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Nurse-Assisted Rehabilitation Protocols Following Anterior Cruciate Ligament Reconstruction

Fang Yu ▼ Li-En Xiao ▼ Tao Wang ▼ Yong Hu ▼ Jun Xiao

Despite significant advancements in surgical instruments and operation skills, short- and long-term outcomes following anterior cruciate ligament reconstruction (ACLR) remain unsatisfactory, as many patients fail to return to their pre-injury level of sports. Inadequate ACL rehabilitation is the primary cause of poor outcomes. Nurses have become a crucial element in the rehabilitation process. Although there is no consensus regarding the optimal post-operative rehabilitation protocols, restoring muscle strength and neuromuscular control are consistently the primary goals. This literature review presents nurse-assisted rehabilitation protocols aiming at improving muscle strength and neuromuscular control. The review discusses postoperative rehabilitation, including home-based and supervised rehabilitation, open and closed kinetic chain exercises, eccentric and concentric training, blood flow restriction training, and plyometric training. Each training protocol has its benefits and drawbacks, and should be used cautiously in specific stages of rehabilitation. Neuromuscular training, such as neuromuscular electrical stimulation, neuromuscular control exercises, and vibration therapy, is considered crucial in rehabilitation.

Background

Arthroscopic-assisted anterior cruciate ligament reconstruction (ACLR) is currently the standard surgical treatment for those suffering from ACL rupture. The incidence of ACL rupture is estimated to range from 30 to 78 per 100,000 person years (Gans et al., 2018; Nordenvall et al., 2012; Sanders et al., 2016; Singh, 2018). Up to 75% of those with ACL-related injuries underwent ACLR (Sanders et al., 2016). Moreover, the rate of ACLR is significantly increasing over time, representing a greater desire to return to an active lifestyle after ACL injury for patients, and reflecting changes in treatment pattern as surgeons develop better techniques (Dai et al., 2022; Mouarbes et al., 2019; Sanders et al., 2016).

Despite significant advancements in surgical instruments and operation skills, short- and long-term outcomes following ACLR remain unsatisfactory, as many patients fail to return to their pre-injury level of sports. Recent research reported that 35% of athletes after ACLR were unable to reach the pre-injury sport level within 2 years (van Melick et al., 2016). Research suggested that inadequate ACL rehabilitation primarily accounted for the poor outcomes after ACLR (Andrade et al., 2020; Ebert et al., 2018; K. Rodriguez et al., 2020). A significant reduction in quadriceps strength after ACLR is common when rehabilitation is inadequate or interventions are improper (Dingenen et al., 2021; K. Rodriguez et al., 2020), leading to a detrimental quality of life, higher risk of recurrent ACL injury, abnormal knee biomechanics during walking, and inevitably causing the development of posttraumatic osteoarthritis in almost half of ACL-reconstructed limbs (Barenius et al., 2014; Grindem et al., 2016; Pottkotter et al., 2018; K. Rodriguez et al., 2020). The nurse has become a basic element of the rehabilitation process (AbdElghany et al., 2019), contributing to

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physiological and psychological patient outcomes. Before beginning rehabilitation, the nurse should educate the patient on the significance of adhering to the rehabilitation program and making lifestyle modifications to promote healing. During the rehabilitation process, the nurse can assist patients with exercises and activities prescribed by the physical therapist or physician, monitor the patient's progress, and identify any potential complications. The study of Lv and Yang (2021) favored the positive effect of nurse-assisted protocols to accelerate rehabilitation following surgery and significantly improve the quality of postoperative orthopedic recovery.

There is still substantial heterogeneity in the available ACL rehabilitation protocols in the scientific literature. Carter et al. (2021) emphasized the importance of prehabilitation, which was recognized as a vital tool to physically and mentally prepare patients for ACLR and post-operative rehabilitation. However, prehabilitation interventions were relatively limited in clinical practice (Carter et al., 2021; R. M. Rodriguez et al., 2019). Researchers have focused more on post-operative rehabilitation following ACLR, which has evolved dramatically over the last several decades. For example, interventions have shifted from absolute immobilization and no muscle activity to minimal range of motion (ROM) restrictions with immediate muscle activation (Awad et al., 2017).

While there is no consensus regarding the optimal post-operative rehabilitation program. Restoring motion and strength, and ultimately returning to the pre-injury activity level, have been consistently identified as the goals of existing rehabilitation protocols (Andrade et al., 2020; Awad et al., 2017; Dingenen et al., 2021; Filbay & Grindem, 2019; Makhni et al., 2016; K. Rodriguez et al., 2020; van Melick et al., 2016). Home-based rehabilitation (HBR) and supervised rehabilitation (SR) are the existing two schools of thought with regard to post-operative rehabilitation following ACLR. Previous studies reported no statistically significant differences between HBR and SR (Beard & Dodd, 1998; Grant et al., 2005). However, the updated study by Lim et al. (2019) has provided additional insights, suggesting that while HBR and SR are equally effective in recovering knee strength, SR is more effective than HBR in the recovery of proprioception and functional knee movement. Modern blood flow restriction systems can regulate the level of restriction, measured in terms of limb occlusion pressure, in a highly controlled manner. This allows for complete venous and partial arterial occlusion, which can facilitate strength recovery following ACLR (Telfer et al., 2021). van Melick et al. (2016) proposed that neuromuscular training should be added to strength training to optimize self-reported outcome measurements. Rehabilitation protocols have evolved over time. Therefore, the objective of this article is to assess and summarize nurse-assisted rehabilitation protocols with regard to strength and neuromuscular training following ACLR.

