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Exercise-Based Rehabilitation Strategies for Quadriceps Strength Following Anterior Cruciate Ligament Reconstruction: A Literature Review

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Purpose:	The purpose of this study was to investigate the differences between exercise-based rehabilitation strategies for quadriceps strength following anterior cruciate ligament reconstruction (ACLR).
Method:	The study design is a quantitative literature review. The articles included were all randomized controlled trials. The Physiotherapy Evidence-Based Database (PEDro) scale was used to ensure methodological quality of the articles in this study. Maximum voluntary isometric contraction (MVIC), peak torque and maximum leg extensor power were used as a measurement outcome in this literature review to evaluate the results.
Result:	The evaluation of the results showed statistical significance for cryotherapy combined with exercise, cross-education (CE), eccentric and isometric isokinetic training, and high-intensity resistance training (HRT). There was no statistical significance for blood-flow restriction training (BFRT).
Conclusion:	Exercise-based rehabilitation strategies including cryotherapy, CE, eccentric and isometric isokinetic training, and HRT provided the best results in the independent outcome measurements. More research needs to be conducted on the independent interventions, as well as comparing the interventions to one another.
Keywords:	Quadriceps Strength, Exercise-Based rehabilitation strategies, Manuel therapy, Osteopathy, Postoperative, Cross Education, Blood flow restriction training, Cryotherapy, Isokinetic training, High-intensity resistance training

Declaration of Conformity

The authors of this thesis hereby assure a completely independent work, and that the sources presented are the ones used throughout the entire study. The authors have no conflict of interest with any institution or other authors.

List of Abbreviations

ACL - Anterior cruciate ligament
ACLR - Anterior cruciate ligament reconstruction
AMI - Atherogenic muscle inhibition
BFRT - Blood flow restriction training
CAR - Central activation ratio
CE - Cross-Education
CG - Conventional group
CKC - Closed kinetic chain
HRT - High-intensity resistance training
IG - Isokinetic group
LCL - Lateral collateral ligament
LRT - Low-intensity resistance training
MCL - Medial collateral ligament
MVIC - Maximum Voluntary Isometric Contractions
NCAA - National Collegiate Athletic Association
PEDro - Physiotherapy Evidence-Based Database
OKC - Open kinetic chain
RM - Repetition Maximum
ROM - Range of motion
RTA - Return to activity
RTP - Return to play
VAS - Visual Analogue Scale

1 Introduction

The anterior cruciate ligament (ACL) is one of the most commonly injured ligaments and can cause long-term physical and psychological trauma for the affected individual (Filbay and Grindem., 2019; Baez et al., 2020). The ACL is most often injured in contact sport activities (Evans J, Nielson Jl, 2022) and the risk of injury is higher for women (Renström, et al., 2008).

ACL injuries can be treated either with surgery or non-surgical treatment strategies. Reconstructions of the ACL are performed arthroscopically and the technique usually involves the patellar or hamstring tendon. For athletes that desire to get back to sport with pivoting and constant direction changes, surgery is normally recommended (Frobell et al., 2010). The review Kostogiannis et al., (2008) suggests and indicates that well-structured and committed rehabilitation is necessary for patients with a torn ACL.

Rehabilitation post anterior cruciate ligament reconstruction (ACLR) is well documented and the consensus among researchers is that stability, proprioceptive and balance exercises should be included as a part of the rehabilitation program for standard guidelines on ACL management (Cooper, Taylor and Feller, 2005).

Quadriceps muscle weakness is an inevitable consequence post ACLR which correlates with poor functional outcome and loss of ability to generate force. Furthermore, quadriceps strength is an important measurement throughout the rehabilitation phases. Sufficient quadriceps strength is also linked to lower risk of reinjury (Schmitt, Paterno and Hewett, 2012).

When reading on the subject the authors of this study found that quadriceps strength is the main outcome measurement in several studies (Hart et al., 2010). However, there were no studies found that compared rehabilitation strategies for quadriceps strength. Interest is therefore directed towards different exercise-based rehabilitation strategies, with the aim to identify what strategies would be most beneficial for quadriceps strength recovery after ACLR.

ACL injuries are common and will as a consequence be presented in the clinical settings for osteopaths. Through a broader insight of the relation between quadriceps femoris strength and ACL injuries osteopaths will be able to develop a deeper understanding on how to manage patients with ACLR. This could potentially increase the probability of the patients returning to previous activity level and lower the risk of reinjury.

2 Background

2.1 Epidemiology

National registries in Norway, Sweden and Denmark monitor the outcomes of ACLR. The annual presentation of females and men between the ages of 10-19 indicate that ACLR occurred in 76 per 100 000 females, and 47 per 100 000 men (Granan., et al 2009). The numbers may be underestimated because of hidden statistics due to patients choosing non-surgical treatment (Labella., 2014)

The National Collegiate Athletic Association (NCAA) further researched on the recurrence after ACL injuries in athletes, between the years 2004-2014 the NCAA pinpointed that out of 350,416 athlete exposure 1105 were ruptures and 126 were recurrence. Even though females are in general more often exposed to ACL injuries, men have a significantly higher recurrent rate of ruptured ACL (4.3) than females (3.0). The recurrence rate decreased as the study continued for both genders, however the decreased rate was steeper for females (Gans et al., 2018)

The NCAA provided a 16 year sample of 15 sports across a college group. The group consisted of male and females between the age of 18-23 and during this period approximately 5000 ACL injuries occurred. Men's spring football was responsible for the highest number of injuries on the men's side and gymnastics on the females side (figure 1). The proportional injury rate is around 3,1% in females and 1,9% in men shown in over several different sports. (Renström, et al., 2008)

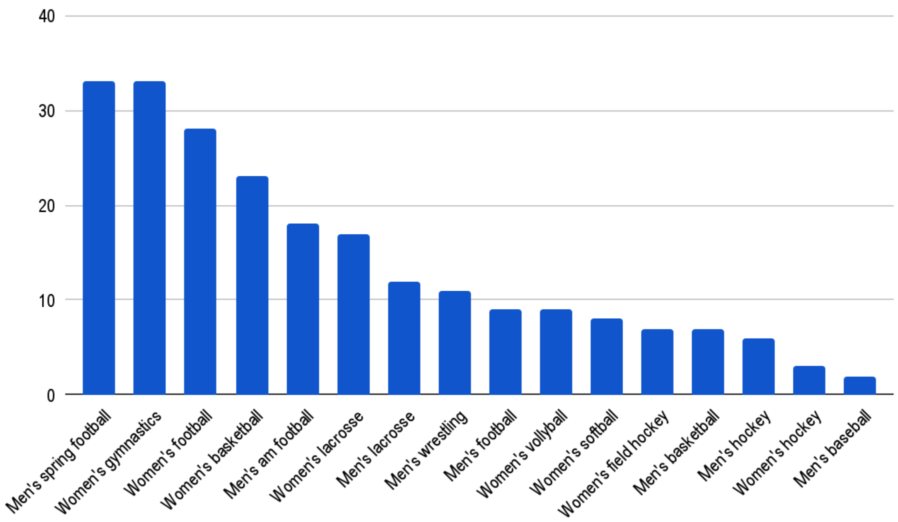

Figure 1. ACL injury rate per 1000 athlete-exposures

The difference between male and females is believed to be related to differences in physical conditioning, muscular strength, and neuromuscular control. It suggests correlation to anatomical variation such as lower extremity and/or pelvic alignment, as well as hormonal and ligament changes in properties, data shows that women have smaller ACL and the ligament is also less extensible leading to higher injury risk (Peterson and Renström., 2017; Wheeler., 2020).

Overall in the US 100,000 to 200,000 individuals receive ACL injuries either with a sprain or a total rupture. Research further indicates that 1 in 3500 is anticipated to damage the ACL, more often through non contacting mechanisms rather than full on external force (Evans J, Nielson Jl, 2022)

2.2 Cruciate Ligament Injuries

ACL injury is the most commonly injured ligament of the knee. The loss of the ACL results directly in abnormal kinematics but with time it also causes degeneration of the tissues in the knee joint. The injury is complex and treatments are still questioned even if a lot of research already exists (Macaulay, Perfetti and Levine, 2011). The ACL is the second strongest ligament found in the knee. The maximum capacity that the ligament can withstand is up to 2200N (Peterson and Renström., 2017).

The ACL injury usually occurs in activities with sudden change of direction. Injuries to these structures are seen in both contact sports (direct collision, hyperextension, twisting or valgus force) and no-contact sports (change of direction or-, pivoting). The injury site is often the midportion of the ligament causing either a complete or partial tear (Drake et al., 2020. p.607).

Collateral and cruciate ligaments are tight in full knee extension which is believed to increase the risk of a tear linked to “heavy or stiff-legged landing”. The valgus position is also a factor that increases the risk of ligament failure (Nikita and Vizniak 2020, p.236-236).

The signs and symptoms of an ACL tear are effusion and antalgic limp, there can also be a bony abnormality. 50% of ACL injuries are accompanied with meniscus or collateral ligament damage, hence palpation of the collateral ligaments and meniscus should be examined. Pain may limit extension in passive and active range of motion (ROM) (Nikita and Vizniak 2020, 236-236).

Physical diagnostic tests can be used when diagnosing patients for ACL injuries. The Lachman test is commonly used for examination of one plane anterior instability in the knee-joint, even if it has been questioned (Katz and Fingeroth, 1986). A negative Lachman test indicates that an rupture is unlikely (Prins, 2006) Drawer sign is also a common test to use when examining one-plane anterior and posterior instabilities but has a lower specificity and sensitivity (Magee, 2014, p.819).

