for return to play. An LSI of >90% could be used as a cut-off point. For pivoting/contact sports, an LSI of $\geq 100\%$ is recommended (see online supplementary appendix 2).¹³³ Qualitative scoring systems as the Jump Landing System and Landing Error Scoring System have been developed in the past few years, but it is still unclear in which manner quality of movement plays a role in the occurrence of ACL reinjuries.^{134–138} Therefore, prospective studies are needed to evaluate whether these scoring systems are able to measure neuromotor control and to investigate the predictive validity of those qualitative scoring systems.

LIMITATIONS

Meta-analyses and systematic reviews were included in this study. A strength is the additional weight in evidence, but a limitation is that the included meta-analyses and systematic reviews may have used other inclusion and exclusion criteria than the ones used in this study. The main discrepancy is that they did not mention the graft choice or brace-free rehabilitation in their information. We accept this limitation because many meta-analyses and systematic reviews are written about rehabilitation after ACLR and they comprise the highest level of evidence. In most cases, they give useful advice for day-to-day clinical practice and add value to the included RCTs and prospective cohort studies.

Despite the extensive literature search, our recommendations are lacking a certain specificity regarding sets, repetitions and resistance used in exercises. This is because included studies are vague in describing these parameters. However, it is extremely difficult to describe this for a population of patients, because these parameters depend on pain, effusion and level of the patient (eg, concerning type of sport and experience with strength training). We expect that every sports physical therapist is able to address the correct parameters to his individual patient, but suggest that more research is needed on this topic.

What are the findings?

- ▶ Rehabilitation after anterior cruciate ligament reconstruction should consist of three phases, which are goal-based rather than time-based. The goals for progression to the next phase and description of interventions during each phase should be based on the International Classification of Functioning, Disability and Health.
- ▶ An extensive test battery, including at least a strength test battery, a hop test battery and measurement of quality of movement, is needed to determine the moment of return to play.

How might it impact on clinical practice in the future?

- ▶ Thirty-five per cent of athletes after anterior cruciate ligament reconstruction (ACLR) do not return to preinjury sport level within 2 years.
- ▶ Closed and open kinetic chain quadriceps training can be used for regaining strength, but neuromuscular training should be added to strength training to optimise outcome measurements after ACLR.
- ▶ Movement quality may affect the ACL (re)injury rate.

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REFERENCES

- 1 Prodromos CC, Han Y, Rogowski J, et al. A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury-reduction regimen. *Arthroscopy* 2007;23:1320–5.
- 2 Moses B, Orchard J, Orchard J. Systematic review: annual incidence of ACL injury and surgery in various populations. *Res Sports Med* 2012;20:157–79.
- 3 Yoo JH, Lim BO, Ha M, et al. A meta-analysis on the effect of neuromuscular training on the prevention of the anterior cruciate ligament injury in female athletes. *Knee Surg Sports Traumatol Arthrosc* 2010;18:824–30.
- 4 Hewett TE, Zazulak BT, Myer GD, et al. A review of electromyographic activation levels, timing differences, and increased anterior cruciate ligament injury incidence in female athletes. *Br J Sports Med* 2005;39:347–50.
- 5 Lephart SM, Ferris CM, Fu FH. Risk factors associated with noncontact anterior cruciate ligament injuries in female athletes. *Instr Course Lect* 2002;51:307–10.
- 6 Toth AP, Cordasco FA. Anterior cruciate ligament injuries in the female athlete. *J Gen Specif Med* 2001;4:25–34.
- 7 Huston LJ, Greenfield ML, Wojtys EM. Anterior cruciate ligament injuries in the female athlete. Potential risk factors. *Clin Orthop Relat Res* 2000;50–63.
- 8 Myer GD, Sugimoto D, Thomas S, et al. The influence of age on the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: a meta-analysis. *Am J Sports Med* 2013;41:203–15.
- 9 Zimmy ML, Schutte M, Dabiezies E. Mechanoreceptors in the human anterior cruciate ligament. *Anat Rec* 1986;214:204–9.