Materials and Methods

To identify relevant studies published from January 2000 to September 2022, international electronic databases including PubMed, Scopus, Embase, Web of Science, EBSCO, Cochrane Central, and Google Scholar were searched using the terms "anterior cruciate ligament reconstruction", "ACL", "rehabilitation" and their related counterparts. Clinical trials and random controlled trials were eligible for the search. The abstracts were independently screened by two reviewers. Full-text reports were retrieved in cases where the abstracts appeared to meet the inclusion criteria or when insufficient information was provided. Subsequently, the full-text articles were independently screened by the same reviewers to assess their eligibility against the criteria.

Inclusion Criteria

The inclusion criteria for this study encompassed a diverse range of individuals. Both males and females were considered eligible for participation, with an age threshold of 16 years and older. Additionally, prospective participants had to meet specific medical criteria, specifically; they must have undergone post-traumatic ACL reconstruction using either a hamstring or a patella tendon auto-graft. Finally, the study included individuals who had received any form of physiotherapy intervention starting from the day of their surgery. These comprehensive criteria ensured a diverse and representative sample for our research

Exclusion Criteria

The study's exclusion criteria were designed to refine the participant selection process. Firstly, individuals who had undergone multiple surgeries involving the ACL (e.g., ACL and meniscectomy) were excluded. Additionally, reviews that focused on conservative physiotherapy intervention for ACL rupture were not considered within the scope of this study. Secondly, participants who had received physiotherapy interventions before operation were also excluded. To maintain the study's focus and rigor, subjects falling into categories such as irrelevant subject matter, comment/editorial letters, conference and meeting abstracts were not included. Lastly, individuals in the non-English language were not eligible for participation.

Comparison between Rehabilitation Protocols

High-quality randomized controlled trials as Level-I studies and lesser-quality randomized controlled trials and prospective comparative studies as Level-II studies were included to examine differences between controversial rehabilitation protocols. This review examined nurse-assisted protocols following ACLR in the home versus with supervision, open (OKC) versus closed kinetic chain (CKC) exercises in the early period following ACLR (see Tables 1, 2, and 3).

TABLE 1. PRIMARY FINDINGS BETWEEN HOME-BASED REHABILITATION AND SUPERVISED REHABILITATION PROTOCOLS.

Study	No. of Patients/ Groups	Follow-up	Group Differences	Parameters Assessed	Significant Findings
Grant et al. (2005)	145 patients	12 weeks	HBR group (4 physical therapy sessions) versus SR group (17 physical therapy sessions)	Range of motion, laxity, strength	No significant differences
Lim et al., (2019)	30 patients	24 weeks	HBR (phone instruction) versus SR (twice per week)	Strength and proprioception	No significant difference in knee strength. SR leads to better recovery of proprioception and functional knee movement
Hohmann et al. (2011)	40 patients	48 weeks	HBR group versus SR group (weekly for the first 6 postoperative weeks, biweekly visits until 6 months, monthly until 9 months after surgery)	Lysholm Score, Tegner Activity Scale, functional hopping tests, and strength	No significant differences
Revenäs et al. (2009)	24 patients	48 weeks	Knee-class Therapy (at least 13 physiotherapy sessions), versus Guided Therapy (limited physiotherapy appointments)	Function, activity level, strength, knee-joint stability and knee-joint mobility	No significant differences
Przybylak et al. (2019)	50 patients	48 weeks	SR group (1.5 hours per individual visits with the physiotherapist) versus HBR group (exercise at home without supervision)	Kujala scale, Tegner scale, the Knee injury and Osteoarthritis Outcome Score, the Functional Movement Screen, and range of motion	SR results in higher activity levels and better quality of life
Grant and Mohtadi (2010)	88 patients (>16 years)	2–4 years	SR group (17 physical therapy sessions) versus HBR group (4 physical therapy sessions)	ACL quality of life questionnaire, range of motion, laxity, strength, and Objective International Knee Documentation Committee score	No significant differences

Note. ACL = anterior cruciate ligament; HBR = home-based rehabilitation; SR = supervised rehabilitation.

Results

The initial database search yielded 143 articles. After duplicates were removed, 87 articles were screened for inclusion. No additional articles were found from the screening of unpublished searches. After title and abstract screening, 60 full-text articles were assessed for eligibility. Twenty-one studies were finally included based on the exclusion criteria. Figure 1 summarizes the study selection process. The results have been synthesized and clarified in the following sections, categorized according to various rehabilitation protocols.

Home-Based Rehabilitation and Supervised Rehabilitation

Functional measures are considered more appropriate than time-based milestones to guide progression through postoperative rehabilitation (Vascellari et al., 2020). Accordingly, it was commonly believed that rehabilitation following ACLR necessitates the involvement of a physical therapist to provide individualized progressive strength/neuromuscular training and to make timely adjustments based on functional performance, from the early postoperative period until the time of return to sports (Andrade et al., 2020; Uchino et al., 2022; Walker et al., 2020). However, previous reports have indicated that there is no significant difference in clinical outcomes between HBR and SR protocols (Chmielewski et al., 2016; Darain et al., 2015; Grant & Mohtadi, 2010). Six randomized controlled trials were included (Table 1).

Grant et al. (2010) performed a long-term follow-up study and suggested that patients who participated in a predominantly HBR program in the first 3 months

Table 2. Primary Findings Between Open Kinetic Chain Exercise and Close Kinetic Chain Exercise.