2.3 Treatments after ACL Injury

Different treatment methods are used to manage ACL injuries. Depending on the lifestyle of the individual conservative treatment may be more beneficial than surgery. An ACL injury that lacks involvement of cartilage or other ligamentous damage can often be well managed with physical therapy only. If the decision is made to perform a non-surgical treatment, high demands on strength, balance and ROM are important to lower the risk of further injuries. This requires a high degree of dedication from the patient (Krause et al., 2018).

Non-operative treatment is also considered depending on the patient's goals after the injury. The patient must be aware that their participation in activities involving cutting, jumping or pivoting are limited. If the patient is planning to return to full-contact sport, surgery is, in the majority of times, the best option (ACL Non-Operative Protocol, 2016).

2.4 Surgery

Surgery towards the ACL involves replacement of the ligament with autograft, specifically the patellar tendon, one of the hamstring tendons or in some circumstances a part of the quadriceps tendon is used as an autograft (Blahd, Thompson and Fu., 2020).

Tissue allografts may occur from deceased donors. Arthroscopic surgery are often used (Blahd, Thompson and Fu., 2020), this is when a small incision is made in the knee that enables instruments to be inserted into the specific operation area. Open surgery involves more risks, and is an alternative approach where larger incisions are made (Blahd, Thompson and Fu., 2020).

Arthrofibrosis is associated with immediate surgery and can limit the quality of outcome (Blahd, Thompson and Fu, 2020). Guidelines suggest no knee effusion, full active and passive ROM and at least 90% quadriceps femoris-symmetry should be achieved before surgery (Schmitt, Paterno and Hewett., 2012).

Arthroscopic surgery is considered being safe with few complications occurring post-surgery (NHS., 2020). Common complications reported are numbness surrounding the area, infection within the incisions and damage to related structures are most relevant post- ACLR (Blahd Jr, Thompson and Fu., 2020).

2.5 Postoperative Phase of Injured ACL

The postoperative phase of an ACL injury is a well studied field because of the high frequency of ACL ruptures. The main focus of the postoperative rehabilitation phase are stability, proprioceptive and balance exercises (Cooper, Taylor and Feller, 2005). However, there is a broad variation of additional methods used which include, but are not limited to, cryotherapy, taping, manual therapy, electrotherapy and heat (Carter et al., 2020).

Evidence-based recommendations following an ACL-injury are often divided into different phases. These phases are mainly based on the amount of quadriceps strength and function of the injured limb compared to the uninjured limb (Filbay and Grindem., 2019).

To monitor the patients' progress and to apply a progressive rehabilitation, four phases are used. Phase 1 starts immediately after surgery. During this phase the goals are to reduce swelling, increase the ROM to 0-100 degrees and to strengthen quadriceps and hamstrings. The length of this phase is 0-2 weeks. Phase 2 lasts week 2-12 and during that time the goal is to have no swelling, full knee extension and almost full knee flexion. The patient should have attained sufficient control and balance, as well as walking without abnormal gait (van Grinsven, van Cingel, Holla and van Loon., 2010) The second phase also requires 80% quadriceps strength symmetry (Filbay and Grindem., 2019)

The goals of phase 3 are full ROM, full strength and power. During this period the patient should be back to jogging and running with some cutting drills, furthermore a quadriceps strength symmetry of 90% should be reached. Focus is also on the activity that the patient aims to return to after rehabilitation. The time period is 3-6 months post surgery. The final phase, phase 4, goal is to RTP, or normal activity. It is similar to phase 3, but with progressive return to sport. It should be sport-specific and is usually 6-12 months post surgery. The length of the final phase depends on the progress during the other phases (Brukner & Khan, 2012, p.745-748).

Psychological factors may also play a role in overall knee function following an ACLR and should therefore be examined during the rehabilitation. Decreased knee self-efficacy and kinesiophobia are commonly self-reported factors (Baez et al., 2020).
Psychological factors can delay, as well as lower the expectations of return to play and pre-injured activity, with fear of reinjury as the main reason why (Nwachukwu et al., 2019). Manual therapy and exercise could present beneficial effects on fear-avoidance and kinesiophobia (Martinez-Calderon., 2020).

2.6 Quadriceps Function in Relation to ACLR

Increasing the quadriceps muscle strength is usually the main focus following ACLR. Objective guidelines state that at least 90% quadriceps symmetry is required to reach a pre-injury activity level. Patients with 90% symmetry, or greater, demonstrated a similar functional performance as an uninjured individual. Meanwhile an asymmetry of more than 90% results in decreased function, uneven gait and increased injury risk. This demonstrates the importance of regaining quadriceps strength after ACLR. (Schmitt, Paterno and Hewett., 2012).

Persistent impairments are potential consequences following an ACLR, which could inhibit the quadriceps muscle function. The quadriceps muscle weakness correlates with poor functional outcome. Furthermore, the literature indicates the importance and correlation between functional control, quadriceps muscle weakness and ability to generate force post ALCR to prevent recurrence (Schmitt, Paterno and Hewett., 2012).

2.7 Rehabilitation Strategies for Quadriceps Strength Following ACLR

Different rehabilitation strategies exist for increasing strength of the quadriceps muscle. The rehabilitation is largely based on exercises and restoring muscle function around the knee-joint. Closed kinetic chain (CKC) and Open kinetic chain (OKC) exercises are often given in rehabilitation programs following ACLR (Glass, Waddell and Hoogenboom, 2010). In addition to the rehabilitation exercises several complementary rehabilitation methods are reported in the literature, blood flow restriction training (BFRT), cryotherapy combined with exercise and cross education (CE) training.

2.8 Blood Flow Restriction Training

BFRT is a modified exercise method that applies a pressurized cuff on the limb which partially restricts the blood flow to the muscles, but largely restricts the venous outflow. When this is combined with light exercise, such as lifting light weights the theory states that an increase in metabolic stress and mechanical tension can be measured. This is thought to enable the patient to train with reduced loads and still reach the same results as heavier loads would give (Erickson et al., 2019).

There are multiple factors concerning BFRT that are believed to stimulate muscle growth and strength. Metabolic accumulation is one of the primary, which is thought to have an effect on increasing anabolic growth factors. Enhanced recruitment of fast-twitch fibers and boosted protein synthesis are also considered as effects from BFRT exercise (Curran et al., 2020).

BFRT studies are reporting different results, but promising effects have been reported when the method was used on healthy participants (Abe, Kearns and Sato, 2006; Loenneke et al., 2012). Studies made on patients undergoing ACLR have a broader variation of results, where both improved strength recovery is found (Ohta et al., 2003) while reports showing no effect size also occur (Iversen, Røstad and Larmo., 2016).

2.9 Cross-Education Training

The idea of CE training is that resistance training increases muscle strength on one side of the body, and can by default improve the strength on the contralateral side. In literature CE training can also be termed contralateral strength training effect or cross-training. The working mechanism behind CE is not clear. The most likely explanation is a contribution of several different mechanisms including neural, spinal cord, cortical and subcortical. The research shows that CE training is a real phenomenon, but that the extent of it is limited (Carroll et al., 2006).

2.10 Cryotherapy

Cryotherapy is a method that can be used for many different purposes. In this case cryotherapy is discussed in relation with ligament injury and rehabilitation. The purpose of using cold therapy on an injured knee-joint is to primarily increase central activation ratio (CAR) which results in increased development of strength. Application of the cryotherapy on the injured area is believed to result in an increase of recruited motor neurons in a short period of time. In this short window, exercise can be performed which may lead to more strength gains (Hart et al., 2014).

2.11 Osteopathy

The growth of osteopathic manual medicine continues to develop. From evidence-based literature and knowledge within anatomy, sports medicine, physiology and biomechanics, osteopathic medicine is therefore intuitive to treat sport related injuries (Brolinson, McGinley and Kerger., 2008). Sports medicine is also part of the curriculum of the Scandinavian School of Osteopathy (Osteopathögskolan., 2022)

A proper physical examination is crucial when an ACL injury is suspected to ensure that the appropriate treatment is provided.The concept of reducing pain is a key aspect especially for athletes who have a limited amount of time before they need to be able to return to play and bearing this in mind, osteopaths utilized their expertise towards somatic dysfunction in order to reduce pain through different techniques and subsequently support guidance to the patient with rehabilitation for injuries such as ACL ruptures (Brolinson, McGinley and Kerger., 2008).

3. Problem

3.1 Problem Statement

It seems that rehabilitation programs following ACLR are primarily based on quadriceps strength as a measurement to continue to the next phase of the rehabilitation and to ensure good knee function. However, there is a gap of knowledge regarding the differences between various exercise based rehabilitation methods with focus on quadriceps strength following ACLR. Therefore, the aim of this literature review is to investigate the differences between different exercise-based rehabilitation strategies on quadriceps strength following ACLR.

3.2 Research Question

Are there any differences between different exercise based rehabilitation strategies on quadriceps strength post ACLR?

4. Method

4.1 Search Methods for Identification of Studies

Electronic searches were carried out on the Pubmed and CINAHL databases. A search string was developed using several keywords and heading terms related to the topic. To exclude studies not related to the topic, the authors of this study analyzed the titles and abstracts of the retrieved studies. The full text of the potential studies were then retrieved for final assessment.

