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Aspetar clinical practice guideline on rehabilitation after anterior cruciate ligament reconstruction

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ABSTRACT

This guideline was developed to inform clinical practice on rehabilitation after anterior cruciate ligament reconstruction (ACLR) and was performed in accordance with the Appraisal of Guidelines for REsearch & Evaluation II (AGREE II) instrument and used the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach. A Guideline Development Group systematically searched and reviewed evidence using randomised clinical trials and systematic reviews to evaluate the effectiveness of rehabilitation interventions and guide clinicians and patients on the content of the optimal rehabilitation protocol after ACLR.

The guideline targets patients during rehabilitation after ACLR and investigates the effectiveness of the available interventions to the physiotherapist, alone or in combination (eg, exercise, modalities, objective progression criteria). Exercise interventions should be considered the mainstay of ACLR rehabilitation. However, there is little evidence on the dose–response relationship between volume and/or intensity of exercise and outcomes. Physical therapy modalities can be helpful as an adjunct in the early phase of rehabilitation when pain, swelling and limitations in range of motion are present. Adding modalities in the early phase may allow earlier pain-free commencement of exercise rehabilitation.

Return to running and return to training/activity are key milestones for rehabilitation after ACLR. However, there is no evidence on which progression or discharge criteria should be used.

While there is a very low level of certainty for most components of rehabilitation, most of the recommendations provided in this guideline were agreed to by expert clinicians. This guideline also highlights several new elements of ACLR management not reported previously.

INTRODUCTION

Rehabilitation is a key component of the recovery process after an anterior cruciate ligament reconstruction (ACLR). The fundamental goal for the athlete is to return to sport as quickly as possible, preferably performing at the same level as preinjury, while minimising the risk of reinjury. Around 80% of ACL-reconstructed patients return to some kind of sporting activities, but only 65% return to their preinjury level and 55% to competitive level sports.[1] Aside from graft failure,[2] short-term (eg, muscle injuries)[3 4] and long-term (eg, knee-related quality of life, meniscal or chondral injuries and osteoarthritis)[5–8] comorbidities of ACLR may also be negatively associated with an individual's rehabilitation.

There is evidence that inadequate rehabilitation combined with a premature and non-objectively evaluated return to sports may limit sporting performance and predispose to subsequent injury.[9 10] There is substantial heterogeneity in the available ACL rehabilitation protocols in the scientific literature.[11–13] There are also a variety of available tools to the physiotherapist (eg, exercises, modalities, progression criteria, etc) but no consensus regarding the content of the rehabilitation programme after ACLR nor the effectiveness of these rehabilitation interventions.[11–14] Importantly, there is no agreement on the objective progression criteria, or the discharge criteria before return to sport.[14–18]

A recent systematic review summarised the recommendations and appraised the quality of the available clinical practice guidelines for rehabilitation after ACLR.[14] Also, recent published work provided an overview of systematic reviews on the effectiveness of rehabilitation interventions after ACLR.[19] However, previous clinical practice guidelines[14] and the recent systematic review[19] fail to provide clinically relevant information required for daily practice, including advice for exercise initiation, eccentric training, plyometrics training, cross-education. The following guideline document translates the available evidence into clinical recommendations based on expert consensus to informing the treating clinician.

This clinical practice guideline aims to inform clinical practice after ACLR. We evaluated the effectiveness of interventions and provide evidence-based recommendations for the various interventions during rehabilitation. We also propose return to running and return to sport criteria based on the current literature and our clinical expertise.

METHODS

Purpose: statement of intent

The purpose of this clinical practice guideline document is to describe the evidence of effectiveness for the components of rehabilitation after ACLR. This information can then be used to inform ACLR rehabilitation protocols. This guideline is intended to be used by physiotherapists managing patients after ACLR in outpatient clinics. Physicians, orthopaedic surgeons, athletic trainers, nurse practitioners and other healthcare professionals may also benefit from this guideline. Insurance payers, governmental bodies and health-policy decision-makers may also find this guideline to be useful as

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an evolving standard of evidence regarding rehabilitation after ACLR. Additional key users of this guideline include researchers since this document may highlight gaps in the literature and grey areas that require future research.

Development process

We followed the Cochrane Handbook for Systematic Reviews of Interventions[20] and the Prisma in Exercise, Rehabilitation, Sport medicine and SporTs science tool.[21] We adhered to the refined Appraisal of Guidelines for REsearch & Evaluation (AGREE II) instrument[22] to ensure the methodological rigour and transparency.

A Guideline Development Group (GDG) was established comprising impartial clinical and methodology experts (nine physiotherapists/researchers, RK, VK, OB, DM, MP, AB, JL, JW and RW) from Aspetar, Orthopaedic and Sports Medicine Hospital, Doha, Qatar. The GDG consisted of two women (one as first author) and seven men, junior, mid-career and senior researchers of different ethnicities. A patient after ACLR (also physiotherapist) was part of the guideline's development group. We did not include patient opinion or other stakeholders via focus groups.

At the first meeting, the GDG reviewed and finalised the scope of the guideline and agreed on the set of population, intervention or exposure, comparator, outcome questions, and critical and important outcomes to be assessed. Selected outcomes included: adverse events, return to activity, pain, laxity, strength, muscle atrophy, range of motion, subjective function using patient-reported outcome measures (PROMs), swelling, functional activities, proprioception and balance. Next, the chair of the GDG coordinated the commissioning of literature searches and systematic evidence reviews and the GDG subworking groups met to review the literature.

The following databases were searched from inception to 27 December 2021: MEDLINE (PubMed), EMBASE (Elsevier), Cochrane Library (Wiley), CINAHL (EBSCO) and SPORTDiscus (EBSCO) (online supplemental file—systematic search strategy). We included peer reviewed, English language, randomised clinical trials (RCTs) in patients after ACLR that compared between physical therapy interventions or against no intervention, placebo or standard care. We excluded randomised trials in patients after ACL treated non-operatively, in patients after completion of their rehabilitation, children (<16 years), studies reporting only biomechanical results, studies reporting only on concomitant injuries such as other knee ligament injuries, meniscal or cartilage injuries, surgical decisions (eg, brace), nutritional and psychological interventions (online supplemental file—study selection and criteria). As it would be unethical to assign patients to return to sport without meeting criteria, it is unlikely there will ever be RCT data on this aspect. Accordingly, for the recommendations regarding return to activities, we included only systematic and scoping reviews.