Study	No. of Patients/ Groups	Follow-up	Group Differences	Parameters Assessed	Significant Findings
Hooper et al. (2001).	37 patients	6 weeks	OKC group (ankle weights or knee and hip extension machines) versus CKC group (a leg press machine)	Hughston Clinic visual analog scale, knee function	No clinically significant differences in the functional improvement.
Kang et al. (2012)	36 patients	12 weeks	OKC group (straight leg raise, leg extension, leg curl) versus CKC group (squat, leg press, lunge)	Isokinetic strength, endurance, and squat strength	OKC exercises resulted in a significantly greater gain in isokinetic strength and endurance of the extensor muscles than CKC exercises
Mikkelsen et al. (2000)	44 patients	30 months	CKC group versus OKC group (CKC plus OKC exercises starting from week 6 after surgery)	Anterior knee laxity, muscle torque, individual knee function and physical activity/ sports	CKC exercises with the addition of OKC exercises results in a significantly better improvement.
Morrissey et al. (2000)	36 patients	4 weeks	OKC group (ankle weights or knee and hip extension machines) versus CKC group (a leg press machine)	Knee laxity	No significant differences in effects to knee laxity.
Perry et al. (2005)	49 patients	14 weeks	OKC group (ankle weights or a knee extension/ham curl machine) versus CKC group (a leg press machine)	Knee laxity, Hughston Clinic Questionnaire, single- leg hop for distance, triple crossover hop test	No significant differences in effects to knee laxity and function.
Uçar et al. (2014)	58 patients	24 weeks	OKC group (isometric quadriceps, flexor-extensor bench, isotonic quadriceps, leg press on-off, stretching) versus CKC group (squatting lunges, standing weight shift, wall sits, one-legged quad dips, lateral step-ups)	Lysholm scores, visual analog scale, knee flexion, thigh circumference	CKC exercise program was more effective than OKC in improving the knee functions.

Note. CKC = closed kinetic chain; OKC = open kinetic chain.

after ACLR have similar 2- to 4-year outcomes compared with those participating in a SR program. Gamble et al. (2021) suggested that frequent SR may not be necessary following ACLR based on their finding that SR was not superior to less SR in any outcomes, including knee function, sport participation, and quality of life. Another recent systematic reviewed by Uchino et al. (2022) also showed a consistent result. Interestingly, Uchino et al. emphasized that HBR required patients to perform the same exercise protocols and to consult with medical professionals for checking adherence, proper form, and progressions of exercise at key time points. It would be reasonable to classify such HBR as minimally SR, accounting for the similar effects. However, the study of Przybylak et al. (2019) favored SR, reporting higher activity levels and better quality of life in the SR protocol 12 months after ACLR. Lim et al. (2019) found no statistically significant differences between HBR and SR group in the isokinetic knee strength of the extensors and flexors, but observed improvements in proprioception in the SR group. It is important to acknowledge that orthopedic registered nurses can contribute to improved patient outcomes in HBR and SR. The orthopedic registered nurse or a trained community-based nurse can provide instructions on proper exercise techniques, help the patient set realistic goals, and monitor progress through regular check-ins. The nurse can also assist in identifying potential environmental hazards, such as loose rugs or uneven surfaces, that may increase the risk of falls during rehabilitation (Lv & Yang, 2021). For postoperative ACLR patients, positive outcomes have been reported with the development of a nursing rehabilitation program (Mohammed et al., 2016). During SR sessions, the nurse can collaborate with

Table 3. Primary Findings Between Concentric and Eccentric Strengthening Protocols.

Study	No. of Patients/ Groups	Follow-up	Group Differences	Parameters Assessed	Significant Findings
Gerber et al. (2007)	32 patients	26 weeks	Concentric group (TRAD) versus eccentric group	Safety and knee stability, functional ability	Eccentric exercise program led to better functional improvement than concentric exercise program.
Gerber et al. (2009)	40 patients	48 weeks	Concentric group (TRAD) versus eccentric group	Imaging assessment, routine knee examinations, self-report assessments, and strength and functional testing	Eccentric group led to greater increases in muscle volume and better functional improvement.
Milandri and Sivarasu (2021)	26 patients	8 weeks	Concentric group versus eccentric group	International Knee Documentation Committee and Knee injury and Osteoarthritis Outcome Score, 36-Item Short Form Health Survey, gait parameters, knee and hip biomechanics muscle torque, muscle volume.	No significant differences in function improvement.

Note. TRAD = traditional.

the physical therapist or physician to ensure proper technique and safety during exercises. The nurse can also monitor vital signs, pain levels, and any potential complications during the rehabilitation session. Additionally, the nurse can provide emotional support and encouragement to the patient during the challenging process of rehabilitation.

Successful rehabilitation following ACLR may not depend solely on HBR or SR. Other important factors, such as the frequency and duration of rehabilitation sessions, the patient's understanding and compliance with their rehabilitation program, and their adherence to prescribed exercises, may also play significant roles in achieving positive outcomes. A comprehensive understanding of the complex, extensive, and demanding rehabilitation regimen allows patients to better understand expectations and improve self-compliance. Psychologically, having a strong motivation to return to sports during the rehabilitation program can be crucial in achieving a full recovery and returning to pre-injury activity levels (Sonesson & Kvist, 2022; Sonesson et al., 2017). Lv and Yang (2021) proposed the concept of nursing rehabilitation following ACLR, which aims to alleviate tension, anxiety, and other negative emotions in patients and boost their confidence by sharing successful case studies of surgery. Brewer et al. (2013) indicated that the adherence to rehabilitation was positively associated with final clinical outcomes. Han et al. (2015) also confirmed that patients who comply with their physical therapist's rehabilitation program may achieve higher functional outcome scores and be more likely to return to sports. Darain et al. (2015) proposed that a greater frequency of SR sessions may be recommended to patients during the early phase of rehabilitation (up to 12 weeks following surgery). This phase was considered to be an important juncture to understand the influence of early "dose-responses" in rehabilitation. In contrast, Yabroudi et al. (2021) argued that a longer rehabilitation duration with a higher frequency of supervised sessions may lead to better outcomes with SR than with HBR and could be associated with a higher chance of returning to the previous level of sports. Ebert et al. (2018) revealed that a duration of >6 months of SR might be appropriate to reach the goal of returning to sports. Some researchers proposed a longer duration of SR (9–12 months) to achieve rehabilitation goals (van Melick et al., 2016; Walker et al., 2020).