- 10 Decker LM, Moraiti C, Stergiou N, et al. New insights into anterior cruciate ligament deficiency and reconstruction through the assessment of knee kinematic variability in terms of nonlinear dynamics. *Knee Surg Sports Traumatol Arthrosc* 2011;19:1620–33.
- 11 Courtney CA, Rine RM. Central somatosensory changes associated with improved dynamic balance in subjects with ACL deficiency. *Gait Posture* 2006;24:190–5.
- 12 Kapreli E, Athanasopoulos S, Gliatis J, et al. ACL deficiency causes brain plasticity: a functional MRI study. *Am J Sports Med* 2009;37:2419–26.
- 13 Ardern CL, Taylor NF, Feller JA, et al. Fifty-five percent return to competitive sport following anterior cruciate ligament surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med* 2014;48:1543–52.
- 14 Ardern CL, Webster KE, Taylor NF, et al. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. *Br J Sports Med* 2011;45:596–606.
- 15 Shah VM, Andrews JR, Fleisig GS, et al. Return to play after anterior cruciate ligament reconstruction in National Football League athletes. *Am J Sports Med* 2010;38:2233–9.
- 16 Ardern CL, Taylor NF, Feller JA, et al. Return-to-sport outcomes at 2 to 7 years after anterior cruciate ligament reconstruction surgery. *Am J Sports Med* 2012;40:41–8.
- 17 Brophy RH, Schmitz L, Wright RW, et al. Return to play and future ACL injury risk after ACL reconstruction in soccer athletes from the Multicenter Orthopaedic Outcomes Network (MOON) group. *Am J Sports Med* 2012;40:2517–22.
- 18 McCullough KA, Phelps KD, Spindler KP, et al. Return to high school- and college-level football after anterior cruciate ligament reconstruction: a Multicenter Orthopaedic Outcomes Network (MOON) cohort study. *Am J Sports Med* 2012;40:2523–9.
- 19 Kvist J, Ek A, Sporrstedt K, et al. Fear of re-injury: a hindrance for returning to sports after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2005;13:393–7.
- 20 Chmielewski TL, Jones D, Day T, et al. The association of pain and fear of movement/reinjury with function during anterior cruciate ligament reconstruction rehabilitation. *J Orthop Sports Phys Ther* 2008;38:746–53.
- 21 Webster KE, Feller JA, Lambros C. Development and preliminary validation of a scale to measure the psychological impact of returning to sport following anterior cruciate ligament reconstruction surgery. *Phys Ther Sport* 2008;9:9–15.
- 22 Langford JL, Webster KE, Feller JA. A prospective longitudinal study to assess psychological changes following anterior cruciate ligament reconstruction surgery. *Br J Sports Med* 2009;43:377–81.
- 23 Ardern CL, Webster KE, Taylor NF, et al. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. *Am J Sports Med* 2011;39:538–43.

- 24 Ardern CL, Taylor NF, Feller JA, *et al.* Psychological responses matter in returning to preinjury level of sport after anterior cruciate ligament reconstruction surgery. *Am J Sports Med* 2013;41:1549–58.
- 25 Flanigan DC, Everhart JS, Pedroza A, *et al.* Fear of reinjury (kinesiophobia) and persistent knee symptoms are common factors for lack of return to sport after anterior cruciate ligament reconstruction. *Arthroscopy* 2013;29:1322–9.
- 26 Ahldén M, Samuelsson K, Sernert N, *et al.* The Swedish National anterior cruciate ligament register. A report on baseline variables and outcomes of surgery for almost 18,000 patients. *Am J Sports Med* 2012;40:2230–5.
- 27 Barber-Westin SD, Noyes FR. Objective criteria for return to athletics after anterior cruciate ligament reconstruction and subsequent reinjury rates: a systematic review. *Phys Sportsmed* 2011;39:100–10.
- 28 Paterno MV, Rauh MJ, Schmitt LC, *et al.* Incidence of contralateral and ipsilateral anterior cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. *Clin J Sport Med* 2012;22:116–21.