All eligible articles were first screened by title and abstract independently by three pairs of two GDG members, and subsequently the full texts of trials that were identified as potentially eligible were retrieved and assessed. For each eligible trial, pairs of GDG members extracted data independently using a standardised, pilot tested, data extraction form developed in accordance with the Cochrane Handbook for Systematic Reviews of Interventions.[20] GDG members collected information regarding patient characteristics (age, sex, type of graft used) and outcomes of interest (means or medians and measures of variability for continuous outcomes, the number of participants analysed and the number of participants who experienced an event for dichotomous outcomes).

We used a priori-defined rules for data extraction: (1) We did not include manual testing as a valid method to measure strength.[23] (2) If data are reported in several ways, we chose to extract results in the following order: difference from baseline>limb symmetry index>raw data. (3) Swelling outcome was extracted if measured at mid-patella (not above or below). (4) Atrophy outcome was extracted if measured>7.5 cm above patella. Data were extracted from figures and graphs when necessary. Continuous data were transformed to mean and SD. Discrepancies were resolved by discussion and, when necessary, with adjudication by the GDG chair.

Extracted data were imported to Review Manager V.5.4 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014) for analysis. We summarised the effect of interventions on continuous outcomes, using the standardised mean difference (random effects) and corresponding 95% confidence interval. For dichotomous outcomes, we used the risk ratio and corresponding 95% confidence interval. When more than one study reported results for the same outcome, data was pooled. Cohen's criteria were used to interpret pooled standardised mean difference: large effect≥0.8, moderate effect 0.5–0.8 and small effect 0.2–0.5.[24]

Risk of bias was assessed using a revision of the Cochrane tool for assessing risk of bias in randomised trials (RoB V.2.0).[25] Risk of bias for systematic reviews included in the recommendations was assessed using the ROBIS tool.[26]

We followed the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach (https://gdt.gradepro.org/app/handbook/handbook.html), and used the GRADEpro Guideline Development Tool online software (https://www.gradepro.org/) to assess the quality of the body of evidence and develop and report the summary of findings tables (online supplemental file—summary of findings tables). We rated the certainty of evidence for each comparison and outcome as high, moderate, low, or very low, based on considerations of: risk of bias, inconsistency, indirectness and imprecision (online supplemental file—GRADE evidence assessment) (table 1). To assess publication bias, we planned to generate funnel plots for meta-analyses including at least 10 trials.[27]

As an additional step, we summarised the evidence findings, in a clinically meaningful way, following the a priori-defined rules: (1) When available, we prioritised pooled results coming from more than one study, over results from single studies. (2) For

Table 1 Certainty of evidence grades

Grade	Letter	Definition
High	A	We are very confident that the true effect lies close to that of the estimate of the effect
Moderate	B	We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low	C	Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect.
Very low	D	We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

muscle strength outcomes, we prioritised concentric assessment over isometric. (3) For isokinetic outcomes, we prioritised results in slower-speed over results in higher-speed (degrees/second). Findings were stratified according to the rehabilitation period in phases: very early (<1 month), early (1–2 months), intermediate (2–4 months) and advanced (>4 months).

For better understanding and interpretation of the evidence findings, the wording of the summary reads as follow: (1) 'might/can/may' for suggestive of improvement or relatively consistent beneficial effect; (2) the 'size of effect' or 'no effect' when consistent significant and clinically relevant findings (either in favour or against); and (3) 'conflicting' when findings were both in favour or against. Due to the extensive list of outcomes (Supplementary file—summary of critical and important outcomes), we opted to report those deemed clinically important in the results section and the full report of findings is available as online supplemental (summary of findings tables).

Going from evidence to recommendations

Initial recommendations were formulated by the chair of the GDG considering: effect size, certainty of evidence, cost of intervention and patient outcomes (desirable, undesirable). These recommendations were discussed at in person or videoconference meetings among the GDG members. Once agreement was achieved within the GDG members, we drafted the provisional recommendations. In total, 24 provisional recommendations were circulated through a survey to a group of experts in our institution (Aspetar, Orthopaedic and Sports Medicine Hospital, Doha, Qatar) for their feedback and the level of agreement (17 physiotherapists, 7 orthopaedic surgeons, 4 sports physicians and 1 physical coach). Each recommendation was graded anonymously on a 7-point Likert Scale, with 1 indicating complete disagreement, 4 neither agreement nor disagreement and 7 complete agreement (and an option for 'no opinion'). Mean scores and 95% CIs of agreement for each recommendation were calculated. This information was used by the GDG to finalise the guideline in a final in person/videoconference meeting.

The GDG members were responsible for reviewing and approving the final version of the guideline. All recommendations are ultimately reviewed and approved by the GDG members before publication.

RESULTS

Study selection flowchart and details on the included patient's characteristics are provided in the online supplemental file. In short, 140 RCTs were included that evaluated the effectiveness of rehabilitation interventions after ACL surgery. There were 5231 participants studied (70% male, 25% female and 5% where sex was not reported). The mean age of the participants (from studies where this was reported) was 27.9 years (online supplemental file—patient demographics). In 94% of the cases, the graft used was bone–tendon–bone (BTB) or hamstring (HS), equally distributed. The critical and important outcomes for each intervention and the risk-of-bias assessment for each outcome are presented in the online supplemental file. Most studies were judged with some concerns or high risk of bias for all outcomes (online supplemental file—risk-of-bias assessment). For the return to activities criteria, there were six systematic reviews identified. Systematic reviews were of high risk of bias, except one[28] (some concerns). Finally, the level of agreement for the proposed recommendations and comments are described in the online supplemental file.

All results are presented in detail in the summary of findings tables (online supplemental file).

Timing and structure of rehabilitation

Preoperative rehabilitation

Three studies reported the effects of a (3–6 weeks) preoperative intervention on postoperative outcomes compared with postrehabilitation only.[29–31] Two studies[32 33] investigated the effect of the addition of perturbation training to a standard preoperative strengthening programme.

Summary

- Preoperative rehabilitation can improve the knee flexion and extension at the early postoperative phase. [D]
- There is a moderate effect of preoperative rehabilitation on improved quadriceps strength 3 months after surgery. [D]
- Preoperative rehabilitation might decrease the time to return to preinjury level of activity. [D]
- There is no effect of preoperative rehabilitation on HS strength, muscle atrophy, laxity or subjective function. [D]
- There is no effect with the addition of perturbation in the preoperative rehabilitation protocol for postoperative strength, functional activities or subjective function. [D]

Unsupervised versus supervised rehabilitation

Nine studies investigated the effectiveness of independently executed (unsupervised) compared with supervised rehabilitation after ACLR.[34–42] Independently executed rehabilitation is a coached and periodised programme executed at home/other venue (gym), without a physiotherapist's supervision.