Strength Training

Restoring quadriceps and hamstring strength is one of the key components in the rehabilitation process following ACLR. Post-operative strength deficits have been associated with alterations in knee mechanics, a reduction in functional performance, a delayed return to pre-injury competitive level, an increased risk of ligament re-injury, and the development of knee osteoarthritis (Vidmar et al., 2020). Furthermore, it has been observed that quadriceps muscle weakness may persist for years following ACLR if rehabilitation is inadequate or improper. Exercise prescription is a fundamental part of physiotherapy care and an important element in an ACL rehabilitation programme (Dai et al., 2022; Vidmar et al., 2020; Wilk & Arrigo, 2017). Variations in exercise interventions for strength training have been proposed by clinicians and researchers to improve ACL rehabilitation techniques. The nurse should work closely with the physical therapist to understand the prescribed exercises and ensure that the patient performs them correctly and safely. It is also essential to educate patients about the importance of gradual progression and

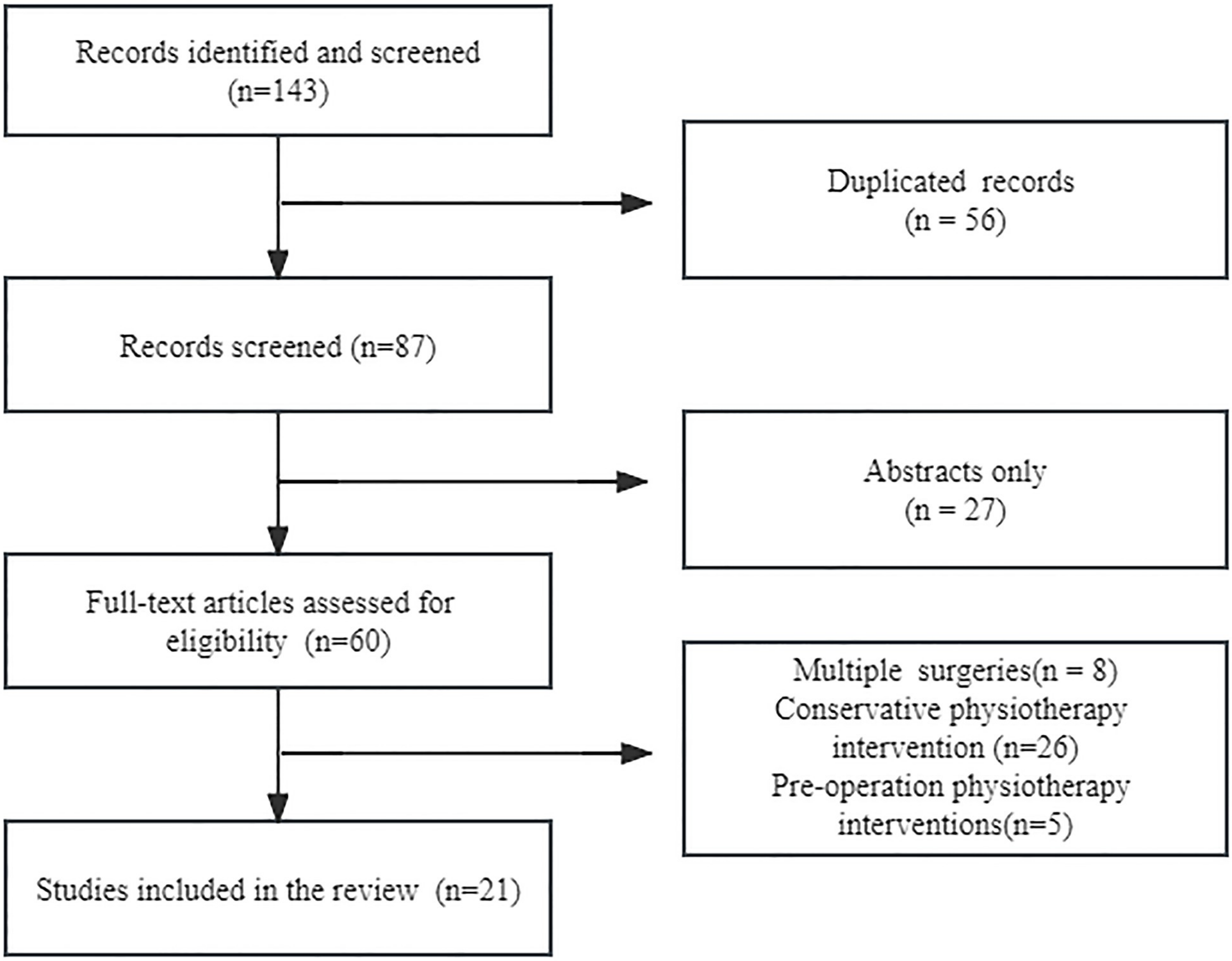

FIGURE 1. PRISMA flow diagram showing the selection criteria of assessed the studies.

avoiding overexertion, which can lead to muscle strain and delayed recovery.

Open Kinetic Chain Exercise and Close Kinetic Chain Exercise

Accelerated rehabilitation protocols allow immediate mobilization and full weight bearing in the initial phase after ACLR, to reach fast recovery (Logerstedt et al., 2017; Wright et al., 2015). Immediate mobilization following ACLR is critical in increasing joint range of motion, reducing knee pain, and preventing soft tissue-related adverse events (Logerstedt et al., 2017; Wright et al., 2015). Thus, CKC exercises are recommended to be prioritized in the early rehabilitation phase, as they mimic functional movements used in activities of daily living and sports, without increasing anterior knee laxity (Awad et al., 2017). In contrast, Heijne and Werner (2007) concluded that an early start of OKC quadriceps exercises had no beneficial effect on quadriceps strength, and even led to more laxity after a follow-up period of 7 months. Andersson et al. (2009) also found that CKC quadriceps exercises produce less pain, less risk of increased laxity and better self-reported knee function compared to OKC quadriceps exercises.