- 29 Wright RW, Dunn WR, Amendola A, *et al.* Risk of tearing the intact anterior cruciate ligament in the contralateral knee and rupturing the anterior cruciate ligament graft during the first 2 years after anterior cruciate ligament reconstruction. A prospective MOON cohort study. *Am J Sports Med* 2007;35:1131–13.
- 30 The Swedish National ACL Register. Annual report 2011. <http://www.aclregister.nu>
- 31 Barber-Westin SD, Noyes FR. Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction. *Arthroscopy* 2011;27:1697–705.
- 32 Engelen-van Melick N, van Cingel REH, Tijssen MPW, *et al.* Assessment of functional performance after anterior cruciate ligament reconstruction: a systematic review of measurement procedures. *Knee Surg Sports Traumatol Arthrosc* 2013;21:869–79.
- 33 Renstrom P, Ljungqvist A, Arendt E, *et al.* Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement. *Br J Sports Med* 2008;42:394–412.
- 34 Padua DA, DiStefano LJ, Beutler AI, *et al.* The landing error scoring system as a screening tool for an anterior cruciate ligament injury-prevention program in elite-youth soccer athletes. *J Athl Train* 2015;50:589–95.
- 35 Hewett TE, Myer GD, Ford KR, *et al.* Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes. A prospective study. *Am J Sports Med* 2005;33:492–501.
- 36 Paterno MV, Schmitt LC, Ford KR, *et al.* Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med* 2010;38:1968–78.
- 37 Vereniging NTVG. EBRO richtlijnen. *Ned Tijdschr Geneesk* 2005;149:213–4.
- 38 Bernards ATM, Berghmans LCM, Van Heeswijk-Faase IC, *et al.* KNGF richtlijn Stress (urine)incontinentie. *Ned Tijdschr Fysiother* 2011;121(Suppl):1–23.
- 39 Kerkhoffs GM, van den Bekerom M, Elders LAM, *et al.* Diagnosis, treatment and prevention of ankle sprains: an evidence-based clinical guideline. *Br J Sports Med* 2012;46:854–60.
- 40 de Valk EJ, Moen MH, Winters M, *et al.* Preoperative patient and injury factors of successful rehabilitation after anterior cruciate ligament reconstruction with single-bundle techniques. *Arthroscopy* 2013;29:1879–95.
- 41 Shaarani SR, O'Hare C, Quinn A, *et al.* Effect of prehabilitation on the outcome of anterior cruciate ligament reconstruction. *Am J Sports Med* 2013;41:2117–27.
- 42 Eitzen I, Holm I, Risberg MA. Preoperative quadriceps strength is a significant predictor of knee function two years after anterior cruciate ligament reconstruction. *Br J Sports Med* 2009;43:371–6.
- 43 Grindem H, Granan LP, Risberg MA, *et al.* How does a combined preoperative and postoperative rehabilitation programme influence the outcome of ACL reconstruction 2 years after surgery? A comparison between patients in the Delaware-Oslo ACL Cohort and the Norwegian National Knee Ligament Registry. *Br J Sports Med* 2015;49:385–9.
- 44 Heijne A, Ång BO, Werner S. Predictive factors for 12-month outcome after anterior cruciate ligament reconstruction. *Scand J Sci Med Sports* 2009;19:842–9.
- 45 Lepley LK, Palmieri-Smith RM. Pre-operative quadriceps is related to post-operative activation, not strength, in patients post-ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2016;24:236–46.
- 46 Månsson O, Kartus J, Sernert N. Pre-operative factors predicting good outcome in terms of health-related quality of life after ACL reconstruction. *Scand J Med Sci Sports* 2013;23:15–22.
- 47 McHugh MP, Tyler TF, Gleim GW, *et al.* Preoperative indicators of motion loss and weakness following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther* 1998;27:407–11.
- 48 McHugh MP, Tyler TF, Browne MG, *et al.* Electromyographic predictors of residual quadriceps muscle weakness after anterior cruciate ligament reconstruction. *Am J Sports Med* 2002;30:334–9.
- 49 Quelard B, Sonnery-Cottet B, Zaïny R, *et al.* Preoperative factors correlating with a prolonged range of motion deficit after anterior cruciate ligament reconstruction. *Am J Sports Med* 2010;38:2034–9.