Summary

- There was no difference between the unsupervised and the supervised programme for laxity [C], subjective function, functional outcomes, strength and atrophy [D].

Rehabilitation duration

One study[43] compared rehabilitation with either a 19-week or a 32-week programme after ACLR with a BTB graft. Another study[44] compared a 19-week to a 24-week programme in patients after ACLR with HS autograft.

Summary

- A 19-week rehabilitation protocol showed no differences on knee laxity or other outcomes (strength, functional, proprioception and subjective function) compared with a longer duration protocol. [D]

Physical therapy modalities

There are 65 studies that investigated the effect of various modalities during rehabilitation after ACL surgery.

Continuous passive motion (CPM)

Four studies compared the use of CPM with no CPM,[45–48] three studies compared the use of CPM with active motion[49–51] and one study[52] compared the short-term versus long-term use of the CPM.

Summary

- There was a beneficial effect on pain medication used, knee flexion and swelling during the first 3 postoperative days when CPM was compared with no CPM. [D]
- There was no difference reported in knee range of motion, pain and swelling when CPM was compared with active knee motion exercises. [D]

Box 1 Timing and structure of rehabilitation recommendations

Preoperative rehabilitation might improve postoperative quadriceps strength, knee range of motion and may decrease the time to return to sport. We recommend at least one visit to ensure that there is adequate voluntary muscle activation and no flexion contracture that may require further preoperative visits and to educate the patient regarding the postoperative rehabilitation course.

Modal agreement: 'strongly agree' (mean: 96.1%, 93%–100%)

Unsupervised exercise execution might be followed by patients after anterior cruciate ligament reconstruction who cannot afford supervised rehabilitation, have reduced access to physiotherapy or have high motivation and are compliant to perform their rehabilitation independently. Irrespective, patients should have their programmes individually prescribed and be monitored regarding the execution of the rehabilitation protocol and to ensure the progression without adverse events.

Modal agreement: 'strongly agree' (mean: 84.7%, 77%–93%)

The **duration of the rehabilitation** protocol is individual specific and depends on the patient demonstrating their ability to safely return to their preinjury activity level (criteria based). Accelerated timelines under the right conditions can be used without adverse events. Specific criteria should be used to progress rehabilitation mindful of minimum time requirements for graft protection and healing.

Modal agreement: 'strongly agree' (mean: 97%, 95%–99%)

Cryotherapy

Nine studies investigated the effectiveness of cryotherapy compared with no cryotherapy in post-ACLR outcomes.[53–61] In one study,[60] the cryotherapy application was done preoperatively and in the remaining studies cryotherapy was applied immediately postoperatively (0–3 days). There was no study that investigated the effect of cryotherapy on the ACLR outcomes later than 2 weeks after the surgery. Four studies[62–65] compared the effectiveness of compressive cryotherapy and cryotherapy alone. One study[66] compared the compressive cryotherapy to usual care (no compressive cryotherapy). Two studies applied the compressive cryotherapy for longer than the immediate post-operative period (1–3 days); one for 2 weeks[64] and one for 6 weeks.[65]

Summary

- There is an effect of cryotherapy on reduced medication use, subjective pain and patient's satisfaction in the first 3 days after surgery. [D]
- There is no effect of 3 days of ice application in swelling reduction during the first 2 weeks after surgery. [D]
- There might be an improvement in knee flexion but not in knee extension. [D]
- Compressive cryotherapy further decreased the medication consumption, pain and had a small effect on swelling reduction compared with cryotherapy alone. [D]

Neuromuscular electrical stimulation (NMES)

Fourteen studies studied the effectiveness of the addition of NMES in the rehabilitation protocol.[67–80] Three studies investigated the effectiveness of NMES application during functional activities. Two of them used usual rehabilitation as the comparator group[81 82] and one used isolated NMES only (not NMES with exercise) as the comparator group.[83]

Summary

- The addition of NMES in usual rehabilitation had a moderate improvement in quadriceps strength [C] and no effect in HS strength [D].
- There was a large reduction in knee joint swelling during the early phase and a moderate reduction in the intermediate and advanced phases. [D]
- There were no significant changes regarding range of motion, laxity, subjective function and time to return to sport. [D]
- The use of NMES during functional activities further improved quadriceps strength and force symmetry restoration. [D]

Electromyographic biofeedback

In patients after ACLR, only two studies explored the effect of the addition of electromyographic biofeedback in the usual rehabilitation protocol.[84 85]

Summary

There might be a potential benefit of electromyographic biofeedback on quadriceps strength and knee extension deficit. [D]

We cannot make any recommendation based on the additional cost and the uncertain beneficial outcomes (very low level of evidence and small sample size) of the intervention.

Low load blood flow restriction training

Five studies[86–90] evaluated the effect of additional low load blood flow restriction training after surgery compared with usual rehabilitation. Two additional studies[91 92] investigated the effect of preoperative low load blood flow restriction training in the postoperative outcomes.

Summary

- Low load blood flow restriction training might improve quadriceps and HS strength and prevent disuse atrophy at the early phase. [D]
- There was a large effect on swelling and subjective pain reduction during training. [D]
- Preoperative low load blood flow restriction training produced improved results in rectus femoris muscle volume and comparable results to standard exercise in quadriceps isometric strength. There was no effect on vastii muscle volume or balance. [D]

Kinesio-taping

Six studies[93–98] investigated the effectiveness of kinesio-tape application compared with no kinesio-tape or sham application in rehabilitation after ACL surgery.

Summary

- There are contradictory results on the effectiveness of kinesio-tape application on pain, swelling, range of motion and quadriceps strength. [D]
- An improvement on HS strength was reported in the very early phase of rehabilitation. [D]
- There is no effect on balance and functional activities at the advanced rehabilitation phase. [D]

Kinesio-tape is of low cost and there are no reported adverse events. However, the available evidence suggests any therapeutic effect of its use is likely small to non-existent.

