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Progress of Rehabilitation Therapy after Anterior Cruciate Ligament Reconstruction of Knee Joint

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Abstract. The anterior cruciate ligament (ACL) arises at the anterior portion of the tibial intercondylar eminence, terminates at the anterior horn of the lateral meniscus, and extends at an oblique angle towards a posterior portion of the medial part of the lateral femoral condyle, which limits anterior displacement, internal rotation, and excessive tibial extension. ACL tear is one of the most prevalent knee joint injuries in sports and its incidence in the US is 1/3,000 and the probability of post-injury development of post-traumatic osteoarthritis is 80 percent. Anterior cruciate ligament reconstruction is the main treatment modality, and postoperative rehabilitation is of great importance. Examples of rehabilitation techniques are physical factor therapy (e.g., low-frequency ultrasound), exercise therapy (e.g., weight-bearing training within the first five days after surgery), manual treatment, and assistive devices. Research has revealed that low-frequency ultrasound (LFU) induces tendon-bone healing, early weight-bearing, and isokinetic eccentric training effectiveness have been proven to increase the strength of muscle. Knee joint functional recovery can be optimized through the comprehensive use of the rehabilitation methods.

Keywords: anterior cruciate ligament, rehabilitation therapy, physical factor therapy

1. Introduction

ACL originates at the medial anterior part of the tibial intercondylar eminence, travels up to the anterior horn of the lateral meniscus and runs obliquely in a posterosuperior and lateral direction. It has fibers arranged in a fan shape, which are fastened to the medial surface of the lateral femoral condyle, and which undertake several functions, which limit anterior tibial mobility, internal tibial rotation, inversion, eversion and hyperextension.

ACL injury is one of the most frequent sporting related knee injuries, which causes serious impairment in the stability and functioning of the knee joint. This injury is increasingly gaining prevalence among the younger groups due to the increased involvement in sporting activities. ACL injury occurs in one out of 3,000 people in the US and the chances of developing post-traumatic osteoarthritis 10-15 years following an ACL injury are even as high as 80 percent in cases of meniscal damage with the injury. In addition to the consequences of ACL injuries following injury like pain and instability, there are adverse effects of these injuries on the quality of life and performance of athletes. In combination with high costs of treatment and rehabilitation, they greatly contribute to the burden in society [1].

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At present, the most common treatment of ACL injury is the reconstruction of the ligament [2], especially among top-level athletes who want to attend to competitive sports. Even though ACL surgery is capable of partially restoring the functionality of the ACL, an additional functional enhancement by employing post-operative adjunct rehabilitation treatment is equally crucial. Of great importance are functional recovery, enhancement of ACL functioning and establishment of reintegration of patients into normal life and athletic sporting activity. The paper will review such treatment modalities and techniques that have achieved impressive therapeutic outcomes over the past few years.

2. Primary rehabilitation methods after ACL reconstruction

Physical therapy, by definition, can be divided into three types: modes based on functional training, also known as exercise therapy or kinesiotherapy; modes based on the use of physical agents, including various physical factors electricity, light, sound, magnetism, cold, heat, and water, and finally, modes based on manual therapy, i.e. massage, joint mobilization, and tuina therapy.

2.1. Physical factor therapy

Physical therapy has become one of the most important supplements in the sphere of anterior cruciate ligament (ACL) reconstruction rehabilitation, as it helps to accelerate the recovery of functions and avoid complications. The medium-frequency therapeutic ultrasound that is widely used in clinical practice has relatively low tissue penetration properties, which means that it has no optimum effectiveness in providing the healing of the deep tendon-bone interface. Moreover, there are traditional rehabilitation exercises which are often ineffective in mobilizing atrophied muscles at the early postoperative period.

There is, therefore, an immediate need to explore more effective physical factor therapies. As an example, low-frequency ultrasound (LFU) that is able to reach deep tissue to support the healing process and electrical stimulation methods that are targeted to activate the neuromuscular functions. These investigations have major implications towards maximization of postoperative rehabilitation programs and better long-term outcomes.

LFU is an emerging treatment designed to address the issue of slow tendon-bone interface healing after anterior cruciate ligament (ACL) reconstruction. Conventional medium-frequency therapeutic ultrasound suffers massive attenuation of energy forces as they pass through soft tissues, bone structures, and joint cavities. This damping makes it hard to achieve favourable biological actions at the deep tendon-bone junction of the knee joint.