4.1.1 Search string

(ACL OR "ACL Reconstruction" OR "Anterior Cruciate Ligament Reconstruction" OR "Anterior Cruciate Ligament Injury" OR "Anterior Cruciate Ligament") AND (Quadriceps OR "Leg Extensor Muscle" OR "Leg Extensor Power" OR "Quadriceps Power" OR "Quadriceps Strength" OR "quadriceps activation") AND (Rehabilitation OR "Resistance Training" OR Recovery OR Endurance OR Hypertrophy) NOT (Nerve OR Pain OR Graft OR Brain OR Dislocation)

4.2 Inclusion and Exclusion Criteria Eligibility Criteria

All articles were checked for eligibility, inclusion and exclusion criteria are summarized in table 1.

4.2.1 Study Design

This essay is a quantitative literature review of randomized control trials (RCT) comparing the effects of different rehabilitation protocols and treatments for patients with ACL injury. Articles in English and Swedish carried out between 2014 and 2021 were accepted.

4.2.2 Participants

Studies including participants of either sex, aged 15 years or older, with ACLR performed with hamstring or patellar-bone tendon autografts were considered. Studies including animals and children were excluded.

4.2.3 Intervention

Studies investigating exercise-based rehabilitation strategies for quadriceps strength post ACLR with a minimum length of 2 weeks were included in this literature review. All articles not including any exercise-based rehabilitation, or not measuring quadriceps strength were excluded. Articles including anterior tibialis autografts were excluded. Interventions consisting of growth hormones, tranexamic acid, and knee sleeves were also excluded.

4.2.4 Outcome Measurements and Data Extraction

Studies measuring quadriceps strength at the baseline and follow-up evaluations were considered for the study. Data from the studies were extracted by the authors manually. Only the data considering quadriceps strength were used from the studies. Studies with MVIC, maximum leg extensor power and peak torque as outcome measurements for quadriceps strength were included in the study. Data examining knee function, pain and psychological factors were not extracted.

4.2.5 Methodological Quality

The Physiotherapy Evidence-Based Database (PEDro) scale was used to ensure statistical relevance of the articles in this study. PEDro-scale is an attested implementation to identify RCT articles within physical therapy with adequate statistical information for the results to be valid (Maher et al., 2003; Yamato et al., 2017). The PEDro-scale consists of 10, 1-point criterion. For the criterion to be awarded it has to be evident and well described. The articles included in this study were independently evaluated by the authors. RCTs with a score of 5 or higher were included in the study.

Table 1. Inclusion and exclusion with motivation for each criteria.

Inclusion	Exclusion
English and Swedish written studies. *(The authors of this study understands swedish and english)*	Articles including animal *(The study is focusing on humans)*
Studies between 2014-2021. *(Limit to updated and relevant information)*	Articles including children *(The vast majority of ACL ruptures take place after the age of 15)*
RCT and analysis. *(Rct's are the strongest measure for effect of different treatments)*	Articles not containing research on quadriceps strength *(Quadriceps strength is our main measurement outcome)*
Quadriceps strength as primary outcome measurement *(Important with increased quadriceps strength after an ACLR)*	Articles not containing research exercise-based rehabilitation strategies *(Quadriceps strength measured through rehabilitation exercise based strategies)*
Age 15-50 *(Adult and late-teenagers represent the major population who undergo ACL injuries and ACLR)*	Articles including tibialis anterior autografts *(Uncommon autograft for ACLR)*
Exercise-based rehabilitation strategies *(Evaluate how exercise alter the quadriceps strength post ACLR)*	Articles including growth hormone *(Misleading towards the general population)*

Intervention Post ACLR *(Quadriceps strength is important for regaining normal knee function post ACLR)*	Articles including tranexamic acid *(Misleading towards the general population and not considered within the frame of a exercise-based rehabilitation strategy)*
	PEDro scale lower than 5/10 *(Score below 5 are considered to have "poor" outcome", according to PEDro database)*
	Articles including knee sleeve *(Excluding assisting supportgear, only compering exercise-based rehabilitation strategies)*
	Minimum 2-week duration *(Unlikely to see strength changes within the first 2 weeks)*

4.2.7 Data Analysis

The data related to quadriceps strength of the included articles were analyzed and presented with descriptive statistics. No statistical calculations could be made because the data in the included articles were presented in different units.

5. Result

5.1 Search Process

The search process in the PubMed database gave 608 results. Filter was applied from 2014-2021 with the purpose to include updated research within the subject and exclude outdated research. Only RCTs written in English showed 29 results. 5 of those 29 fulfill the inclusion and exclusion criteria.

The search process in the CINAHL database gave 371 results. Filter was applied from 2014-2021 with the purpose to include updated research within the subject and exclude outdated research. Only RCTs written in English showed 18 results. 4 of those 18 fulfill the inclusion and exclusion criteria. All of which were duplications from the PubMed database search.

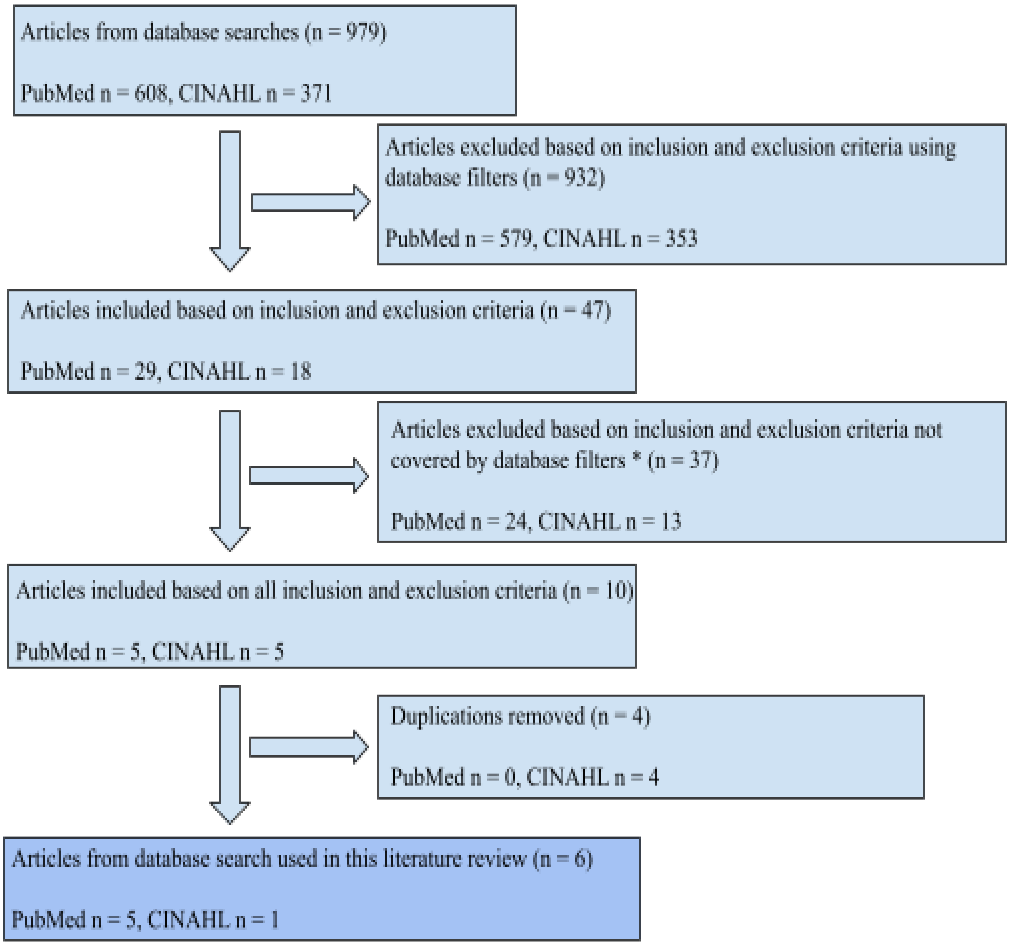

Figure 2. Database searches flow chart

26 articles were manually excluded based on the exclusion criteria presented in 4.3 which were not covered by database filters. Supplementary data can be found in Appendix A. See figure 2 for a flow chart of this process.

In table 2 attributes of the included articles are presented.