Dry needling

One study reported the effect of adding vastus medialis trigger point dry needling (one session) in the very early phase of rehabilitation (7–21 days post ACLR).[99]

Summary

- A 14% risk of adverse events was reported (haemorrhages). [D]
- A significant increase in pain the first hour post intervention. [D]
- There was a significant improvement in ROM and subjective function during the early phase of rehabilitation. [D]

Whole-body vibration

Six studies applied a series of whole-body vibration programmes in addition to standard rehabilitation lasting from 2 to 16 weeks.[100–105] One study only applied a single session of whole-body vibration.[106] One study replaced strength training and proprioception training in conventional rehabilitation by an independent whole-body vibration programme.[100]

Summary

- There is a positive effect of whole-body vibration training on aspects of static balance. [C]
- There is no effect on quadriceps and HS strength at the early and intermediate phases. There are conflicting results about its effect on quadriceps and HS strength at the advanced phase. There was improved quadriceps strength when whole-body vibration was used in combination with conventional rehabilitation but not when it replaced conventional rehabilitation. [D]
- There is no effect with the addition of whole-body vibration on range of motion, laxity, proprioception and subjective knee function. [D]

Local vibration

One study evaluated the effect of local mechanical vibration of quadriceps when the muscle was isometrically contracted, 1 month after ACLR. Vibration was applied for short periods over 3 consecutive days.[107] One study applied local body vibration with built-in vibroacoustic sound for the first 8 weeks after ACLR.[108] One study added 1 hour local vibration sessions at the end of each rehabilitation session for the first 10 weeks after ACLR.[109]

Summary

- There is a large beneficial effect of the addition of local vibration to usual care on quadriceps and HS strength, postural control, range of motion, subjective function and pain. There is no effect on functional activities. [D]

Despite the reported positive effects of local vibration, we are reluctant in making a recommendation for or against this intervention using the current available evidence.

Exercise initiation

The accelerated early rehabilitation protocol is characterised by early unrestricted motion and weight-bearing, without the use of an immobilising brace and commencing early strength training.[110–114]

Eight studies[115–122] investigated the effect of early knee joint mobilisation.

Immediate weight-bearing was investigated by only one study.[123]

Two studies investigated the effect of adding open kinetic chain exercises early (4 weeks) in the rehabilitation protocol compared with later (12 weeks).[124 125] The protocol in one study[125] started with seated knee extension with no resistance at week 4 from 90° to 40° of knee flexion, at week 5 from 90° to 20° and at week 6 from 90° to 0°. The other study[124] initiated the open kinetic chain protocol with seated knee extension at week 4 from 90° to 45° of knee flexion and maintained this until 12 weeks (HS graft patients).

One study[126] investigated the effectiveness of quadriceps exercises (straight leg raises and isometric quadriceps contractions) throughout the first 2 postoperative weeks.

One study[127] evaluated the addition of quadriceps and HS strengthening exercises with an eccentric and concentric component such as leg press at 3 weeks post operative.

One study[128] compared the effect of starting isokinetic HS strengthening at either 3 or 9 weeks after ACLR in patients with bone-patellar tendon autograft.

Box 2 Modalities recommendations

There is no additional benefit for pain, range of motion or swelling in using **continuous passive motion** compared with active motion exercises. We recommend against using it in the rehabilitation protocol as it is time-consuming and costly.

Modal agreement: 'strongly agree' (mean: 75.5%, 65%–86%)

Cryotherapy can be applied inexpensively, it is easy to use, has a high level of patient satisfaction and is rarely associated with adverse events, therefore it is justified in the early phase of postoperative management after anterior cruciate ligament reconstruction. However, patients should be educated on safe ice application to avoid injury. Compressive cryotherapy, if available, might be more effective than cryotherapy alone.

Modal agreement: 'strongly agree' (mean: 97%, 95%–99%)

We recommend the use of **neuromuscular electrical stimulation (NMES)** in the very early phase after surgery to stimulate muscle activation or minimise the expected disuse atrophy. At the early phase, NMES might be used during functional activities to further facilitate strength gains.

Modal agreement: 'strongly agree' (mean: 93.4%, 91%–96%)

Low load **blood flow restriction** training might be used in addition to standard care in the early phase of rehabilitation to improve quadriceps and hamstring strength, particularly when patients have increased knee pain or cannot tolerate high knee joint loads. However, clinicians should be aware of the contraindications (eg, cardiovascular disease, extensive swelling, skin irritation, etc).

Modal agreement: 'strongly agree' (mean: 92.6%, 89%–97%)

We do not recommend the use of vastus medialis trigger point **dry needling** in the very early rehabilitation phase due to increased risk of haemorrhage.

Modal agreement: 'strongly agree' (mean: 67.6%, 53%–83%)

Whole-body vibration might be used as an additional intervention to improve quadriceps strength and static balance but cannot replace conventional rehabilitation. Given the additional cost, and the reported complications (pain or swelling) when using this intervention, we suggest not including this in the rehabilitation protocol.

Modal agreement: 'agree' (mean: 83.2%, 75%–91%)

Gerber *et al*, published three studies[129–131] evaluating progressive eccentric exercise using recumbent eccentric ergometer starting at 3 weeks after ACLR compared with starting at 12 weeks.

Summary

- Early mobilisation can improve early phase knee flexion and extension range of motion without compromising knee laxity, regardless of the graft type used. [D]
- A large effect on patellofemoral pain reduction in patients with bone-patellar tendon graft from 35% to 8% was demonstrated compared with patients who kept non-weight-bearing for 2 weeks. There was no effect on laxity, range of motion or subjective knee function at 1-year follow-up. [D]
- There were no differences between starting open kinetic chain exercises early or late in terms of laxity, strength, pain, range of motion, knee function, functional activities and balance. HS grafts might be more vulnerable to the early introduction of open kinetic chain compared with BTB grafts. There is no evidence of the effect on starting open kinetic chain earlier than the fourth week after surgery. [D]
- Isometric quadriceps exercises including static quadriceps contractions and straight leg raises can be safely prescribed during the first 2 postoperative weeks and confer advantages for faster recovery of knee range of motion (at 1 month) without compromising stability. [D]
- Starting leg press at 3 weeks can improve subjective knee function and functional outcomes, but no gains in strength at 4 months after surgery. [D]
- Starting isokinetic HS strengthening at 3 weeks after ACLR with bone-patellar tendon autograft improved HS strength, patient-reported knee function and had no effect on quadriceps strength and no harmful effects. [D]
- Eccentric cycle ergometer training may result in greater strength gains, better daily activity level and greater quadriceps muscle hypertrophy if initiated at 3 weeks instead of 12 weeks after surgery, with the beneficial effects persisting 1 year after ACLR. There was no effect on laxity, pain or swelling. [D]

Strength and motor control training

Open versus closed kinetic chain exercises

Nine studies[132–140] explored the differences between open and closed kinetic chain exercises in the rehabilitation after ACL surgery.