Zhang Caihua et al. created a rabbit ACL reconstruction model to determine the promoting effect of LFU. One hundred and eight experimental animals have been randomly assigned to a control group, medium frequency ultrasound group (1.5 MHz) and low frequency ultrasound group (45 kHz). The therapy was initiated after the operation as 20-minute sessions on a daily basis, and the recovery results were assessed at various times [3].

The main biomechanical data were as follows: at 4 and 8 weeks of postoperative time the animal group exposed to LFU of 45 kHz compared to the control group and medium frequency ultrasound group. The animal group showed considerably greater maximum tensile load and stiffness at the tendon-bone interface ($p < 0.05$). This paper shows that low-frequency ultrasound, compared to the conventional intermediate-frequency type, has better tissue penetration and cavitation effects. Therefore, low-frequency ultrasound is better at inhibiting inflammatory response during the early healing phase and promoting bone morphogenetic protein - 2 (BMP - 2) expression. These are

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aiding the production of new bones and interface remedies. On the other hand, intermediate-frequency ultrasound failed to have any significant pro-inflammatory effects at similar levels of intensity. The results provide important experimental data to the clinical initiation of deep tissue-targeted therapeutic tools [3].

The active physical modality of neuromuscular electrical stimulation (NMES) is largely used to solve the most frequent postoperative issues, including muscle inhibition, muscle atrophy, and medical control. Despite a systematic increase in the mobility of the joints and muscle strength, using the conventional type of rehabilitation training, patients may have problems with the successful performance of voluntary muscle contracts caused by early pain and swelling after surgery, which makes the rehabilitation process tardy. The article by Chang Jianan et al. discussed the clinical usefulness of combined neuromuscular electrical stimulation. The sample size of their study included 80 patients, who received anterior cruciate ligament reconstruction, randomly divided into either control group (only conventional rehabilitation training) or observation group (neuro muscular electrical stimulation of affected hamstring muscles beginning on the third postoperative day), where the treatment lasted 6 weeks. An important muscular strength test showed that the isometric muscle strength of the hamstring muscles affected in the observation group was 31.87 ± 4.64 N·m/kg after treatment over 6 weeks whereas the same was 26.85±4.91 in control group ($P < 0.05$). This observation confirms that application of neuromuscular electrical stimulation early may directly trigger the development of normal contractions in the specific muscles using electrical, which current effectively reverses postoperative early muscle disuse. This therapy not only helps restore muscle fiber strength in the semitendinosus and biceps femoris muscles but also enhances local blood circulation and neuromuscular recruitment efficiency, thereby synergistically improving gait parameters such as step length and speed [4]. Meanwhile, ultrasound-conductive acupoint drug penetration is another type of medication delivery in which the medication is administered following ultrasound-conductive penetration of four acupoints including Liangqiu, Xuehai, Ququan, and Sanyinjiao [5]. This method incorporates the latest technology with the traditional Chinese medicine when modern technology is used to complement other rehabilitation activities, which helps to relieve the symptoms of joint swelling and pain after surgery on reconstruction of ACL injuries. It is very suitable to prevent adhesion of the soft tissues of the joints, as well as recovering normal joints mobility.

2.2. Exercise therapy

Rehabilitation exercise after surgery is of crucial importance in functional recovery of knee joint. It does not only tighten muscles around the knee joint and increase the stability of the joint, but also contributes to the restoration of the intra-articular environment. The rehabilitation setting within the postoperative period is critical in decreasing the rates of occurrence of postoperative complications. The weight-bearing training as an essential part of exercise therapy is efficient to increase the strength of the most critical muscular groups including hamstring muscles and quadriceps femoris. Its mechanism of action is to slowly increase the load on the knee joint while promoting the nutritional metabolism of joint cartilage.

ACL arthroscopy has also become the first line of surgery in the treatment of ACL injury. The method is extensively beneficial in that it causes minimum damage to the joint cavity, small cuts, fast recovery, less postoperative pain, and low incidence of complications and less time in the hospital.

To address the issue of the most optimal timing during weight-bearing training after arthroscopic reconstruction of the ACL further, He Nana et al. carried out a review on the functionality recovery

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and the range of motion of the affected knee joints throughout the various time spans of weight-bearing training rehabilitation [6]. The number of recruited was 90 patients that were separated into three groups (A, B, and C). On the 3rd, 5th and 7th day of operation, the patients in these groups started wearing splint braces respectively and performed weight bearing physical exercises under the aid of crutches.