Table 2. Attributes of articles included in the study

Author/year	Study Design	Population	Time Period	Intervention	Diagnostic Criteria	Outcome Measure	PEDro scale
Joseph M. Hart et al. 2014	-Cross sectional study (type of RCT) - Single blinded	- 30 Patients - 27 Average age - Time since reconstruction average 34 months	- 2 weeks - Once a day - 14 sessions	- CRYO: 20 min of cryotherapy once a day - EXERC: Training program daily - CRYO + EXERC: Cryotherapy + Training program daily	- ACLR - 90% CAR or less - 6 months or more since surgery	- MVIC - H:M RATIO - CAR	- 5/10
Theresa Bieler et al. 2014	- Single blinded, RCT	- 50 participants - 18-45 years old - Rehabilitation began immediately after surgery	- 20 weeks - Twice a week - 40 sessions	- Leg press, knee flexion, knee extension. 20 to 8 RM. - Leg press, knee flexion, heel raises. 30 to 20 RM.	- ACLR - Rehabilitation at Bispebjerg Hospital.	- Maximum Leg Extensor Power - (Force x Velocity = Power)	- 6/10
Marlon F. Vidmar et al. 2020	- Assessor-blinded, RCT	- 30 Patients - 25 Average age - Engaged in the rehabilitation program 45 days post-surgery	- 6 weeks - Twice a week - 12 sessions	- Quadriceps eccentric training program in extensor chair, 2/week - Quadriceps eccentric isokinetic dynamometer, 2/week - Single leg hop test post rehabilitation program	- ACLR - Training frequency of once a week - No re-injury	- Peak torque - One-leg hop test post training evaluation	- 7/10
Michael T. Curran et al. 2020	-Single blinded, RCT	-34 Patients - 16,5 average age - Engaged in the rehabilitation program 10 weeks post surgery.	- 8 weeks - Twice a week - 16 sessions	- Single-leg isokinetic leg press 70% intensity (concentric or eccentric with or without BRFT depending on group)	-ACLR - Scheduled to undergo ACLR	-MVIC -CAR - Maximal isokinetic strength	- 6/10
Michael Curran et al. 2019	-RCT	-36 Patients - Engaged in rehabilitation 8 weeks post ACLR.	- 8 weeks - Twice week - 16 sessions	- Single-leg isokinetic leg press 70% intensity with BFRT or without.	- ACLR	- Isometric and isokinetic quadriceps symmetry	- 6/10
Gulcan Harput et al. 2018	- RCT	- 48 participants - 29.4 average age - Rehabilitation began immediately after surgery	- 12 weeks, followed by 12 weeks at home - 3 sessions per week. Plus 3 extra for the intervention group	- Cross-Education training 3 times per week.	- ACLR - Hamstring tendon autograft	- MVIC - One-leg hop for distance Test (OLHDT)	- 8/10

5.2 Article Summaries

5.2.1 Article 1, Joseph M. Hart et al

Title: *Quadriceps Muscle Function After Rehabilitation With Cryotherapy in Patients With Anterior Cruciate Ligament Reconstruction*
Authors: *Joseph M. Hart, PhD, ATC*; Christopher M. Kuenze, PhD, ATC*; David R. Diduch, MD*; Christopher D. Ingersoll, PhD, ATC, FNATA, FACSM*
Publish date and forum: *2014 in the Journal of Athletic Training.*
Ethical Approval: *American orthopedic society for Sports Medicine, approved by the institutional review board for health science research (University of Virginia)*
PEDro-Scale: *5/10*

5.2.1.1 Purpose

The purpose of this study was to investigate the effects of cryotherapy on quadriceps muscle function on patients suffering from quadriceps dysfunction post ACLR. This was investigated by comparing interventions including exercise, cryotherapy or both.

5.2.1.2 Article Method

The article is a cross-sectional study comparing 3 different groups on a short time interval (2 weeks). All recruited participants had undergone the reconstruction at least six months before the period of enrollment. 30 patients fulfilled the criteria of chronic quadriceps dysfunction meaning that quadriceps CAR is 90% or less on the affected leg. All the 30 participants had been released by their surgeon to full activity levels. Patients with multiple ligament injuries, post operative infections or graft failures were excluded in an earlier phase in the recruitment.

All the baseline and post rehabilitation measures were performed by one investigator that was blinded to the group assignment. The 30 participants (20 men 10 women average age of 27.3) were randomly assigned to the groups by a random-number generator after completion of the baseline testing. The study consisted of three groups, one cryotherapy group (CRYO), one exercise group (EXERC), and one cryotherapy + exercise group (CRYO + EXERC).

The cryotherapy group used 2 bags of 1.5L crushed ice which they applied to the anterior and posterior aspect of the knee. The bags were secured with elastic wrap and were kept in the same position for 20 minutes once a day. The exercise group performed a lower extremity program consisting of progressive strengthening exercises, muscle stretching and balance training.

The exercise group had 4 supervised sessions with an unblinded investigator, the sessions included stretching warm up, proggresive CKC quadriceps and hamstring exercises and standard OKC exercises with resistance. As home exercises this group performed quadriceps sets, straight-leg raise and calf raises. All participants in this group noted their home exercises daily.

The combined group performed the same exercises as the second group (exercise group) and included cryotherapy treatment as the first group (cryotherapy group) before the training session.

Table 3. Clarification of interventions performed by each group

	Cryotherapy		Exercise		Cryotherapy + Exercise	
	Clinic	Home	Clinic	Home	Clinic	Home
Cryotherapy treatment	■	■			■	■
Stretching			■	■	■	■
Quadriceps sets			■	■	■	■
Straight-leg raise			■	■	■	■
Calf raises			■	■	■	■
Resisted knee extension			■		■	
Resisted knee flexion			■		■	
Lunges			■	■	■	■
Lateral step-down			■		■	
Wall squats			■		■	
Balance training			■		■	

5.2.1.3 Result

Differences from baseline to post therapy results are summarized in table 4.
4 participants withdrew from the study, 2 from CRYO group and 2 from EXERC group. Compliance of the remaining participants was high.

The results showed no significant difference in self reported outcomes. However a significant difference was found in knee-extension torque concerning the cryo + exercise group, the MVIC increased from 1.6 to 2.2 (P = 0,002) (figure 3) with an effect size of 1.4 co (95% CI) (figure 4). No other significant effects were found in the study.

Table 4. Results for the 3 intervention groups regarding MVIC, CAR and H-Reflex: M-response ratio from baseline to post-therapy.

	Cryotherapy				**Exercise**				**Cryotherapy + Exercise**			
	Baseline	**Post therapy**	**P-value**	**Effect size (95% CI)**	**Baseline**	**Post therapy**	**P-value**	**Effect size (95% CI)**	**Baseline**	**Post therapy**	**P-value**	**Effect size (95% CI)**
Maximal voluntary isometric contraction Nm/kg	1.5 ± 0.3	1.7 ± 0.4	0,16	0,58 (-031, 1,48)	1.4 ± 0.6	1.6 ± 0.7	0.16	0.30 (-0.58, 1.18)	1.6 ± 0.4	2.2 ± 0.7	0.002	1.4 (0.42, 2.4)
Central activation ratio %	78.1 ± 4.4	80.4 ± 10.5	NA	0.29 (-0.59, 1.17)	73.3 ± 12.6	83.4 ± 8.4	NA	0.94 (0.02, 1.86)	76.0 ± 10.6	88.2 ± 5.5	NA	1.4 (0.45. 2.4)
H-reflex: M-response ratio	0.21 ± 0.19	0.20 ± 0.15	NA	-0.05 (-0.89, 0.86)	1.4 ± 0.6	1.6 ± 0.7	NA	0.73 (-0.18, 1.63)	0.40 ± 0.20	0.40 ± 0.19	NA	-0.02 (-0.89, 0.86)

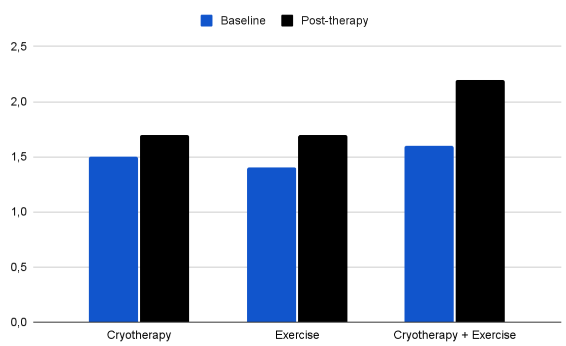

Figure 3. MVIC in Nm/kg from baseline to post-therapy for the 3 intervention groups.

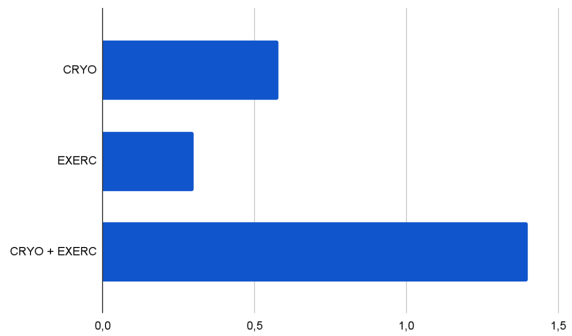

Figure **4.** The effect size of MVIC in Nm/kg for the 3 intervention groups from baseline to post-therapy.

5.2.2 Article 2, Theresa Bieler et al.

Title: *The Effects of High-Intensity versus Low-Intensity Resistance Training on Leg Extensor Power and Recovery of Knee Function after ACL-Reconstruction*
Authors: *Theresa Bieler, Nanna Aue Sobol, Lars L. Andersen, Peter Kiel, Peter Løfholm, Per Aagaard, S. Peter Magnusson, Michael R. Krogsgaard and Nina Beyer*
Publish date and forum: *27 April 2014 in BioMed Research International*
Ethical Approval: *The local ethics committee (KF01-008/04) approved the study*
PEDro-Scale: *6/10*

5.2.2.1 Purpose

The purpose of this study was to measure the effects of high-intensity (HRT) compared to low-intensity (LRT) resistance training on extensor muscles of the knee (e.g. quadriceps) as well as function of the knee when recovering from an ACLR. The hypothesis was that HRT would lead to better muscle power and knee function compared to LRT.

5.2.2.2 Article Method

The study method used in this study was a single blinded RCT. A rehabilitation program consisting of two types of resistance training were used following ACLR. 31 men and 19 women with ACL rupture who underwent an ACLR and rehabilitation participated. The participants were randomized and divided into the HRT or the LRT program.

Starting immediately after surgery the participants underwent a 20-week standardized rehabilitation program. Starting from week 4 supervised one-hour group-based sessions targeting neuromuscular control and sport-specific training was executed twice a week.
8 weeks after the ACLR a progressive 30-minute weight training program started. As the number of repetitions increased, so did the resistance. Bilateral and unilateral exercises were included in the HRT-program and the high-intensity training started at week 14 and consisted of leg press, knee flexion, and seated knee extension. The LRT-program consisted of leg press, knee flexion and heel raises.