Summary

- There was no significant difference in anterior tibial laxity between open and closed kinetic chain exercises. No differences were reported in subjective knee function, range of motion, atrophy or functional activities between open and closed kinetic chain exercises. [D]
- Evidence recommends the use of both open and closed kinetic chain exercises post-ACLR for regaining quadriceps strength. [D]
- Open kinetic chain exercises might induce more anterior knee pain compared with closed kinetic chain exercises. [D]
- Evidence reports that both types of exercise improved functional activities. [D]

Eccentric training

Three studies[141–143] investigated the effect of eccentric training in the rehabilitation protocol after ACL surgery. One study investigated if a 12-week quadriceps strength training with eccentric overload is more efficient to induce muscle regeneration than conventional concentric/eccentric strength training.[141] The second study evaluated the difference between concentric and eccentric training in an isokinetic cycle ergometer.[143] The third study assessed the effect of 6 weeks (initiated at 3 months after ACLR) of eccentric training, plyometric training or a combination of these two modalities (eccentric/plyometric) on the outcomes after ACL surgery in elite female athletes.[142]

Summary

- Both concentric and eccentric training improved quadriceps [D] and HS [C] strength without differences between groups. Eccentric overload training did not enhance quadriceps strength gains.
- Eccentric training might improve functional outcomes and psychological readiness to return to sport. [D]
- Adding eccentric training to the usual care did not improve subjective outcomes and balance. [D]
- A combination of eccentric and plyometric exercises was more effective in improving balance, functional activities, subjective knee function and psychological readiness than eccentric or plyometric training in isolation. [D]

Box 3 Exercise initiation recommendations

Active knee motion should begin immediately after surgery, mindful of any surgical instruction. Immobilisation does not decrease pain and can lead to muscle atrophy, which slows the recovery of function.

Modal agreement: 'strongly agree' (mean: 97%, 95%–99%)

Early weight-bearing (first week) should be done in a progressive, controlled manner, as tolerated by each patient, mindful of any surgical instructions.

Modal agreement: 'strongly agree' (mean: 95.6%, 90%–100%)

Patient may **start open kinetic chain** exercises in limited range of motion (90°–45° of knee flexion) from the fourth week after surgery without compromising knee stability. Clinicians and patients should monitor for anterior knee pain and adjust the knee load and the progression of strengthening accordingly.

Modal agreement: 'strongly agree' (mean: 88.8%, 84%–93%)

Isometric quadriceps exercises including static quadriceps contractions and straight leg raises might have a small effect on faster knee flexion recovery, but not on quadriceps strength. They may be prescribed during the first 2 weeks after surgery without compromising the graft integrity.

Modal agreement: 'strongly agree' (mean: 84.7%, 76%–93%)

Leg press may be initiated as early as 3 weeks after surgery in patients with hamstring graft, using a functional pattern similar to a half squat (0°–45°) to improve quadriceps and hamstring strength, functional activities and subjective function. Anterior knee pain should be monitored, with load progressed accordingly.

Modal agreement: 'agree' (mean: 88.3%, 84%–92%)

Early quadriceps eccentric strengthening, using eccentric cycle or stepper ergometer, between 20° and 60° of knee flexion, may be initiated at 3 weeks after surgery in patients with patellar tendon or hamstring autograft to improve quadriceps strength and hypertrophy without compromising graft integrity.

Modal agreement: 'agree' (mean: 82.7%, 76%–90%)

Isokinetic training

Two studies[144 145] investigated the effectiveness of isokinetic training in rehabilitation. One study assessed three groups; one using only isotonic strengthening exercises, one using exclusively isokinetic strengthening exercises and a third group trained with a combined programme of isokinetic and isotonic exercises.[144] The second study[145] compared the effects of conventional (constant load) eccentric training and a 6-week (two sessions/week) isokinetic eccentric training on quadriceps muscle mass, strength and functional performance in recreational athletes following ACL reconstruction.

Summary

- Isotonic and isokinetic exercise significantly improved strength outcomes. However, the group with a mixed isokinetic–isotonic programme achieved better strength outcomes and reduced atrophy. [D]
- Isokinetic eccentric quadriceps training improved isometric and eccentric strength at 3 months but not concentric strength. [C]
- There was no difference between isotonic and isokinetic training for atrophy [C], subjective knee function and functional activities [D].

Low intensity versus high intensity resistance training

One study investigated the effects of high-intensity versus low-intensity resistance training from week 8–20 after ACLR on leg extensor power and recovery of knee function.[146]

Summary

- There is insufficient evidence supporting the use of either high-intensity or low-intensity resistance training after ACL surgery due to the lack of significant differences in strength, PROMs, functional activities and joint laxity. [D]

Motor control training versus usual care

Seven studies evaluated the effect of the addition of a motor control/proprioception training programme in the traditional rehabilitation.[147–153] The heterogeneity of dose, duration and intensity of the exercises in the studies preclude describing an optimal training protocol.

Summary

- The addition of a motor control training programme (comprising training on an unstable surface (balance pad or foam roller), backward walking on an inclined treadmill and single-leg dynamic balance exercises) resulted in significant improvement in knee joint proprioception in early and intermediate phase and moderate effect at 2 years after ACLR. [D]
- There was no additional benefit of the above-mentioned balance/proprioception exercises regarding strength, subjective function, single leg hop for distance, muscle atrophy, range of motion and pain. [D]
- Using the Nintendo Wii Fit showed no additional benefit on knee strength, balance, proprioception, coordination and response time at 8th and 12th weeks, compared with a traditional programme. [D]
- The SpeedCourt system showed a significant improvement of the jump height, reaction time and calf muscle atrophy. [D]

Motor control versus strength training

Two studies compared balance and proprioception exercises to a strength training programme.[154 155]

Summary

- Both training modules (motor control and strengthening) significantly improved quadriceps and HS strength. [D]
- Balance and proprioception training had no difference in subjective function or functional outcomes compared with strength training. [D]

Plyometric and agility training versus usual care

Four studies compared a neuromuscular training programme that included plyometrics, agility and sports-specific exercises to the usual rehabilitation protocol (that included strength training).[142 156–158] One study additionally compared the combination of plyometric and eccentric training to a usual rehabilitation protocol.[142] One study compared the effect of an 8-week programme of low-intensity and high-intensity plyometric exercises consisting of running, jumping and agility activities on knee function, articular cartilage metabolism and other clinically relevant measures.[159]

Summary

- Plyometric and agility training had an additional benefit at the advanced rehabilitation phase on subjective function and functional outcomes compared with the usual rehabilitation protocol. [D]
- Plyometric and agility training had no difference in strength, balance, proprioception, pain and laxity compared with the usual rehabilitation protocol. [C]
- The combination of plyometric and eccentric training showed significant improvement in balance, subjective function and functional activities compared with the usual rehabilitation protocol. [D]
- Regardless of intensity, 8 weeks of plyometric exercise implemented during rehabilitation after ACLR had positive effects on knee function, knee impairments and psychosocial status. [D]

Cross-education

Seven studies[160–166] investigated the effect of contralateral limb strength training on the injured limb outcomes after ACL surgery.