However, a more recent systematic review has reported that both CKC and OKC exercises were equally effective in restoring quadriceps strength and improving functional outcomes following ACLR (OKC versus CKC) (Andrade et al., 2020; Awad et al., 2017). The study of Noehren and Snyder-Mackler (2020) identified three evidence-based keywords related to OKC exercises: they are safe, critical to restoring quadriceps strength, and key for assessing readiness to return to sport. Indeed, the effect of CKC exercises in combating the ubiquitous quadriceps weakness is limited. Noehren and Snyder-Mackler (2020) clarified that the key to performing OKC exercises properly is to apply appropriate loads. A knee extension machine or an electromechanical dynamometer capable of generating appropriate quadriceps load is a promising method for producing progressive resistance during OKC. Additionally, they advocate for a protocol that combines electric stimulation and OKC exercises to facilitate greater recruitment and reverse muscle inhibition soon after injury and surgery (Noehren & Snyder-Mackler, 2020). Fukuda et al. (2013) recommended that isotonic knee extension exercises with OKC should be started 4 weeks after surgery, limiting the knee range of motion between 90° and 45° of flexion. In conclusion, both OKC and CKC exercises are applicable for quadriceps strength recovery after ACLR. However, they should be used cautiously and in specific stages during rehabilitation. CKC exercises are recommended in the early phase to mimic functional movements used in daily activities and sports, whereas OKC exercises are recommended later in the rehabilitation process to restore quadriceps strength. Six randomized controlled trials were included (Table 2).

During OKC exercises, the nurse should ensure that the patient is using proper form and technique to prevent injury and maximize effectiveness. It is important to monitor the patient's pain level and range of motion during OKC exercises, as excessive strain can delay healing and cause further damage. The nurse should ensure that the patient is performing the exercises with proper alignment and stability, and modify the exercise as necessary to prevent pain or discomfort.

Eccentric Training and Concentric Training

Eccentric training is supported by the literature to be effective to restore quadriceps muscle mass, strength and functional performance in individuals undergoing ACLR (Friedmann-Bette et al., 2018; Vidmar et al., 2020), but potentially increasing the injury risk of the graft, articular cartilage or surrounding soft tissue structures in the acute stages following ACLR. In contrast, the review of Lepley and Palmieri-Smith (2013) proposed that early, progressive, high-force eccentric resistance exercises can be safely applied to the affected limb to increase muscle volume and strength in individuals who have undergone ACLR. Friedmann-Bette et al. (2018) also supported the use of overload eccentric exercise, as they found that it is more effective than conventional eccentric strength training for developing muscle hypertrophy and a fast muscle phenotype. The study of Vidmar et al. (2020) reported that eccentric loading had a positive effect on the outcome after ACLR. Specifically, isokinetic eccentric training was found to promote greater muscle hypertrophy and strengthening compared to constant load eccentric training. Another potential advantage of eccentric training is that it may be able to uniquely target the underlying neural factors that drive neuromuscular dysfunction after injury (Lepley et al., 2017). Lepley et al. (2018) suggested that an 8-week eccentric cross-exercise intervention facilitates positive adaptations in brain activation, corticospinal and spinal reflex excitability. They found that eccentric cross exercise after ACLR may provoke a favorable neural environment in patients that historically have neural deficits that are resistant to the current standard of care (Lepley et al., 2018). Taken together, some researchers claimed that eccentric training may be the most effective method to facilitate recovery after ACLR (Gokeler et al., 2014; Lepley & Palmieri-Smith, 2013; Lepley et al., 2015b; Roig et al., 2009).

On the other hand, Harput et al. (2019) stated that both concentric and eccentric strengthening were equally effective in improving isometric quadriceps strength recovery in the early stages following ACL. Another randomized controlled trial with high evidence-level by also reported a similar result, concluding that progressive eccentric cycle training was not more clinically effective than concentric training at a matched perceived intensity dose in male patients (Milandri & Sivarasu, 2021). Interestingly, they found that concentric training was more effective for some variables, such as, reducing large baseline asymmetries in tibial rotation angle (Milandri & Sivarasu, 2021). Three randomized controlled trials were selected for this review to compare concentric and eccentric strengthening (Table 3).

The nurse can confirm that patients are properly engaging their quadriceps and hamstrings during the eccentric phase of the exercise. For concentric training, the nurse can ensure the patient is using proper form and technique, such as maintaining proper alignment of the knee joint during the movement. Additionally, the nurse can also monitor the patient's progress and adjust their exercise program as needed to continue to challenge them.

Blood Flow Restriction Training

Blood flow restriction training (BFRT) involves the use of a tourniquet applied to the proximal aspect of a limb during exercise to compress the underlying vascular structures. This technique has shown promising effects for increasing muscle strength. The important point to note is that when compared to heavy load resistance training, BFRT, using light external loads of 20–30% of one repetition maximum, leads to similar effects in skeletal muscle hypertrophy and strength adaptations, but with greater overall improvements in physical function (Hughes et al., 2017, 2018; Hughes, Rosenblatt, et al., 2019). Thus, BFRT has been a favorable option during the early post-surgery phases of ACLR rehabilitation. Hughes et al. (2018) reported that BFRT was well tolerated in the early ACLR rehabilitation, in agreement with the result of their other study that found significantly less knee pain during and 24 hours after training with BFRT compared to heavy load resistance training (Hughes, Patterson, et al., 2019). Such an advantage might be attributed to three aspects: (1) lower knee joint forces and less strain associated with lighter external load used with BFRT compared to heavy load resistance training (30% vs. 70% one repetition maximum) (Hughes, Patterson, et al., 2019); (2) with BFRT, pressure-induced muscle ischemia might alter pain sensitivity and augment hypoalgesic effect (Hughes et al., 2018; Leffler et al., 2002); and (3) release of endogenous opioids and endocannabinoids may be induced by ischemia and hypoxia with BFRT during exercise (Hughes, Patterson, et al., 2019; Koltyn et al., 2014).