- 50 Coppola SM, Collins SM. Is physical therapy more beneficial than unsupervised home exercise in treatment of post surgical knee disorders? A systematic review. *Knee* 2009;16:171–5.
- 51 van Grinsven S, van Cingel RE, Holla CJ, *et al.* Evidence-based rehabilitation following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2010;18:1128–44.
- 52 Wright RW, Preston E, Fleming BC, *et al.* A systematic review of anterior cruciate ligament reconstruction rehabilitation. Part I: continuous passive motion, early weight bearing, postoperative bracing, and home-based rehabilitation. *J Knee Surg* 2008;21:217–24.
- 53 Beard DJ, Dodd CAF. Home or supervised rehabilitation following anterior cruciate ligament reconstruction: a randomized controlled trial. *J Orthop Sports Phys Ther* 1998;27:134–43.
- 54 Beynonn BD, Uh BS, Johnson RJ, *et al.* Rehabilitation after anterior cruciate ligament reconstruction. A prospective, randomized, double-blind comparison of programs administered over 2 different time intervals. *Am J Sports Med* 2005;33:347–59.
- 55 Beynonn BD, Johnson RJ, Naud S, *et al.* Accelerated versus nonaccelerated rehabilitation after anterior cruciate ligament reconstruction. A prospective, randomized, double-blind investigation evaluating knee joint laxity using roentgen stereophotogrammetric analysis. *Am J Sports Med* 2011;39:2536–48.
- 56 Grant JA, Mohtadi NGH. Two- to 4-year follow-up to a comparison of home versus physical therapy-supervised rehabilitation programs after anterior cruciate ligament reconstruction. *Am J Sports Med* 2010;38:1389–94.
- 57 Hohmann E, Tetsworth K, Bryant A. Physiotherapy-guided versus home-based, unsupervised rehabilitation in isolated anterior cruciate injuries following surgical reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2011;19:1158–67.
- 58 Dragicevic-Cvetkovic D, Jandric S, Bijeljic S, *et al.* The effects of rehabilitation protocol on functional recovery after anterior cruciate ligament reconstruction. *Med Arch* 2014;68:350–2.
- 59 Muneta T, Sekiya I, Ogiuchi T, *et al.* Effects of aggressive early rehabilitation on the outcome of anterior cruciate ligament reconstruction with multi-strand semitendinosus tendon. *Int Orthop* 1998;22:352–6.
- 60 Andersson D, Samuelsson K, Karlsson J. Treatment of anterior cruciate ligament injuries with special reference to surgical technique and rehabilitation: an assessment of randomized controlled trials. *Arthroscopy* 2009;25:653–85.
- 61 Glass R, Waddell J, Hoogenboom B. The effects of open versus closed kinetic chain exercises on patients with ACL deficient or reconstructed knees: a systematic review. *N Am J Sports Phys Ther* 2010;5:74–84.
- 62 Lobb R, Tumilty S, Claydon LS. A review of systematic reviews on anterior cruciate ligament reconstruction. *Phys Ther Sport* 2012;13:270–8.
- 63 Wright RW, Preston E, Fleming BC, *et al.* A systematic review of anterior cruciate ligament reconstruction rehabilitation. Part II: open versus closed kinetic chain exercises, neuromuscular electrical stimulation, accelerated rehabilitation, and miscellaneous topics. *J Knee Surg* 2008;21:225–34.
- 64 Bynum EB, Barrack RL, Alexander AH. Open versus closed chain kinetic exercises after anterior cruciate ligament reconstruction. A prospective randomized study. *Am J Sports Med* 1995;23:401–6.
- 65 Fukuda TY, Fingerhut D, Coimbra Moreira V, *et al.* Open kinetic chain exercises in a restricted range of motion after anterior cruciate ligament reconstruction. A randomized controlled trial. *Am J Sports Med* 2013;41:788–94.
- 66 Heijne A, Werner S. Early versus late start of open kinetic chain quadriceps exercises after ACL reconstruction with patellar tendon or hamstring grafts: a prospective randomized outcome study. *Knee Surg Sports Traumatol Arthrosc* 2007;15:402–14.