Summary

- There is conflicting evidence for an effect of cross-training on quadriceps strength at the early and intermediate phase. There is no effect at the advanced phase of rehabilitation. [D]
- Cross-training has no effect on HS strength, single-leg hop for distance, balance and proprioception. [D]
- Cross training might have a positive effect in the early phase of rehabilitation for the subjective knee function, but no difference in the following phases. [D]

Core stability training

Two studies evaluated a core stability exercise programme addition in the usual rehabilitation protocol. One study added a 4-week core stability exercise programme in the usual rehabilitation protocol during the early phase of rehabilitation[167] and another study added 6 months of core-stability training.[168]

Summary

- The addition of core stability exercises in the usual rehabilitation protocol might improve gait, subjective knee function and range of motion but no benefit for pain. [D]

Aquatic therapy

Three studies[169–171] investigated the role of aquatic therapy in the rehabilitation protocol after ACLR.

Summary

Box 4 Strength and motor control training recommendations

A combination of **closed and open kinetic chain** exercise may lead to significantly better quadriceps strength and earlier return to sports, without any increase in laxity, compared with closed chain alone. Monitor for anterior knee pain during open kinetic chain exercises and adjust loading accordingly.

Modal agreement: 'strongly agree' (mean: 91.3%, 86%–97%)

We suggest using **eccentric training** in combination with concentric training to elicit improved strength and functional outcomes after anterior cruciate ligament (ACL) surgery.

Modal agreement: 'strongly agree' (mean: 91.8%, 88%–96%)

The exclusive use of **isokinetic training** for muscle strengthening after ACL surgery is not suggested. The combination of isotonic and isokinetic training appears to improve muscle strength more than these interventions in isolation.

Modal agreement: 'strongly agree' (mean: 90.5%, 85%–96%)

Motor control and strength training are both integral parts of the rehabilitation and should be combined in the rehabilitation protocol to improve outcomes.

Modal agreement: 'strongly agree' (mean: 98.5%, 97%–100%)

Plyometric and agility training may further improve subjective function and functional activities compared with usual care, without any increase in laxity or pain.

Modal agreement: 'agree' (mean: 80%, 71%–89%)

There are conflicting results on the effect of **cross-education** training programme on quadriceps strength. However, we do not suggest the implementation of an exaggerated cross-education training programme for strength gains in the injured leg. The uninvolved limb's strength should be monitored and restored to baseline/optimal levels as indicated.

Modal agreement: 'strongly agree' (mean: 83.7%, 77%–91%)

Core stability exercises might improve functional outcomes and subjective knee function and can be used as an addition to the rehabilitation protocol.

Modal agreement: 'strongly agree' (mean: 92.6%, 89%–96%)

Aquatic therapy may be used in addition to the usual care during the early phase of rehabilitation to improve subjective knee function. We recommend that is it initiated 3–4 weeks postoperative, once the wound has completely healed.

Modal agreement: 'strongly agree' (mean: 96.1%, 93%–99%)

- At 2 months after surgery, there was no difference in quadriceps strength between a land-based programme and a water-based programme but there was a decrease in HS strength and thigh circumference in the water-based group. [D]
- No difference was reported for knee flexion and extension. [D]
- Better subjective knee function was reported for the water-based training at the early phase, and no difference between groups at the advanced phase. [D]
- No difference between groups was reported for balance [C], laxity, proprioception and swelling [D].

Return to activities

Driving

According to one systematic review,[172] brake response time returns to normal values at approximately 4–6 weeks after right-sided ACLR and approximately 2–3 weeks after left-sided ACLR.

Running

Return to running is an important milestone in ACL rehabilitation. A recent scoping review[17] investigated the criteria used to determine when to initiate running, and recommended a combination of: time-based, clinical and functional criteria. Most of the studies included, proposed a minimum timeframe of 12 weeks, but there were also studies suggesting 8 weeks or 16 weeks.

There are no conclusive results whether return to running at or before 12 weeks is safe; prospective studies investigating if the return to running at 12 weeks is associated with new knee injury or exacerbation of current status are missing.

Prognostic value of return to sport criteria

Until the early 90s, time was the only criterion used to clear athletes to RTS.[16] While a minimum time postoperatively is required to allow biological recovery of the graft, there has been a progressive shift towards a criterion-based approach. In addition to time, literature reports the use of strength tests, clinical examination, performance criteria, hop tests and patients reports as RTS criteria.[16]

Four reviews examined the association between passing return to sport criteria and risk of second ACL injury: three meta-analyses[28 173 174] and one systematic review.[175]

The meta-analysis of Webster and Hewett[173] concluded that passing the current return-to-sport criteria reduced the risk of graft rupture. Losciale *et al*[28] did not find a statistically significant association between passing RTS criteria with risk of a second ACL injury and Ashigbi *et al*[175] concluded that passing a combination of functional tests and self-reported function with predetermined cut-off points used as RTS criteria is associated with reduced knee reinjury rates. More recently, Hurley *et al*[174] concluded that passing RTS testing results in a lower rate of ACL graft rupture, but not contralateral ACL injury.

However, imprecision of pooled estimates and substantial levels of heterogeneity were seen which could be explained by the low number of studies meeting selection criteria and differences in populations (age and competition levels). Importantly, included studies in these reviews fail to inform about the mechanism of the second ACL injury (contact or non-contact); a direct contact injury likely cannot be predicted by any battery of tests.

Currently, it is not clear if passing a battery of tests is associated with lower risk of second ACL injury. Relatively rare events (such as ACL reinjury) are statistically difficult, if not impossible, to predict with absolute confidence. Despite this caveat, we maintain that our clinical goals should be to restore all impairments and return the athlete back to the previous status, if not better.