The implementation of BFRT appears to be particularly suitable for HBR because it requires minimal equipment, allows for rapid strength gains, and is inexpensive (Kilgas et al., 2019). Kilgas et al. (2019) stated that a 4-week home-based BFRT significantly increased the quadriceps muscle volume. Furthermore, symmetry levels of the lower limbs after ACLR with BFRT were almost equal to those of healthy controls (96–99% compared to 99–101%). A biomechanical experiment conducted by Telfer et al. (2021) supported the safety of BFRT during the early post-rehabilitation period following ACLR. They found that subjects used compensatory strategies while performing movements with BFRT, which helped protect the knee from abnormal loads (Telfer et al., 2021). The nurse should provide instructions on how to safely perform BFRT by only restricting the return blood flow, rather than completely occluding (stopping) it. It is important to monitor complications such as rhabdomyolysis, retinal vascular occlusion, pulmonary embolism, and venous thrombosis, and react promptly if any symptoms arise (de Queiros et al., 2021).

Additionally, it should be noted that the use of BFRT in conjunction with high-intensity resistance exercise may negate the previously mentioned benefits. Curran et al. (2020) found that an 8-week BFRT combined with high-intensity resistance exercise did not lead to significant improvements in quadriceps muscle strength, activation, or volume. Factors related to BFRT, such as limb occlusion pressure, duration of application, and the number of intervention sessions, may also have an impact on the outcomes following ACLR. Curran et al. (2020) suggested that a therapeutic effect in patients after ACLR requires a limb occlusion pressure higher than 80% of a patient's limb occlusion pressure. Loenneke et al. (2012) suggested that performing BFRT 2–3 days per week resulted in the greatest effect size for muscle strength compared to 4–5 days per week. Therefore, the amount of exercise and the duration of BFRT required to optimize quadriceps muscle function after ACLR should be systematically considered in future studies. Examples are shown in supplemented material 1, available at: http://links.lww.com/ONJ/A29.

Plyometric Training

Lower extremity plyometric training (PT) is commonly used to develop explosive speed, strength, and power (Donoghue et al., 2011), which features stretch-shortening cycle activities, such as running, jumping, and agility drills (Chmielewski et al., 2006). PT has been highlighted for its advantages in enhancing jumping performance and improving balance and neuromuscular control during landing (Myer et al., 2006), appropriate in the late phase of rehabilitation following ACLR. Chmielewski et al. (2016) reported 8-week PT induced positive changes in knee function, knee impairments, and psychosocial status that would support the return to sports participation after ACLR, regardless of low- or high-intensity. They found that PT was able to decrease patients' kinesiophobia (fear of movement) (Chmielewski et al., 2016), as psychological fear is an important factor that hinders ACL-injury patients from returning to their pre-injury level of activity after ACLR (van Melick et al., 2016). Hewett et al. (2006) demonstrated that PT was foundational for ACL injury prevention. Escamilla et al. (2012) stated that PT should be performed prior to final return to sport to prevent additional ACL injury after ACLR.

Cautious consideration should be noted that PT produced vertical ground-reaction forces that ranged from 2 to over 6 times the body weight (Chmielewski et al., 2016; Donoghue et al., 2011; Jensen & Ebben, 2007). Therefore, PT should not be initiated until enough time has passed to allow for sufficient tendon-to-bone healing. Chmielewski et al. (2006) recommended that PT was typically initiated 12 weeks after a patellar tendon autograft reconstruction and delayed until 16 weeks after a semitendinosus autograft. Before performing PT, patients should be taught proper landing techniques to minimize ACL loading. This includes landing softly with adequate knee flexion and forward trunk tilt to enhance hamstring activity, as well as controlling knee valgus, hip adduction, and internal rotation (Escamilla et al., 2012). The nurse should educate the patient on the importance of gradually increasing the intensity and frequency of the PT and the need for adequate rest and recovery between sessions. Examples are shown in supplemented material 2, available at: http://links.lww.com/ONJ/A30.

Neuromuscular Training

Previous research findings have supported the notion that persistent muscle strength deficits after ACLR are primarily due to quadriceps activation failure and muscle atrophy (Andrade et al., 2020; Welling et al., 2019; Williams et al., 2005). Quadriceps activation failure is attributed to a decreased ability to activate the available muscle fibers, which is believed to be a protective and reflexive response that alters neural drive to the surrounding musculature following joint injury (Hauger et al., 2018). Labanca et al. (2018) argued that in the early phases after surgery, strengthening exercises may not effectively stimulate the quadriceps muscle due to the inhibitory effect of high external loads, which can lead to ongoing arthrogenic muscle inhibition. Neuromuscular control defects of the muscles have been considered as another important factor leading to asymmetries in physical performance, such as hopping, jumping, landing, loading, and movement patterns between the reconstructed and uninjured legs after ACLR (Kaya et al., 2019). Therefore, van Melick et al. (2016) proposed that superimposed neuromuscular training should be included in the rehabilitation protocol after ACLR in addition to strength training. It is important for the nurse to have a solid understanding of lower limb anatomy in order to provide high-quality care and assist with neuromuscular training. When targeting small muscles, monopolar electrode placement is used, with the motor point of the target muscle and the anode placed proximally on a nearby muscle supplied by the same nerve. For larger muscles, bipolar electrode placement is typically used, with both electrodes placed on the muscle belly or one at the proximal end and another on the distal end of the muscle.