- 67 Mikkelsen C, Werner S, Eriksson E. Closed kinetic chain alone compared to combined open and closed kinetic chain exercises for quadriceps strengthening after anterior cruciate ligament reconstruction with respect to return to sports. *Knee Surg Sports Traumatol Arthrosc* 2000;8:337–42.
- 68 Morrissey MC, Drechsler WI, Morrissey D, *et al.* Effects of distally fixated versus nondistally fixated leg extensor resistance training on knee pain in the early period after anterior cruciate ligament reconstruction. *Phys Ther* 2002;82:35–43.
- 69 Perry MC, Morrissey MC, King JB, *et al.* Effects of closed versus open kinetic chain knee extensor resistance training on knee laxity and leg function in patients during the 8- to 14-week post-operative period after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2005;13:357–69.
- 70 Uçar M, Koca I, Eroglu M, *et al.* Evaluation of open and closed kinetic chain exercises in rehabilitation following anterior cruciate ligament reconstruction. *J Phys Ther Sci* 2014;26:1875–8.
- 71 Augustsson J. Documentation of strength training for research purposes after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2014;21:1849–55.
- 72 Gokeler A, Bisschop M, Benjaminse A, *et al.* Quadriceps function following ACL reconstruction and rehabilitation: implications for optimization of current practices. *Knee Surg Sports Traumatol* 2014;22:1163–74.
- 73 Kruse LM, Gray B, Wright RW. Rehabilitation after anterior cruciate ligament reconstruction. A systematic review. *J Bone Joint Surg Am* 2012;94:1737–48.
- 74 Baltaci G, Harput G, Haksever B, *et al.* Comparison between Nintendo Wii Fit and conventional rehabilitation on functional performance outcomes after hamstring

- anterior cruciate ligament reconstruction: prospective, randomized, controlled, double-blind clinical trial. *Knee Surg Sports Traumatol Arthrosc* 2013;21:880–7.
- 75 Berschin G, Sommer B, Behrens A, *et al.* Whole body vibration exercise protocol versus a standard exercise protocol after ACL reconstruction: a clinical randomized controlled trial with short term follow-up. *J Sports Sci Med* 2014;13:580–9.
- 76 Bieler T, Sobol NA, Andersen LL, *et al.* The effects of high-intensity versus low-intensity resistance training on leg extensor power and recovery of knee function after ACL-reconstruction. *Biomed Res Int* 2014;2014:278512.
- 77 Cappellino F, Paolucci T, Zangrando F, *et al.* Neurocognitive rehabilitation approach effectiveness after anterior cruciate ligament reconstruction with patellar tendon. A randomized controlled trial. *Eur J Phys Rehabil Med* 2012;48:17–30.
- 78 Cooper RL, Taylor NF, Feller JA. A randomised controlled trial of proprioceptive and balance training after surgical reconstruction of the anterior cruciate ligament. *Res Sports Med* 2005;13:217–30.
- 79 Fu CLA, Yung SHP, Law KYB, *et al.* The effect of whole-body vibration therapy on neuromuscular control after anterior cruciate ligament reconstruction: a randomized controlled trial. *Am J Sports Med* 2013;41:804–14.
- 80 Gerber JP, Marcus RL, Dibble LE, *et al.* Safety, feasibility, and efficacy of negative work exercise via eccentric muscle activity following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther* 2007;37:10–18.
- 81 Gerber JP, Marcus RL, Dibble LE, *et al.* Effects of early progressive eccentric exercise on muscle structure after anterior cruciate ligament reconstruction. *J Bone Joint Surg Am* 2007;89:559–70.
- 82 Gerber JP, Marcus RL, Dibble LE, *et al.* Effects of early progressive eccentric exercise on muscle size and function after anterior cruciate ligament reconstruction: a 1-year follow-up study of a randomized clinical trial. *Phys Ther* 2009;89:51–9.