We propose minimum criteria required for a professional athlete to be cleared from the clinic/hospital setting and start training with their club, whereupon they should then gradually return to full participation. These criteria can be adjusted and individualised according to their previous activity level. Our proposed discharge criteria are based on our clinical experience, research findings and our normative data.

Box 5 Return to activities recommendations

Return to driving

We recommend that a patient does not attempt to drive before they can safely activate the brake in a simulated emergency. Typically, this will be at approximately 4–6 weeks after right-sided ACLR and approximately 2–3 weeks after left-sided ACLR.

Modal agreement: 'strongly agree' (mean: 92.1%, 87%–97%)

Return to running

Despite an absence of research findings, we feel it is warranted to suggest criteria for return to running (where running has a volume and intensity to achieve cardiovascular adaptation):

⇒ 95% knee flexion range of motion (ROM).
⇒ Full extension ROM.
⇒ No effusion/trace of effusion.
⇒ Limb symmetry index (LSI)>80% for quadriceps strength.
⇒ LSI>80% eccentric impulse during countermovement jump.
⇒ Pain-free aqua jogging and Alter-G running.
⇒ Pain-free repeated single-leg hopping ('pogos').

Modal agreement: 'agree' (mean: 87.8%, 83%–93%)

Return to sport

Return to sport/completion of rehabilitation

We propose the below minimum criteria required for a professional athlete to be cleared from the clinic/hospital setting and start training with their club, whereupon they should then gradually return to full participation.

⇒ No pain or swelling.
⇒ Knee full ROM.
⇒ Stable knee (pivot shift, Lachman, instrumented laxity evaluation).
⇒ Normalised subjective knee function and psychological readiness using patient-reported outcomes (most commonly the International Knee Documentation Commitee subjective knee form (IKDC), the ACL-Return to Sport after Injury scale (ACL-RSI) and Tampa Scale of Kinesiophobia).
⇒ Isokinetic quadriceps and hamstring peak torque at 60°/s should display 100% symmetry for return to high demand pivoting sports. Restore (as a minimum) preoperative absolute values (if available) and normative values according to the sport and level of activity.
⇒ Countermovement jump and drop jump>90% symmetry of jump height and concentric and eccentric impulse. Reactive strength index (height/time)>1.3 for double leg and 0.5 for single leg for field sport athletes (higher for track and field).
⇒ Jumping biomechanics—normalise absolute and symmetry values for moments, angles and work in vertical and horizontal jumps especially in sagittal and frontal plane at hip, knee and ankle.
⇒ Running mechanics—restoration of>90% symmetry of vertical ground reaction forces and knee biomechanics during stance during high-speed running and change of direction.
⇒ Complete a sports-specific training programme.

Modal agreement: 'agree' (mean: 88.8%, 84%–94%)

DISCUSSION

Exercise interventions should be considered the foundation of ACLR rehabilitation. Yet, there is little information on the dose–response relationship between volume and/or intensity of exercise and outcomes and what constitutes the optimal rehabilitation strategy. Rehabilitation has changed over time. Early accelerated rehabilitation characterised by joint mobilisation and weight-bearing within 3 days after surgery should be the mainstream approach in isolated ACL surgeries. When concomitant injuries (ie, meniscal, cartilage) are present, the early rehabilitation phase should be adapted according to the surgeon's instructions. Physical therapy modalities can be beneficial as an adjunct in the early phase of rehabilitation when pain and other postoperative issues are present. However, the evidence for some modalities is conflicting, and the adverse effects, as well as the cost and time required, probably outweigh any benefits.

A summary of the recommendations can be viewed in figure 1.

Most of the findings are based on very-low certainty of evidence, and there are concerns in risk of bias for most of the included studies for nearly all intervention comparisons and outcomes. Despite the low certainty of evidence expert clinicians who reviewed the recommendations were largely in agreement with them. All recommendations reached an average agreement of at least 75.7% ('agree') with one exception: dry needling (mode: strongly agree, mean: 67.6% (52%–83%)). A possible reason might be the impression that the recommendation was misinterpreted by the respondents as an intervention for the entire duration of rehabilitation while some clinicians expressed grave reservations for the use of dry needling before any wounds had healed. The GDG after discussion agreed not to make any changes in the recommendation and clearly state the risk of haemorrhage with vastus medialis dry needling at the very early phase of rehabilitation.

The term 'neuromuscular training' is often reported in the literature to describe subcomponents of balance, proprioception, agility and plyometric training. However, since every type of training (except visualisation) involves nerve and muscle action, we chose to use the term 'motor control' to better distinguish from strength/resistance training. Strength and motor control training should be combined in the rehabilitation protocol and one cannot replace the other.

Running and return to training are key milestones for rehabilitation after ACLR. However, the entire rehabilitation protocol should be based on progression criteria with time since surgery considered necessary but not sufficient for progression unless coupled with objective physical and psychological criteria. This approach better ensures knee and graft protection, although we note that these criteria are yet to be fully validated. Psychological factors, particularly fear of reinjury, are the most significant contributors to not returning to sport.[176] A contributing factor might be that patients are not exposed enough to a sports-specific training programme.

Completion of the rehabilitation protocol and clearance to return to sport is not the same as return to competition. Before clearance for return to unrestricted competition, there should be a transition phase from sports participation to sports performance with progressive and controlled exposure to athlete's sport.[177]

Barriers

The cost or access to a rehabilitation clinic might be challenging. However, less intensive supervised rehabilitation might be a viable solution for patients after ACLR who cannot afford