Neuromuscular Electrical Stimulation

To address muscles with activation failure, neuromuscular electrical stimulation (NMES) has shown promising ability to induce action potentials in the related nerves and override inhibition (Hauger et al., 2018). The review by Hauger et al. (2018) found adding NMES intervention to standard physical therapy treatment led to significant improvement compared to control groups that only received standard physical therapy treatment after ACLR. The authors recommend utilizing NMES in the early phase of rehabilitation to achieve early strength gains, prevent quadriceps muscle inhibition and atrophy, and provide the rehabilitation subject with the most effective course of treatment (Hauger et al., 2018).

However, evidence of the effectiveness of NMES in treating arthrogenic muscle inhibition after ACLR was graded as low quality, as reported by the review conducted by Sonnery-Cottet and Saithna (2019). Glaviano et al. (2014) observed a placebo effect where the intervention of NMES failed to demonstrate any significant difference in knee extension torque or quadriceps activation compared with a sham treatment. Based on their parallel longitudinal design study, Lepley et al. (2015b) also did not recommend utilizing NMES alone in the rehabilitation following ACLR. Individuals receiving the combined NMES and eccentric exercise intervention or eccentrics-only recovered quadriceps strength better than individuals that received just the NMES therapy or the standard of care (Lepley et al., 2015b). Compared to healthy individuals, both the combined NMES and eccentric exercise intervention and eccentrics-only were effective in restoring similar levels of quadriceps activation and strength (Lepley et al., 2015b). Another biomechanical study by Lepley et al. (2015a) further demonstrated that the combination intervention positively restored biomechanical limb symmetry after ACLR. This combination intervention resulted in superior improvements compared to NMES and eccentric exercise alone. They proposed that the positive effects of NMES on the neural components of muscle contributed to better movement augmentation and promoted the utilization of the quadriceps muscle during physical activity (Lepley et al., 2015a). Another potential mechanism of NMES proposed by Durigan et al. (2014) was the promotion of beneficial adaptations to the quadriceps extracellular matrix by reducing the formation of fibrotic tissue following ACL injury.

During the procedure, the nurse should assist the physical therapist or physician with electrode placement and adjustment to ensure optimal muscle activation. In addition, they should also monitor the patient's muscle response and adjust the stimulation parameters as needed. After the NMES, patients are encouraged to follow any home exercise program prescribed by the physical therapist or physician to maximize the benefits of NMES. Examples are shown in supplemented material 3, available at: http://links.lww.com/ONJ/A31.

Neuromuscular Control Exercises/ Proprioceptive Training

ACL injury is believed to interfere with joint afferent sensation and lead to proprioceptive deficits. It is widely accepted that there is a significant reduction in kinesthetic awareness of the affected knee after ACLR. Furthermore, surgical reconstruction after a complete ACL tear using tendinous allografts or autografts has been unable to re-innervate the related mechanoreceptors, resulting in persistent compromise of knee proprioception for 6 to 24 months after ACLR (Fleming et al., 2022). Neuromuscular control exercises, such as single-leg balance drills, cone stepping, lateral lunge drills, and perturbation training, are recommended to promote dynamic stabilization, enhance bilateral symmetry, and restore the patient's confidence in the reconstructed knee (Wilk & Arrigo, 2017).

A randomized-controlled study with two-year follow-up by Kaya et al. (2019) proposed that neuromuscular control exercises should be included in the rehabilitation protocol to improve bilateral symmetry and motor control of the leg after ACLR. The progressive program was initiated 3 weeks after surgery and lasted for 24 weeks. Although there was no significant difference in muscle strength, the addition of neuromuscular control exercises to a standard rehabilitation regimen was found to significantly improve knee proprioception after ACLR (Kaya et al., 2019). Joint position sense was separately assessed at 75°, 45°, and 15° on the operative side. Neuromuscular control exercises, which are designed to control lower extremity alignment and aid weight-bearing during functional activities, contribute to improving knee proprioception sense. Akbari et al. (2015) found that proprioceptive and balance exercises were safe and effective in improving postural stability in subjects with ACL deficiency during the early stage of ACLR rehabilitation. The exercises included single-leg stance with eyes closed or open and step-up exercises (anterior, lateral, and posterior) for the uninvolved and involved legs.

Whole-Body and Local-Muscle Vibration

Whole-body vibration (WBV) is a promising intervention modality for enhancing muscle strength and reestablishing neuromuscular control by inducing neural adaptation and improving neuromuscular efficiency (Salvarani et al., 2003). For subjects who underwent ACLR, significant improvements in muscle strength were reported in the group that combined a standardized rehabilitation program with 8 weeks of WBV exercise (Costantino et al., 2018). Local muscle vibration (LMV) also improves quadriceps function and is potentially a portable and practical alternative stimulation method. Brunetti et al. (2006) reported that the LMV group demonstrated significant improvement in single-leg balance and peak torques of the operated leg extensor muscles. The peak torques of the operated leg extensor muscles increased and reached values similar to those of the healthy leg. Moezy et al. (2008) reported that stability indices and proprioception of the reconstructed knee were significantly improved after four-weeks of intervention with WBV. However, LMV failed to show direct improvement on proprioception in the reconstructed knee (Nagai et al., 2018). Nagai et al. (2018) assumed that vibration-induced sensory changes might be muscle-specific, in line with the findings of Hirjaková et al. (2016). In subjects who have undergone ACLR, minimal changes in postural altered reactions were observed with vibration of the quadriceps and hamstrings, but significant improvement was seen with vibration of the triceps surae compared to preoperative levels (Hirjaková et al., 2016). Mechanical properties of the patella and surrounding structures, acting to absorb the applied vibration and divert the vibration stimulus from achieving adequate intensity to cause aberrant sensory information of the quadriceps musculature, might be another reason accounting for the ineffectiveness of LMV (Nagai et al., 2018). Nurses can provide patient education on the proper use of vibration equipment and home exercises, and encourage adherence to the prescribed therapy program. They can also monitor and report any adverse effects or complications that may arise from the therapy.