- 83 Isberg J, Faxén E, Brandsson S, *et al.* Early active extension after anterior cruciate ligament reconstruction does not result in increased laxity of the knee. *Knee Surg Sports Traumatol Arthrosc* 2006;14:1108–15.
- 84 Kinikli GI, Yüksel I, Baltacı G, *et al.* The effect of progressive eccentric and concentric training on functional performance after autogenous hamstring anterior cruciate ligament reconstruction: a randomized controlled study. *Acta Orthop Traumatol Turc* 2014;48:283–9.
- 85 Liu-Ambrose T, Taunton JE, MacIntyre D, *et al.* The effects of proprioceptive or strength training on the neuromuscular function of the ACL reconstructed knee: a randomized clinical trial. *Scand J Med Sci Sports* 2003;13:115–23.
- 86 Moezy A, Olyaei G, Hadian M, *et al.* A comparative study of whole body vibration training and conventional training on knee proprioception and postural stability after anterior cruciate ligament reconstruction. *Br J Sports Med* 2008;42:373–8.
- 87 Risberg MA, Holm I, Myklebust G, *et al.* Neuromuscular training versus strength training during first 6 months after anterior cruciate ligament reconstruction: a randomized clinical trial. *Phys Ther* 2007;87:737–50.
- 88 Risberg MA, Holm I. The long-term effect of 2 postoperative rehabilitation programs after anterior cruciate ligament reconstruction: a randomized controlled clinical trial with 2 years follow-up. *Am J Sports Med* 2009;37:1958–66.
- 89 Sekir U, Gur H, Akova B. Early versus late start of isokinetic hamstring-strengthening exercise after anterior cruciate ligament reconstruction with patellar tendon graft. *Am J Sports Med* 2010;38:492–500.
- 90 Shaw T, Williams MT, Chipchase LS. Do early quadriceps exercises affect the outcome of ACL reconstruction? A randomized controlled trial. *Austr J Phys* 2005;51:9–17.
- 91 Tyler TF, McHugh MP, Gleim GW, *et al.* The effect of immediate weightbearing after anterior cruciate ligament reconstruction. *Clin Orthop Relat Res* 1998:141–8.
- 92 Risberg MA, Mørk M, Jenssen HK, *et al.* Design and implementation of a neuromuscular training program following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther* 2001;31:620–31.
- 93 Imoto AM, Peccin S, Melo Almeida GJ, *et al.* Effectiveness of electrical stimulation on rehabilitation after ligament and meniscal injuries: a systematic review. *Sao Paulo Med J* 2011;129:414–23.
- 94 Kim KM, Croy T, Hertel J, *et al.* Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: a systematic review. *J Orthop Sport Phys Ther* 2010;40:383–91.
- 95 Wasielewski NJ, Parker TM, Kotsko KM. Evaluation of electromyographic biofeedback for the quadriceps femoris: a systematic review. *J Athl Train* 2011;46:543–54.
- 96 Christanell F, Hoser C, Huber R, *et al.* The influence of electromyographic biofeedback therapy on knee extension following anterior cruciate ligament reconstruction: a randomized controlled trial. *Sports Med Arthrosc Rehabil Ther Technol* 2012;4:41.
- 97 Ediz L, Ceylan MF, Turktas U, *et al.* A randomized controlled trial of electrostimulation effects on effusion, swelling and pain after anterior cruciate ligament reconstruction: a pilot study. *Clin Rehabil* 2012;26:413–22.
- 98 Feil S, Newell J, Minogue C, *et al.* The effectiveness of supplementing a standard rehabilitation program with superimposed neuromuscular electrical stimulation after anterior cruciate ligament reconstruction: a prospective, randomized, single-blind study. *Am J Sports Med* 2011;39:1238–47.
- 99 Fitzgerald GK, Piva SR, Irrgang JJ. A modified neuromuscular electrical stimulation protocol for quadriceps strength training following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther* 2003;33:492–501.
- 100 Paternostro-Sluga T, Fialka C, Alacamlioglu Y, *et al.* Neuromuscular electrical stimulation after anterior cruciate ligament surgery. *Clin Orthop Relat Res* 1999:166–75.