Assessment of the participants were made before and 7, 14 and 20 weeks after surgery by the same blinded investigator. External physical therapists did the measurements, they were blinded for group allocation. The Leg Extensor Power Rig was used to measure maximal leg extensor muscle power. This was done as a unilateral extension in seated position. The highest value after, at least, 5 repetitions were used.

5.2.2.3 Results

The muscle power in the injured leg was 90.1% of the non injured leg before surgery, in both groups. This percentage had declined to 64.3% at 7 weeks after surgery. From week 7-20 a significant increase in power can be seen in the HRT-group. The P-value for the group by time interaction during this time was $P = 0.020$. The P-value at 14 and 20 weeks was $P = 0.027$ and $P = 0.006$ respectively. 38 participants completed the study. Results are presented in table 5 and figure 5. 6 participants from each group did not complete the study. This left the HRT group with 18 participants and 20 in the LRT.

Table 5. Results for maximum leg extensor power from baseline to 7, 14 and 20 weeks post -surgery. P-values presented are between-group differences.

Leg Extensor Power	7 weeks after surgery Power	P-value	14 weeks after surgery Power	P-value	20 weeks after surgery Power	P-value
HRT	64.0 ± 3.4	N/A	84.1 ± 3.4	P = 0.027	97.5 ± 3.6	P = 0.006
LRT	64.8 ± 3.2	N/A	73.3 ± 3.3	N/A	83.5 ± 3.2	N/A

Results are presented in percentage of the non injured leg before surgery.

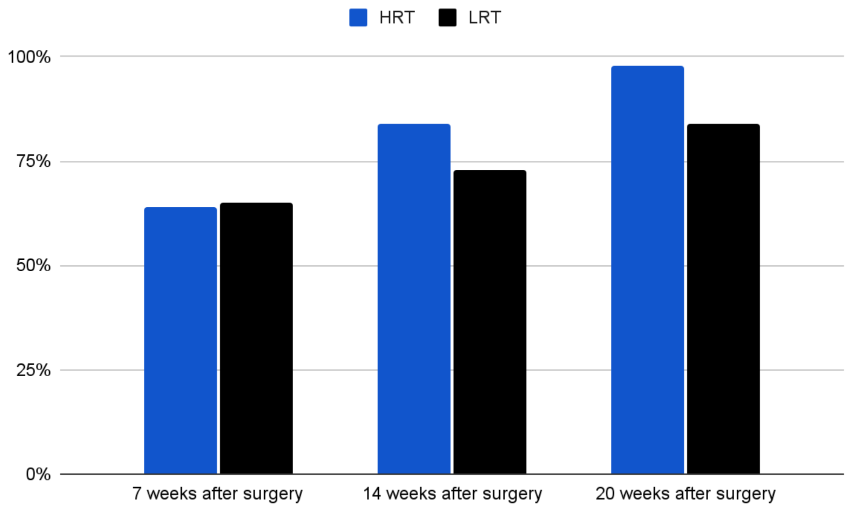

Figure 5. Change in leg extensor power during the intervention period

5.2.3 Article 3, Vidmar et al.

Title: *Isokinetic eccentric training is more effective than constant load eccentric training for quadriceps rehabilitation following anterior cruciate ligament reconstruction: a randomized controlled trial*
Authors: *Marlon Francys Vidmar, Bruno Manfredini Baroni, Alexandre Fróes Michelin, Márcio Mezzomo, Ricardo Lugokenski, Gilnei Lopes Pimentel and Marcelo Faria Silva*
Publish date and forum: *October 2020 in Brazilian Journal of Physical Therapy*
Ethical approval: *The ethics committee of the Universidade Federal de Ciências da Saúde de Porto Alegre, Porto Alegre***,** *approved the study.*
PEDro-Scale: *7/10*

5.2.3.1 Purpose

The purpose of the study was to compare the effects of conventional eccentric training and isokinetic eccentric training on quadriceps strength, functional performance and muscle mass in physically active men following ACLR.

5.2.3.2 Article Method

The study design was an assessor-blinded RCT with 30 recreational male athletes who had undergone an ACLR with autografts from semitendinosus or gracilis tendon. The participants were randomized into either an isokinetic group (IG) or a conventional group (CG) with 15 participants in each group through coin flipping. The interventions lasted over a 6 week period with two sessions/week, starting 45 days post-surgery.

Up to the 30th day all participants received a post-surgery rehabilitation program from a physical therapy protocol with a daily 60 minute session.

The IG group used a Biodex dynamometer which allows maximal strength level at each joint angle to be performed by the individual. There were intervals of 72 hours between each training session. Both groups had the same amount of sets (3-4) and repetitions (10) with one minute rest between sets.

The CG performed a conventional eccentric training program with an extensor chair. CG and IG received the same training duration and weekly frequency. The exercise load successively increased throughout the training program.

Measurements of maximal eccentric, concentric and isometric peak torques were taken before intervention and after the 6 week training program using a Biodex dynamometer.

5.2.3.3 Result

Differences from pre-intervention phase to post-intervention phase are summarized in table 6. The IG group had significant improvements compared to the CG group for isometric and eccentric peak torque ($p < 0.05$). There were no significant differences between the groups for concentric peak torque. All the participants completed the study.

Table 6. Quadriceps strength (mean and standard deviation) pre and post-training for conventional group (CG) and isokinetic group (IG).

Quadriceps Strength (Nm)	CG (n=15)		IG (n=15)	
	Pre	**Post**	**Pre**	**Post**
Isometric PT	181.2 ± 30.3	215.5 ± 33.5	197.7 ± 45.2	256.0 ± 32.2
Concentric PT	176.6 ± 51.8	205.7 ± 44.1	165.1 ± 38.8	206.0 ± 41.6
Eccentric PT	109.1 ± 34.3	128.8 ± 30.7	97.7 ± 30.4	162.1 ± 38.3

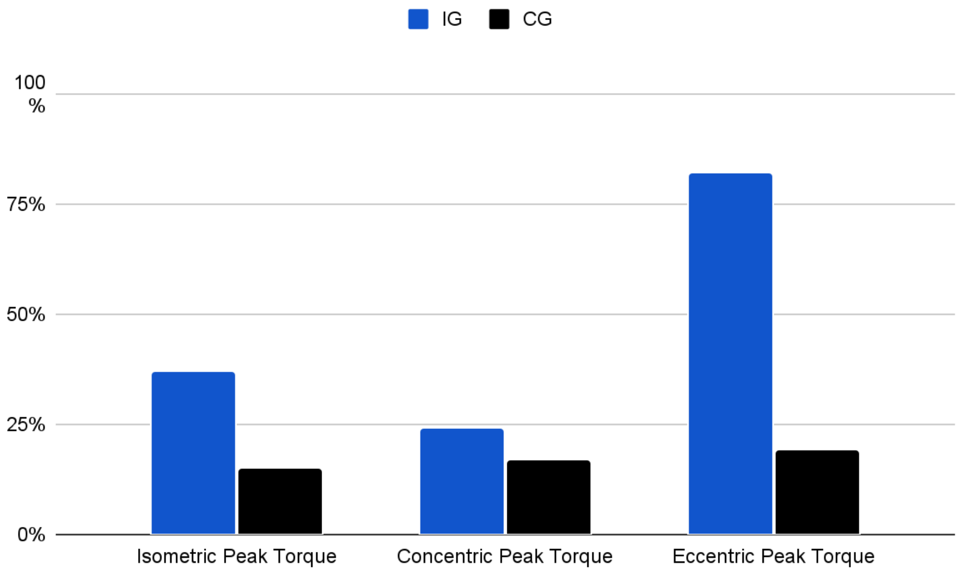

Figure 6. Change in percentage (mean and standard error) pre- to post-training for conventional group (CG) and isokinetic (IG). Significant difference (baseline x post-training; $p < 0.05$).

5.2.4 Article 4, Michael T. Curran et al.

Title: *Blood Flow Restriction Training Applied With High-Intensity Exercise Does Not Improve Quadriceps Muscle Function After Anterior Cruciate Ligament Reconstruction*
Authors: *Michael T. Curran, MEd, ATC, Asheesh Bedi, MD, Christopher L. Mendias, PhD, ATC, Edward M. Wojtys MD, Megan V. Kujawa, and Riann M. Palmieri-Smith, PhD, ATC*
Publish date and forum: *13 march 2020 in The American Journal of Sports Medicine*
Ethical Approval: *Riann Palmieri-Smith, University of Michigan*
PEDro-scale: *6/10*

5.2.4.1 Purpose

The purpose of this study was to examine the benefits regarding BFRT in combination with concentric and eccentric high intensity training on the recovery of quadriceps muscle function post ACLR. Additionally a second analysis studied the differences between BFRT and non-BFRT training regardless of exercise type.

5.2.4.2 Article Method

This study is an unblinded RCT made on 34 patients which all were scheduled to undergo ACLR. Two examinations were made in this RCT.

Firstly (RCT 1) the 34 participants were randomly assigned to 4 groups depending on exercise type: concentric (8), eccentric (8), concentric with BFRT (9) and eccentric with BFRT (9).

Secondly (RCT 2) the 34 participants were divided into two groups where the eccentric and concentric groups were merged to a Non-BFRT group and the eccentric + BFRT and concentric + BFRT groups became the BFRT group. This second analysis was measuring the difference in quadriceps function between BFRT and non - BFRT groups regardless of exercise type.