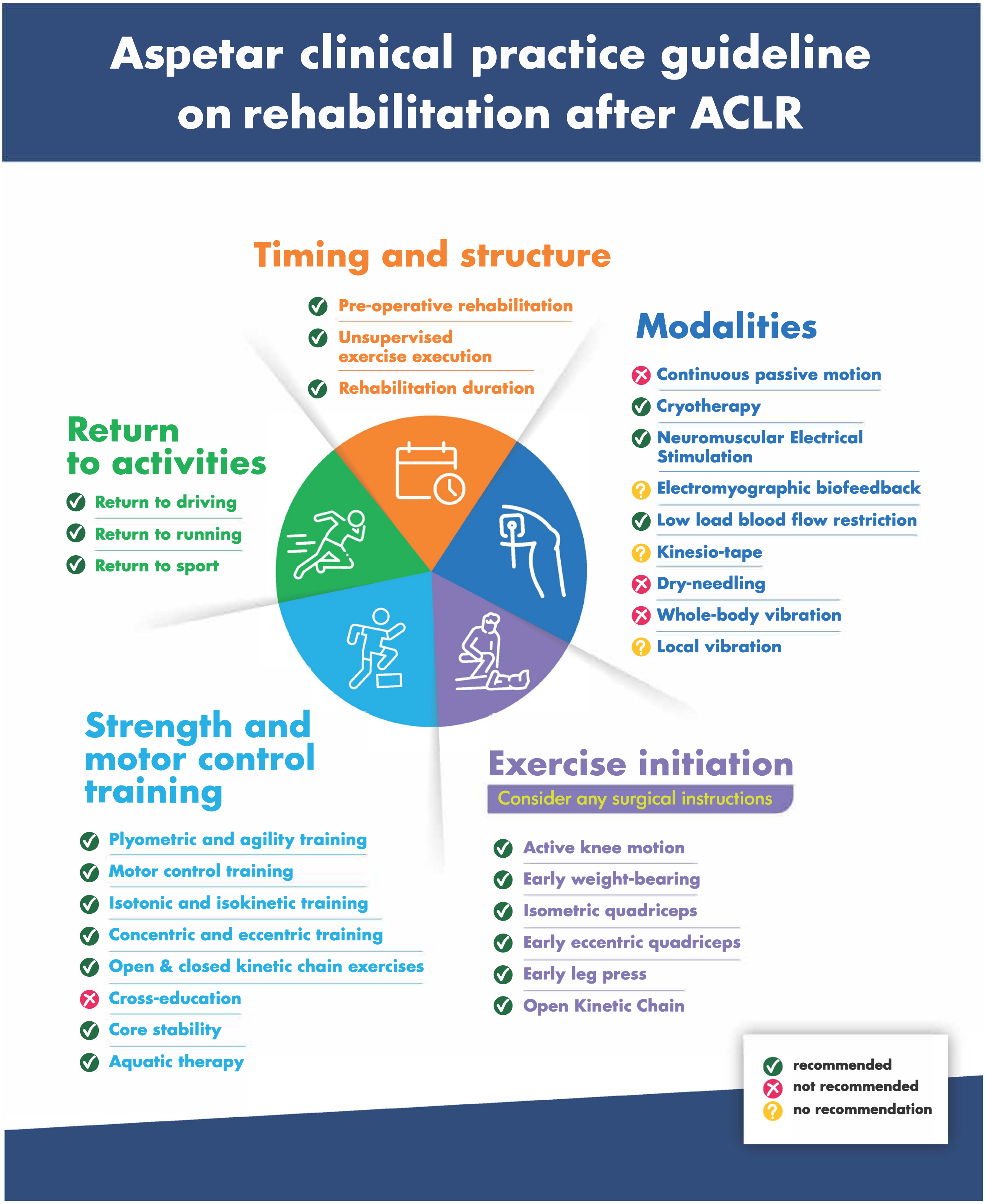

Figure 1 Summary of the recommendations on rehabilitation after anterior cruciate ligament reconstruction.

supervised rehabilitation, have poor access to physiotherapy or have high motivation to perform their rehabilitation independently.[178 179]

One of the greatest challenges during the rehabilitation after ACLR is patient compliance. Athlete expectations should be discussed, and the long rehabilitation journey should be explained, ideally before surgery. Setting realistic goals and achieving well-defined milestones along the way will keep the athlete motivated to continue and complete the rehabilitation protocol.[178 179] Periodic assessments during rehabilitation can also help achieve this goal.

Completing a sports-specific programme might be challenging to some clinicians due to space limitations in their clinics; however, adaptations are proposed instead of excluding this important part of rehabilitation. Some of the recommendations require expensive equipment, not easily found in the average physiotherapy clinic (eg, swimming pool, Alter-G and end-stage evaluation using advanced technology such as force plates and motion capture systems). In some cases, for example, hop testing, less expensive options such as smart phone-based analyses are available; however, other aspects, for example, kinetics during direction change, remain out of reach for most practitioners.

Dissemination and implementation tools

In addition to publishing this guideline in the *British Journal of Sports Medicine*, this guideline will be posted on the Aspetar website (www.aspetar.com). The implementation tools are planned to be made available for patients, clinicians, educators, payers, policy-makers and researchers. We plan to produce videos and infographics summarising the recommendations and guide 'how to' implement evidence into practice for healthcare professionals and patients. We also plan to translate the recommendations to other languages. We will embrace social media platforms to widely disseminate new and existing knowledge. We will share the recommendations in conferences, workshops and educational webinars for healthcare practitioners.

While this guideline is current at the time of writing, to keep in line with ongoing scientific evidence, the guideline should be updated within 3 years based on newly published literature. Importantly, assessment of clinical practice should be included in this process, especially in light of previous research showing relatively low compliance with, and even knowledge of, clinical practice guidelines.[11 12]

Moving forward, further research should evaluate the implementation of the current recommendations and the impact on patient's progress, return to performance and future injuries. Clinicians would benefit from clear objective progression criteria as well as a better understanding of the dose–response nature of exercise interventions.

Limitations

The development and validation of this guideline has strengths and weaknesses. The main strength relies on the strong methodological design, with consensus of different healthcare experts in our institution. The weakness of this guideline could be the inclusion of only RCTs. Although, RCTs are recommended to evaluate the effectiveness of interventions, in future updates we should include also prospective and cross-sectional studies and adapt the level of evidence accordingly. GRADE recommendations suggest downgrading evidence where there is evidence of publication bias however, to formally assess this a minimum of 10 publications (per item) is suggested.[20] This was never the case in the current review, and we have arbitrarily not adhered to this recommendation. We did not downgrade the certainty of evidence when reporting findings from a single study but downgraded due to imprecision when the sample size was below 800 participants. The panel members are from the same organisation/institution. Probably, there is no bias in the synthesis of the results (systematic, defined approach); however, there might be bias in the recommendations. We did not include patient opinion via focus groups and structured interviews in the formulation of the recommendations; however, a patient after ACLR (also physiotherapist) was part of the guideline's development group. We included patient's opinion as reported in the literature (barriers).

CONCLUSION

The recommendations for the components of rehabilitation after ACL surgery are described based on the available evidence. Overall, there is a low level of certainty for most components of rehabilitation; however, expert clinicians were largely in agreement with the recommendations. These data may be used as the basis in developing care pathways for rehabilitation after ACLR. The guideline also highlights several new elements of care management in addition to existing guidelines.

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