- 101 Taradaj J, Halski T, Kucharzewski M, *et al.* The effect of neuromuscular electrical stimulation on quadriceps strength and knee function in professional soccer players: return to sport after ACL reconstruction. *Biomed Res Int* 2013;2013:802534.
- 102 Lepley LK, Wojtys EM, Palmieri-Smith RM. Combination of eccentric exercise and neuromuscular electrical stimulation to improve biomechanical limb symmetry after anterior cruciate ligament reconstruction. *Clin Biomech* 2015;30:738–47.
- 103 Martimbianco AL, Gomes da Silva BN, de Carvalho AP, *et al.* Effectiveness and safety of cryotherapy after arthroscopic anterior cruciate ligament reconstruction. A systematic review of the literature. *Phys Ther* 2014;15:261–8.
- 104 Raynor MC, Pietrobon R, Guller U, *et al.* Cryotherapy after ACL reconstruction: a meta-analysis. *J Knee Surg* 2005;18:123–9.
- 105 Hubbard TJ, Denegar CR. Does cryotherapy improve outcomes with soft tissue injury? *J Athl Train* 2004;39:278–9.
- 106 Edwards DJ, Rimmer M, Keene GCR. The use of cold therapy in the postoperative management of patients undergoing arthroscopic anterior cruciate ligament reconstruction. *Am J Sports Med* 1996;24:193–5.
- 107 Glenn RE, Spindler KP, Warren TA, *et al.* Cryotherapy decreases intraarticular temperature after ACL reconstruction. *Clin Orthop Relat Res* 2004:268–72.
- 108 Czuppon S, Racette BA, Klein SE, *et al.* Variables associated with return to sport following anterior cruciate ligament reconstruction: a systematic review. *Br J Sports Med* 2014;48:356–64.
- 109 Harris JD, Abrams GD, Bach BR, *et al.* Return to sport after ACL reconstruction. *Orthopedics* 2014;37:e103–8.
- 110 Narducci E, Waltz A, Gorski K, *et al.* The clinical utility of functional performance tests within one-year post-ACL reconstruction: a systematic review. *Int J Sports Phys Ther* 2011;6:333–42.
- 111 Müller U, Krüger-Franke M, Schmidt M, *et al.* Predictive parameters for return to pre-injury level of sport 6 months following anterior cruciate ligament reconstruction surgery. *Knee Surg Sports Traumatol Arthrosc* 2015;23:3623–31.
- 112 Thomeé R, Neeter C, Gustavsson A, *et al.* Variability in leg muscle power and hop performance after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2012;20:1134–51.
- 113 Everhart JS, Best TM, Flanigan DC. Psychological predictors of anterior cruciate ligament reconstruction outcomes: a systematic review. *Knee Surg Sports Traumatol Arthrosc* 2015;23:752–62.
- 114 te Wierike SC, van der Sluis A, van den Akker-Scheek I, *et al.* Psychosocial factors influencing the recovery of athletes with anterior cruciate ligament injury: a systematic review. *Scand J Med Sci Sports* 2012;23:527–40.
- 115 Gobbi A, Francisco R. Factors affecting return to sports after anterior cruciate ligament reconstruction with patellar tendon and hamstring graft: a prospective clinical investigation. *Knee Surg Sports Traumatol Arthrosc* 2006;14:1021–8.
- 116 Laboute E, Savalli L, Puig P, *et al.* Analysis of return to competition and repeat rupture for 298 anterior cruciate ligament reconstructions with patellar or hamstring tendon autograft in sportspeople. *Ann Phys Rehabil Med* 2010;53:598–614.
- 117 Thomeé P, Währborg P, Börjesson M, *et al.* Determinants of self-efficacy in the rehabilitation of patients with anterior cruciate ligament injury. *J Rehabil Med* 2007;39:486–92.
- 118 Zaffagnini S, Grassi A, Marcheggiani Muccioli GM, *et al.* Return to sport after anterior cruciate ligament reconstruction in professional soccer players. *Knee* 2014;21:731–5.