The exercise intervention consisted of a single-leg isokinetic leg press at a weight of 70% of the patients 1- repetition maximum (RM). In the first analysis the exercise was performed either in eccentric or concentric action depending on which group the patient belonged to. Furthermore, the BFRT groups performed the task with a cuff applied to the thigh causing an occlusion pressure of 80%, the cuff was deflated after each set and re-deflated after 2 minutes, before starting the next set. The session was performed twice a week and included 4 sets of 10 repetitions, excluding warm up. In the second analysis similar exercises were performed but the eccentric and concentric factor was excluded. Both groups performed identical types of exercise but with restricted blood flow or not.

The data was collected before the surgery, after the intervention and at the time the patient returned to activity.

5.2.4.3 Results (RCT 1)

The study found no significant difference between the 4 groups from the preoperative to post intervention interval and neither the preoperative to return to activity (RTA) phase concerning the maximal isokinetic knee extension. The only notable but not significant effect found in the study was a moderate effect size in the concentric BFRT groups regarding CAR (d = 0,68 (95% CI, –1.65 to 0.37) from the preoperative phase to RTA (P-value 0,06).

5.2.4.4 Results (RCT 2)

When merging the groups into BFRT and non-BFRT groups in this second analysis no differences were found between preoperative to post intervention phase concerning maximal isokinetic knee extension ($F_{1,33}$ = 0,50; P = .49) MVIC ($F_{1,33}$ = 0.72; P = .40). However a small effect-size was noted on the maximal isokinetic knee extension strength for the BFRT group between the preoperative and RTA phase (d = 0.26 [95% CI, –0.43 to 0.93]). The results for changes from preoperative to RTA showed no significant differences in maximal knee extension ($F_{1,33}$ = 1.55; P =.22) MVIC ($F_{1,33}$ = 0.14; P = .71).

Table 7. Results for (RCT 2) regarding MVIC, Isokinetic strength, CAR and RFMV from preoperative to post intervention and return to activity phase.

		Pre to Postintervention				Preoperative to RTA			
Groups	**N**	**Isokinetic strength Δ Nm**	**Mvic Δ Nm**	**CAR Δ**	**RFMV ***	**Isokinetic strength Δ Nm**	**Mvic Δ Nm**	**CAR Δ**	**RFMV***
Non-BFRT	16	- 15 ± 34.4	-11.8 ± 38.3	-3.4 ± 10.0	-2.7 ± 3.8	0.4 ± 26.8	-3.2 ± 30.0	0.1 ± 7.5	-0.8 ± 3.6
BFRT	18	- 12.4 ± 19.2	-16.3 ± 31.1	-2.8 ± 8.9	-1.7 ± 2.5	8.2 ± 33.3	- 2.8 ± 45.5	-2.3 ± 10.4	-0.6 ±3.8

The data is reported as mean ± SD. The negative values shown indicate that the variable decreased from preoperative time point. No significant differences were observed at any point of time.
*** Rectus femoris muscle volume Δ cm 3**

5.2.5 Article 5. Michael T. Curran et al.

Title: *Blood Flow Restriction Training Does Not Improve Quadriceps Strength After Anterior Cruciate Ligament Reconstruction*
Authors: *Michael Curran, Asheesh Bedi, Christopher Mendias, Edward M. Wojtys, Megan Kujawa, Riann Palmieri Smith*
Publish date and forum: *29 July 2019 in The Orthopaedic Journal of Sports Medicine*
Ethical Approval: *Unable to present ethical approval*
PEDro-Scale: *6/10*

5.2.5.1 Purpose

The purpose of the study was to investigate the effects of BFRT on quadriceps strength in patients after ACLR.

5.2.5.2 Article Method

In this study 36 patients that underwent ACLR were randomized into two groups. Both groups performed rehabilitation exercise, however one group performed the exercise with a blood flow restriction cuff applied to the thigh. The limb occlusion pressure was 80% and the intervention consisted of a single leg isokinetic leg press at 70% of the patients 1 RM. Four sets of 10 reps were performed twice a week for 8 weeks, the intervention began 8 weeks post surgery. Data for peak isometric and isokinetic quadriceps strength were collected before intervention (baseline) and post intervention.

5.2.5.3 Result

There were no significant differences in change from baseline isokinetic quadriceps symmetry index. The BFRT group presented a value of 0.05 while the control group showed 0.19 (P = 0.39). And from baseline isometric quadriceps symmetry index where the BFRT group presented a result of 0.04 and the control group 0.10 (P=0.62). The effect size found for isokinetic and isometric quadriceps symmetry indexes were small and had a confidence interval that crossed zero.

Table 8. Changes from baseline isokinetic quadriceps symmetry index.

BFTR Mean ±	Control Mean ±	P-Value
= -0.05*	= -0.19*	P= 0.39*
= -0.04**	= -0.10**	P= 0.62**

*Baseline isokinetic quadriceps symmetry index
**Change from baseline isometric quadriceps symmetry index

5.2.6 Article 6, Harput et al.

Title: *Cross-Education improves quadriceps strength recovery after ACL-reconstruction: a randomized controlled trial*
Authors: *G. Harput, B. Ulusoy, T. I. Yildiz, S. Demirci, L. Eraslan, E. Turhan, V. B. Tunay*
Publish date and forum: *29 June 2018 in European Society of Sports Traumatology, Knee Surgery, Arthroscopy.*
Ethical Approval: *All individuals signed a consent form, and Hacettepe University Institutional Review Board confirmed the protocol of the study.*
PEDro-Scale: *8/10*

5.2.6.1 Purpose

The purpose of this study was to compare quadriceps strength and knee function recovery after ACLR using concentric and eccentric CE.

5.2.6.2 Article Method

This study was conducted using a RCT method. The study included 48 individuals who had hamstring tendon autograft used for their ACLR. The individuals' ages ranged from 17-45 years old.

There were three different training groups, one concentric CE with ACLR rehabilitation, one eccentric CE with ACL rehabilitation, and one group with only ACL rehabilitation. The participants were randomly divided into the three groups. The groups had the same ACLR rehabilitation programs, which started during the first week after surgery and consisted of rehabilitation with physical therapists three times per week. The following 8 weeks of rehabilitation consisted of neuromuscular training, including core balance and resistance training in weight bearing positions. From week 12 to 24 the participants were given instructions for home-exercises. These were to be performed on both limbs, 3 times a week and consisted of knee and hip strengthening, plyometric, running, and balance exercises. The CE groups had performed isokinetic concentric or eccentric contralateral limb exercises 3 times per week, as well as the ACL rehabilitation program between week 4-12.

The main outcome measure for quadriceps strength was MVIC and it was measured on an isokinetic dynamometer. The participants performed three MVIC with two minutes rest between.

5.2.6.3 Result

At the baseline measure, 4 weeks after surgery there were no significant differences among the three groups ($P > 0.05$). After 12 weeks the concentric ($P = 0.04$) and eccentric (P =0.03) CE groups showed improved quadriceps MVIC compared to the control group. This was also true for the concentric (P = 0.01) and eccentric (P <0.001) CE groups compared to the control group at the 24th week measurement. No significant differences were found between the CE groups. Results are presented in table 9 and figure 7.

Table 9. Change in muscle power during the intervention

Quadriceps Strength (Nm/kg)	4 weeks		12 weeks		24 weeks	
	Units*	P-value	Units*	P-value	Units*	P-value
Concentric CE (n=16)	1.2 ± 0.5	*P >0.05*	2.5 ± 0.5	*P =0.04*	2.9 ± 0.4	*P =0.01*
Eccentric CE (n=16)	1.2 ± 0.3	*P > 0.05*	2.5 ± 0.4	*P =0.03*	3.0 ± 0.5	*P <0.001*
Control Group (n=16)	1.2 ± 0.4	*P > 0.05*	2.2 ± 0.5	*P =na*	2.4 ± 0.3	*P =na*

* Units = Nm/kg

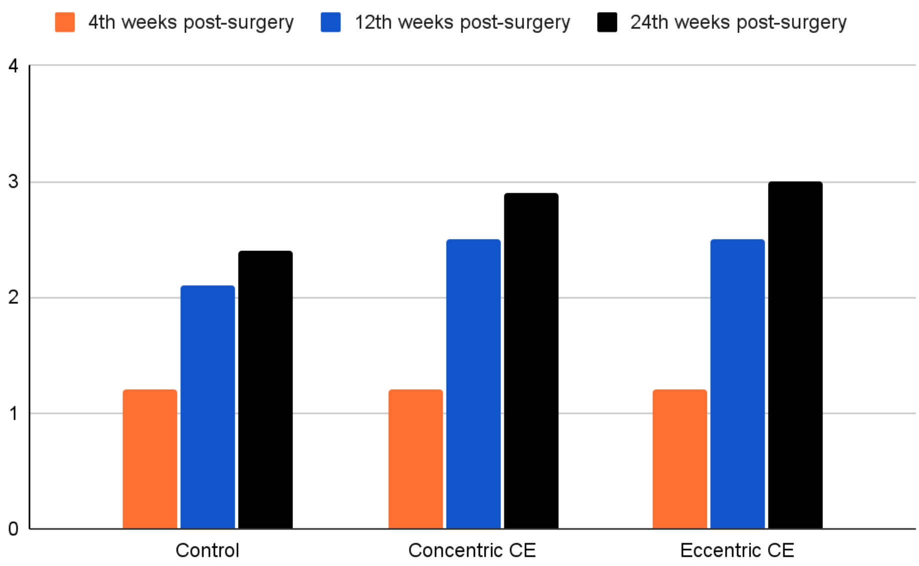

Figure 7. Change in muscle power during the intervention

5.3 Summary of Results in Included Articles

Table 10. Summary of differences from baseline to outcome for the included articles