Pamukoff et al. (2016) indicated that both WBV and LMV improve quadriceps strength, voluntary activation, and corticomotor excitability in individuals with ACLR. It is worth noting that they included patients who had reconstructive surgery almost four years prior who had demonstrated evidence of reduced quadriceps function (Pamukoff et al., 2016). Thus, WBV and LMV are also applicable for patients with persistent strength weakness after ACLR. A meta-analysis by Maghbouli et al. (2021) favored LMV over WBV as a modality to facilitate rehabilitation after ACLR. The study showed that LMV was more effective in strengthening the hamstring/quadriceps than WBV. Neglecting hamstring weakness during ACLR rehabilitation can lead to functional disability and unsatisfactory outcomes, as the hamstring plays a crucial role in limiting anterior translation and rotation of the tibia on the femur.

Rittweger (2010) suggested that the frequency of vibration could impact the activation of the alpha motor neuron pool, which plays a role in muscle strength and endurance. Specifically, muscle relaxation was reported to occur at around 50 Hz, inhibition of spasticity at 100 Hz, pain relief at 200 Hz, and muscle training at 100–300 Hz. Accordingly, Maghbouli et al. (2021) recommended that local vibration therapy should be performed with a frequency of higher than 100 Hz. However, the optimal vibration parameters have yet to be fully determined and require further investigation due to the limited data available in current literature. Troy Blackburn et al. (2021) observed a rapid effect of WBV and LMV on increasing maximal muscle force output, specifically peak isometric knee extension torque, for several minutes following application. Moreover, their results indicated that vibration enhances quadriceps function for at least 20 min (LMV) and up to 1 h (WBV) following application in individuals with ACLR, which was attributed to enhanced excitability of the central nervous system. Taken together, while both WBV and LMV have demonstrated benefits for ACLR rehabilitation, the optimal vibration therapy protocol remains controversial and warrants further investigation.

Limitations

While this review has highlighted a range of ACLR rehabilitation strategies, it is essential to acknowledge limitations related to the methods used and the available literature. Firstly, the majority of the studies cited in this review are based on randomized controlled trials (RCTs). However, variations in study designs, interventions, and outcome measures across studies can introduce heterogeneity and make direct comparisons challenging. Secondly, the knowledge presented here is based on research available up to 2022, and there may have been further advancements or updates in ACLR rehabilitation protocols and techniques since that time. Thirdly, the effectiveness of some interventions, such as BFRT and vibration-based therapies, may vary depending on individual patient factors, such as age, gender, graft choice, and the presence of concomitant injuries. Lastly, while this review attempts to provide a comprehensive overview, it does not substitute for individualized clinical assessment and treatment planning by healthcare professionals.

Nurses occupy a central role in facilitating the rehabilitation journey of individuals undergoing ACLR, and awareness of the clinical implications associated with diverse rehabilitation strategies is pivotal for nursing practice in this context. Recognizing that ACLR rehabilitation is inherently individualized is paramount; graft type, comorbidities, and patient objectives must inform personalized rehabilitation plans. Collaboration within the interdisciplinary healthcare team is essential to tailor interventions to each patient's unique requirements and optimize the rehabilitation process. Moreover, nurses serve as educators, imparting clear and concise information to patients regarding exercise compliance, proper technique, and the potential advantages and risks associated with each rehabilitation approach, empowering patients to actively participate in their recovery.

As vigilant monitors, nurses assess patient progress and promptly report any complications or adverse effects stemming from rehabilitation interventions. Routine evaluations encompassing pain levels, range of motion, muscle strength, and functional performance, facilitate early issue identification and adjustments to treatment plans. Acknowledging the psychological facet of ACLR rehabilitation is critical, as patients frequently grapple with fear, frustration, and anxiety. Nurses' provision of emotional support, addressing concerns, and fostering a positive mindset can enhance overall well-being and motivation throughout the recovery process.

Safety remains a paramount concern in rehabilitation, with nurses ensuring that patients execute exercises with precision to prevent injury. Vigilance for signs of overexertion or complications, such as heightened pain or swelling, is pivotal. The meticulous documentation of patient progress and any encountered issues during rehabilitation is indispensable. Effective communication with the healthcare team, including physical therapists and physicians, fosters coordinated care and timely adaptations to treatment plans.

Conclusion

Rehabilitation plays a vital role in restoring muscle strength and neuromuscular control following ACLR. Muscle weakness and neuromuscular disruption may persist for years following ACLR if rehabilitation is inadequate or improper. This literature review summarizes nurse-assisted rehabilitation protocols with regard to strength and neuromuscular training following ACLR. Both OKC and CKC exercises are effective for muscle strength recovery after ACLR at different stages of the rehabilitation process. Concentric and eccentric strengthening may have similar effects on improving quadriceps strength after ACLR. BFRT with light external loads has unique advantages in the early phase of rehabilitation due to its ability to induce muscle hypertrophy and strength gains with low-intensity training. However, various factors, such as the limb occlusion pressure, duration of application, and the number of intervention sessions, can also impact the outcomes of BFRT. Prior to returning to sports, PT is considered necessary. NMES is recommended during the early phase of rehabilitation to achieve early strength gains and prevent quadriceps muscle inhibition and atrophy. Additionally, neuromuscular control exercises are beneficial for promoting dynamic stabilization and improving bilateral symmetry. WBV and LMV help improves muscle strength and quadriceps functions, but the optimal parameters need further discussing. Each training protocol has its own advantages and disadvantages and should be cautiously used at specific stages during rehabilitation. Nurses play a pivotal role in the comprehensive care of patients undergoing ACLR rehabilitation. By considering the limitations of current knowledge and understanding the clinical implications of various rehabilitation strategies, nurses can contribute to improved patient outcomes, enhanced recovery experiences, and successful returns to active lifestyles. Despite the large amount of literature available, randomized controlled trials are needed to determine the optimal rehabilitation protocols to further improve the care and function of patients following ACLR.

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