- 119 Swärd P, Kostogiannis I, Roos H. Risk factors for a contralateral anterior cruciate ligament injury. *Knee Surg Sports Traumatol Arthrosc* 2010;18:277–91.
- 120 Wright RW, Magnussen RA, Dunn WR, *et al.* Ipsilateral graft and contralateral ACL rupture five years or more following ACL reconstruction. A systematic review. *J Bone Joint Surg Am* 2011;93:1159–65.
- 121 de Jong SN, Caspel DR, van Haeff MJ, *et al.* Functional assessment and muscle strength before and after reconstruction of chronic anterior cruciate ligament lesions. *Arthroscopy* 2007;23:21–8.
- 122 Mueller MJ, Maluf KS. Tissue adaptation to physical stress: a proposed “physical stress theory” to guide physical therapist practice, education, and research. *Phys Ther* 2002;82:383–403.
- 123 Claes S, Verdonk P, Forsyth R, *et al.* The ‘ligamentization’ process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. *Am J Sports Med* 2011;39:2476–83.
- 124 Janssen RPA, Wijk J, van derFiedler A, *et al.* Remodelling of human hamstring autografts after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2011;19:1299–306.
- 125 Ntoulia A, Papadopoulou F, Ristanis S, *et al.* Revascularization process of the bone-patellar tendon-bone autograft evaluated by contrast-enhanced magnetic resonance imaging 6 and 12 months after anterior cruciate ligament reconstruction. *Am J Sports Med* 2011;39:1478–86.

- 126 Scheffler SU, Unterhauser FN, Weiler A. Graft remodeling and ligamentization after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2008;16:834–42.
- 127 Della Villa S, Bolchini L, Ricci M, et al. Clinical outcomes and return-to-sports participation of 50 soccer players after anterior cruciate ligament reconstruction through a sport-specific rehabilitation protocol. *Sports Health* 2012;4:17–24.
- 128 Grindem H, Snyder-Mackler L, Moksnes H, et al. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med* 2016;50:804–8.
- 129 Hildebrandt C, Müller L, Zisch B, et al. Functional assessments for decision-making regarding return to sports following ACL reconstruction. Part I: development of a new test battery. *Knee Surg Sports Traumatol Arthrosc* 2015;23:1273–81.
- 130 Benjaminse A, Otten E. ACL injury prevention, more effective with a different way of motor learning? *Knee Surg Sports Traumatol Arthrosc* 2011;19:622–7.
- 131 Herbst E, Hoser C, Hildebrandt C, et al. Functional assessments for decision-making regarding return to sports following ACL reconstruction. Part II: clinical application of a new test battery. *Knee Surg Sports Traumatol Arthrosc* 2015;23:1283–91.
- 132 Maxwell JP, Masters RSW, Eves F. From novice to no know-how: a longitudinal study of implicit motor learning. *J Sports Sci* 2000;18:111–20.
- 133 Thomeé R, Kaplan Y, Kvist J, et al. Muscle strength and hop performance criteria prior to return to sports after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2011;19:1798–805.
- 134 Aerts I, Cumps E, Verhagen E, et al. Efficacy of a 3 month training program on the jump-landing technique in jump-landing sports. Design of a cluster randomized controlled trial. *BMC Musculoskelet Disord* 2010;11:281.
- 135 Bell DR, Smith MD, Pennuto AP, et al. Jump-landing mechanics after anterior cruciate ligament reconstruction: a landing-error scoring system study. *J Athl Train* 2014;49:435–41.
- 136 Bien DP, Dubuque TJ. Considerations for late stage acl rehabilitation and return to sport to limit re-injury risk and maximize athletic performance. *Int J Sports Phys Ther* 2015;10:256–71.
- 137 Padua DA, Boling MC, DiStefano LJ, et al. Reliability of the Landing Error Scoring System-real time, a clinical assessment tool of jump-landing biomechanics. *J Sport Rehabil* 2011;20:145–56.
- 138 Smith HC, Johnson RJ, Shultz SJ, et al. A prospective evaluation of the Landing Error Scoring System (LESS) as a screening tool for anterior cruciate ligament injury risk. *Am J Sports Med* 2012;40:521–6.