Author/year	Intervention Groups	Weeks of Intervention	MVIC	P-value	Peak Torque	P-value	Maximum Leg Extensor Power	P-value
Joseph M. Hart et al. 2014	- Cryo - Exercise - Cryo + Exercise	- 2 w.	Cryo: 1.7 ± 0.4 Exercise: 1.6 ± 0.7 Cryo + Exercise: 2.2 ± 0.7	- P = 0.16 - P = 0.16 - P = 0.02	N/A	N/A	N/A	N/A
Theresa Bieler et al. 2014	- HRT* - LRT*	- 20 w.	N/A	N/A	N/A	N/A	HRT*: 97.5 ± 3.6 LRT*: 83.5 ± 3.2	HRT*: P = 0.006
Marlon F. Vidmar et al. 2020	-Conventional eccentric training - Isokinetic eccentric training	- 6 w.	N/A	N/A	- CG Isometric 215.5 ± 33.5 Eccentric 128.8 ± 30.7 Concentric 205.7 ± 44.1 - IG Isometric 256.0 ± 32.2 Eccentric 162.1 ± 38.3 Concentric 206.0 ± 41.6	- IG Eccentric PT*** = (P<0.05) Isometric PT*** = (P<0.05)	N/A	N/A
Gulcan Harput et al. 2018	- Concentric CE + rehabilitation - Eccentric CE + rehabilitation - Rehabilitation	- 24 w.	- Concentric CE: = 2.9 ± 0.4 - Eccentric CE: 3.0 ± 0.5 - Rehabilitation: 2.4 ± 0.3	- P =0.01 - P <0.001 - P = N/A	N/A	N/A	N/A	N/A
Michael T. Curran et al. 2019	-BFRT** -Non-BFRT**	- 8 w.	N/A	N/A	N/A	N/A	N/A	N/A
Michael T. Curran et al. 2020	- BFRT** - Non-BFRT**	- 8 w.	BFRT** = -16.3 ± 31.1 Non-BFRT** = -11.8 ± 38.3	-P<0.05 -P<0.05	N/A	N/A	N/A	N/A

* HRT = High-Intensity Resistance Training. LRT = Low-Intensity Resistance Training

** BFRT = Blood Flow Restriction Training

*** PT = Peak Torque

6. Discussion

6.1 Methodology

This thesis consists of 3 single blinded and 1 assessor blinded study. The studies from Michael Curran et al., (2019) and Gulcan Harput et al., (2018) are unable to present which type of RCT-study design they used, potentially generating a source of error with communicative validity. Furthermore, the reliability for these articles will be affected because of the lack of transparency in the study design. Therefore, decrease the chances of recreating the same results as in the articles. Single blinded study design is when the patients remain unaware which study group they are in whereas double blinded refers to that neither the patients nor the researchers know which study group the patients are in. The study from Vidmar et al., (2020) was an assessor blinded study which means that the participants were ignorant concerning the treatments which the participants were receiving.

This thesis includes RCTs that measure the effectiveness of new interventions or treatments. RCTs provide a way to rule out bias and examine the relationship between intervention and outcome as well as reliability when selecting interventions and population. However, RCTs has the downside of probability of generalizability and loss of follow-up (Hariton and Locascio., 2018). Through manual evaluation of articles via PEDro-scale it immediately identifies trials that are likely to provide internally valid and have adequate statistical information. This process increases the value of validity and further provides a higher reliability due to reproducibility. This thesis represents the sample of the majority of the population which provides a quantitative generalization of the matter of subject, however with generalizability as a source of error.

Females, particularly teenage girls are more likely to suffer an ACL injury (Peterson and Renström., 2017). The articles in this study included both men and women, and all of them did not specify the gender of the participants. Bieler et al., (2014) includes 38% women, whereas Hart et al., (2014) includes 33% women. Furthermore, Vidmar et al., (2020) only had male participants in the study. The selected populations may therefore not reflect a gender balanced result which affects the reliability of this review. The articles included between 30 to 50 participants. Vidmar et al,. (2020) and Hart et al., (2014) had 30 participants each, which was the lowest among the studies. Less participants included in the study could lead to lower plausibility of a reliable result.

The articles in this study include participants who had ACLR carried out with patellar tendon or hamstrings tendon. According to Staghøj Sinding et al., (2020) and Horteur et al., (2021) the quadriceps muscle strength is not affected by the choice of patellar tendon or hamstring tendon autograft. On the other hand, Nakamura et al., (2002) suggests that hamstring tendon autograft could lead to significant loss of hamstring strength and function, which would affect the function of the knee. The choice of autograft tendon is still a debated subject, and different benefits and disadvantages are granted (Macaulay, Perfetti and Levine, 2011). Moreover, research suggests that the type of autograft may influence the results of quadriceps strength following the surgery. In the majority of articles the choice of autograft was not presented leading to deficient reliability. This factor also affects the validity in the included articles because only one article (Gulcan et al., 2018) used one type of tendon graft for all participants.

The average time for RTA following an ACLR is 6-12 months (Brukner & Khan, 2012, p.639-668). Even though most people undergo careful, and professional rehabilitation throughout these months, 1 in 9 people will rerupture or have a clinical failure within 10 years (Crawford et al., 2013). The articles included in this study examine the effect of different exercise-based interventions for quadriceps strength post ACLR during a 2-24 week span, depending on the article. The chosen time interval could affect the reliability of the review, especially the article by Joseph M. Hart et. al., (2014) which lasted 2 weeks. It remains unclear if the article can show evidence of strength gains after only 2 weeks of intervention. As the authors of the article suggest, the increase in quadriceps strength that was found in the study is more likely a result of neuromuscular adaptations (Cannon J et al., 2010). The other studies are more likely to present hypertrophy and strength gains due to the longer duration of intervention time.

Two of the studies by Curran et al., (2019, 2020) investigated BFRT, both for 8 weeks. In one of the studies by Curran (2020) the baseline measurements were performed before surgery, which causes the results for this article to be misleading in relation to the other articles where the measurements were performed post ACLR. In the post surgery phase the quadriceps strength is largely affected and a significant strength loss is evident (Brown et al., 2021).

Bieler et al., (2014) also performed the baseline measurements before surgery, and therefore the results are misleading in relation to other articles. It was also the only article that used maximum leg extensor power as the outcome measurement, and reporting changes in percentage. Therefore, the result of the article cannot be compared to the others.

6.2 Limitations and Strengths to this Literature Review

Curran et al., (2019, 2020) provided two out of six articles in total and two out of two articles about BFRT which could potentially narrow the perspective in that field, a broader outcome and perspective could be presented if the author selection would vary. Furthermore, the authors of this thesis have limited experience to construct a literature review and could therefore be an improvement towards exclusion and inclusion criteria reasoning, search process and critical analysis concerning the included articles.

None of the included articles conducted any follow-up measurements. Because of this there was a lack of evidence for the long-term effects of the independent exercise-based rehabilitation strategies. Therefore, the long-term effects of the interventions require further research in order to determine the RTA ratio of patients.

To the authors knowledge this is the first literature review to investigate the difference between different exercise-based rehabilitation strategies on quadriceps strength following ACLR. Another strength of this literature review is that the included articles scored 5 or higher on the criterias of the PEDro scale, ranging from 1-10. In addition the articles were reviewed by the three authors writing this review, which results in a more objective evaluation of the included articles.

6.3. Discussion of Results

The primary findings suggested that cryotherapy combined with exercise resulted in an increase of MVIC compared to regular exercise (Hart et al, 2014). Harput et al., (2018) also showed an increase in MVIC, which would suggest that eccentric and concentric isokinetic training as CE is beneficial for quadriceps strength post ACLR. Other important findings in this study was that HRT increased maximum leg extensor power compared to LRT according to Bieler et al., (2014) study. Vidmar et al., (2020) showed a significant increase in eccentric and isometric peak torque following eccentric isokinetic training when compared to eccentric conventional training. However, the findings of the two BFRT studies by Michael T. Curran et al., (2019, 2020) suggested no benefits of BFRT when compared to regular exercise.

The article by Joseph M. Hart., (2014) used cryotherapy, not as pain relieving, but to treat the underlying source of arthrogenic muscle inhibition (AMI). Patients performing exercise immediately after cryotherapy might seem worrying for clinicians concerning the possibility that the joint function will be negatively affected due to the loss of peripheral sensory input resulting in a higher reinjury risk (Uchio Y et al., 2003). In this study the cooling therapy was intended to enhance motorneuron-pool availability during controlled rehabilitation exercises which may be negatively affected by pain, swelling and inflammation. These factors influence the mechano and nociceptors associated with the joint, resulting in changes of sensory distribution to the central nervous system. Causing the excitability of numerous spinal and supraspinal pathways to become impair which limits the ability to activate the muscles in the affected area (Rice and McNair., 2010).

This study seems to confirm the statement that patients with AMI can benefit from cryotherapy through the process of “opening” inhibited motorneuron pools in a short period of time after the cryo intervention. Resulting in an opportunity of recruiting more motor units while performing the exercise in this short window of time (Hart et al., 2014) Cryotherapy will not heal or undo the joint-damage, and neither will it completely remove AMI permanently. (Kuenze et al., 2010).

According to Bieler et al., (2014), leg extensor muscle power improves considerably with the HRT rehabilitation program compared to the LRT during weight training from 8 to 20 weeks after surgery. This suggests that HRT should be included in ACL rehabilitation programs. However, the HRT-group had a higher training intensity, lifted heavier loads, and there was also a difference in exercises between the groups. Therefore, the significant results for HRT could be due to neuromuscular adaptations, and also greater hypertrophy response (Mikko et al., 2011; Wernbom et al., 2007).

Harput et al., (2018) results suggest that CE should be considered during early phases of an ACL rehabilitation program. Other studies also support the function of CE on achieving muscle strength gains in the untrained limb (Manca et al., 2017). The effects of CE may come from central inhibition (Latella et al., 2011) and improved neuromuscular facilitation and voluntary activation in the untrained limb (Lee and Carroll, 2007).

Vidmar et al., (2020) presented a significant difference in isometric and eccentric peak torque for the IG, however no-between group difference in concentric peak torque. This suggests that the use of OKC eccentric training could be effective for strength in quadriceps rehabilitation after ACLR.

Eccentric training programs or those containing eccentric overloading optimize and modify the muscle responses to strength training. Superior enhancement in power function has also been suggested from applied eccentric training. Power and strength are two major outcomes when committing to an eccentric training program as well as hypertrophy and tissue changes when the magnitude of strain is imposed (Douglas et al., 2016).

Studies performed with 80% occlusion in combination with training claim no functional improvements in relation to quadriceps muscle strength compared to non-BFRT exercise. All the primary and secondary outcome measures found in the study have a p-value higher than 0,05 which makes it not significant (Curran et al, 2019; 2020)

The exercise-based rehabilitation strategies presented in this review indicate that cryotherapy in combination with exercise may be beneficial in the early stages of the rehabilitation to increase quadriceps strength. This could also be the case for CE, because of the possible neuromuscular adaptations in the reconstructed limb. HRT and isometric/eccentric isokinetic exercise could be more useful in the later phases of the rehabilitation. This is due to the higher intensity of these strategies, and therefore increased re-injury risk.

6.4 Clinical Relevance

The rehabilitation phase following ACLR can be extensive and several factors need to be included during the process. This study supports that statement by suggesting 4 different exercise-based rehabilitation strategies for quadriceps strength (Hart et al, 2014; Harput et al., 2018; Bieler et al., 2014; Vidmar et al., 2020). Still, it is important to highlight that quadriceps strength alone is unlikely to represent the total success of the ACL rehabilitation and its outcome. Other factors to take into consideration are function of the knee, pain and psychological. All of these components are therefore important to take into consideration when a case with an ACLR characteristic presents in a clinical setting (Belandra et al., 2021; Nwachukwu et al., 2019).

Sports medicine includes physical fitness, treatment and prevention of injuries that are related to sports and exercise. Sports medicine is an important part of the osteopathic profession, among other subjects such as anatomy, physiology and biomechanics. Furthermore, osteopaths have a broad set of techniques to treat dysfunctions in the neuromusculoskeletal system (Brolinson, McGinley and Kerger., 2008). Pain in the somatic structures around the injured knee is common following ACLR. Manual therapy in combination with exercise has been linked with decreased pain sensation around the knee (Nunes et al., 2016) and in other regions of the body (Hidalgo et al., 2017; Ulger et al., 2017). Thus, osteopaths can aid with possible pain sensation around the knee, as well as the exercise-based phases throughout the rehabilitation. Hence, increase the possibility of a successful RTA for patients.

The psychological aspects of RTP following ACLR has been recognized throughout this article. Kinesiophobia and knee self-efficacy has been mentioned as two common factors related to delay in the rehabilitation process (Baez et al., 2020; Nwachukwu et al., 2019). Osteopathy has a history of patient-centered care and to acknowledge the biopsychosocial model, both of which focus on the patients mental health (Thomson et al., 2012). When considering the many factors to a successful ACL rehabilitation, osteopaths have the required skills and knowledge to treat and aid patients during this period. It is therefore of clinical relevance for osteopaths to be updated on exercise-based rehabilitation strategies to improve quadriceps strength following an ACLR.

7. Conclusion

The results indicated that the exercise-based rehabilitation strategies CE and cryotherapy are superior to BFTR when evaluating quadriceps strength. Furthermore, the results suggest that isokinetic and eccentric strength training are superior to concentric training in quadriceps strength. The results also indicated that HRT increased quadriceps strength whereas LRT did not. To conclude, CE, cryotherapy, isokinetic or eccentric strength training, and HRT are rehabilitation strategies that, in combination with exercise, should be considered as management post ACLR. More research is necessary to increase the evidence for each of the interventions in regards to quadriceps strength, but also knee function and kinesiophobia. Research also needs to be conducted on comparing the different interventions to each other.

8. Appendices

8.1 Appendix A

Authors	Year	Reason for Exclusion
Kaya D, Guney-Deniz H, Sayaca C, Calik M, Doral MN.	2019	Tibialis anterior autografts
Friedmann-Bette B, Profit F, Gwechenberger T, Weiberg N, Parstorfer M, Weber MA, Streich N, Barié A.	2018	Not measuring quadriceps strength as primary outcome
Jeong J, Choi DH, Shin CS.	2021	No ACLR
Zebis MK, Sørensen MH, Lauridsen HB, Bencke J, Andersen CH, Carlsbæk JB, Jespersen P, Kallehauge AH, Andersen LL.	2019	No ACLR
Nagai T, Bates NA, Hewett TE, Schilaty ND.	2018	Not measuring quadriceps strength as primary outcome
Barnett S, Badger GJ, Kiapour A, Yen YM, Henderson R, Freiberger C, Proffen B, Sant N, Trainor B, Fleming BC, Micheli LJ, Murray MM, Kramer DE.	2020	Age-criteria
Jeong J, Choi DH, Song Y, Shin CS.	2019	Not measuring quadriceps strength as primary outcome
Çelik D, Turkel N.	2015	No ACLR
Bodkin SG, Bruce AS, Hertel J, Diduch DR, Saliba SA, Novicoff WM, Hart JM.	2020	Not measuring quadriceps strength as primary outcome
Zult T, Gokeler A, van Raay JJAM, Brouwer RW, Zijdewind I, Farthing JP, Hortobágyi T.	2018	Age-criteria
Kacin A, Drobnič M, Marš T, Miš K, Petrič M, Weber D, Tomc Žargi T, Martinčič D, Pirkmajer S.	2021	Not measuring quadriceps strength as primary outcome
Barcellona MG, Morrissey MC, Milligan P, Clinton M, Amis AA.	2014	No ACLR
Mendias CL, Enselman ERS, Olszewski AM, Gumucio JP, Edon DL, Konnaris MA, Carpenter JE, Awan TM, Jacobson JA, Gagnier JJ, Barkan AL, Bedi A.	2020	Using growth-hormone
Blackburn JT, Pamukoff DN, Sakr M, Vaughan AJ, Berkoff DJ.	2014	Not measuring quadriceps strength as primary outcome
Hunt ER, Villasanta-Tezanos AG, Butterfield TA, Lattermann C, Jacobs CA.	2020	Not measuring quadriceps strength as primary outcome
Chandramouli Krishnan, Paul Theuerkauf	2015	No rehabilitation
Tina Grapar Zargi , Matej Drobnic, Jadran Jkoder, Klemen Strazar, Alan Kacin	2016	Pre-surgery
Araken K A Oliveira , Daniel T Borges , Caio A A Lins , Rafael L Cavalcanti , Liane B Macedo , Jamilson S Brasileiro	2016	PEDro-scale less than 5
Gisela Sole, Peter Lamb, Todd Pataky, Stefan Klima, Pierre Navarre, Niels Hammer	2021	Knee Sleeve
Rodriguez, Kazandra; Garcia, Steven A; Spino, Cathie; Lepley, Lindsey K; Pang, Yuxi; Wojtys, Edward; Bedi, Asheesh; Angelini, Mike; Ruffino, Bethany; Bolley, Tyler; Block, Corey; Kellum,	2020	Age-criteria

Authors	Year	Reason for Exclusion
Jessica; Swartout, Andrew; Palmieri-Smith, Riann M		
Chen, Jia; Gu, Aiqun; Jiang, Haitao; Zhang, Wenjie; Yu, Xiangrong	2014	Artificial ligament
Hoogeslag, Roy A. G.; Brouwer, Reinoud W.; Boer, Barbara C.; de Vries, Astrid J.; Huis in 't Veld, Rianne	2019	Repair or reconstruction
Lauren N Erickson,Kathryn C Hickey Lucas, Kylie A Davis ,Cale A Jacobs Katherine L Thompson, Peter A Hardy, Anders H Andersen Christopher S Fry ,Brian W Noehren	2019	Still ongoing study, no result.
da Costa, K., Borges, D., de Brito Macedo, L., de Almeida Lins, C. and Brasileiro, J.,	2019	Less than 2 weeks research time
Pamukoff, D., Pietrosimone, B., Ryan, E., Lee, D., Brown, L. and Blackburn, J.,	2017	Less than 2 weeks research time
Pamukoff, D., Pietrosimone, B., Lewek, M., Ryan, E., Weinhold, P., Lee, D. and Blackburn, J.,	2016	Less than 2 weeks research time

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Dr. Nikita, A, Vizniak 2020 *Orthopedic Conditions* Prohealthsys

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