According to the functional grading evaluation of the knee joints at predetermined intervals, recovery results of patients in Group B were much remarkable when compared to others in the two groups at the time of discharge ($P < 0.05$). The present study suggests that the best period that can be used to start weight-bearing exercises is the 5th day after the arthroscopic ACL surgery. At this phase, the climax inflammatory phase has passed, which involves a decrease in the severity of the inflammatory response of the body and acute exudation. Most of the extravasation of blood and fluid in the joint cavity would be taken up by the body, leading to the slow disappearance of the symptoms of swelling in the joint and the significant disappearance of the pains. At this stage, patients are able to exert autonomous control over their own movements, subjectively perceive an increase in muscle strength, and experience heightened mental alertness. All these factors contribute to the restoration of joint function.

Pan Heng et al. conducted a study on the effects of various lengths of weight-bearing training on the functions and stability of joint at the post-operative period in patients who had their ACL reconstructed through arthroscopy [7]. The research will use 90 ACL reconstruction patients and randomly assign them to three groups, 30 each. Group A began weight bearing training on the 3 rd day after surgery, group B began weight bearing training on the 5th day after surgery and group C began weight bearing training 7 days after the operation. The weight-bearing training was performed by using a brace, crutches, and the assistance of medical workers. Patients stood 5 minutes after getting out of bed, and the ratio of the weight that patients held was 15 percent and then gradually raised to 30 percent. Training was done in 15 to 30-minute sessions with two sessions a diem and continued through weight-bearing training in all three groups through 1-month post-discharge. The results of the drawer test indicated that Group B recorded the most proportions of Grade 0 and Grade 1 results. In reference to the tibial tunnel diameter, the tunnel diameter in the right and left femur (9.16 ± 0.03, 9.16 ± 0.03) was lower than that in the tibial tunnel (9.52 ± 0.05, 9.70 ± 0.07) [7]. These results indicate that the initiation of weight-bearing training 5 days after the operation has a relatively more desirable effect on both postoperative knee joint functioning and stability in patients in a state of arthroscopic ACL reconstruction, and 5 days post-operation is a clinically significant time during weight-bearing training.

Another important aspect of exercise therapy is strength training. It would also enhance the power and stability of the muscles around the knee joint with the assistance of specific strength training and thus provide solid support to the joint stability and functional restoration. Strength training applicable for post ACL surgery normally involve a variety of exercises including isometric contraction training, isotonic contraction training and isokinetic strength training. According to the revised guidelines of clinical practice of American Physical Therapy Association Orthopedic Branch (APTA), the performance of weight-bearing and non-weight-bearing concentric and eccentric isometric exercises is the most important part of all the physical therapists [8]. Weight-bearing and non-weight-bearing concentric and eccentric exercises should be initiated and performed between 4 and 6 weeks and maintained between 6 and 10 months which should be performed 2-3 times per week. The aim is to improve the performance and the strength of the thigh muscles after ACL reconstruction. As per the guidelines, this training has been classified as Strong evidence implying that it has a high recommendation value.

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Sun et al. investigated the effects of isokinetic eccentric strength training on strength, functions, as well as postural control of the knee flexor and extensor muscle in young male patients in the period of the recovery period following ACL reconstruction [9]. According to the postoperative strength training intervention mode, patients were divided into the concentric or eccentric group (47 and 48 patients, respectively). Except for the centripetal group using centripetal centripetal training and the centrifugal group using centrifugal centrifugal training, all other training conditions were kept constant. The two were trained on a weekly basis (3 times/week) over a period of eight weeks.

At the end of eight weeks of intervention, there were significant differences in visual analog scale (VAS) scores and swelling levels in both groups as compared to the levels prior to the intervention. The disparities in the eccentric group showed a greater improvement in all the indicators than the concentric group ($P < 0.05$). These findings suggest that eccentric contraction produces a stronger stimulation to nerves, has a higher durability of adaptation, consumes less oxygen and at the same time quickens the blood flow. This augmentation improves microvascular driving pressure, oxygen carrying capacity as well as oxygen metabolism and efficiency. Therefore, it enhances the performance of the phagocytes, decreases the discharge of the inflammatory factors, stimulates the growth of skeletal muscles and absorption of inflammatory particles, strengthens the muscles, strengthens the bodies defence system and removes the swelling and pain in the limb in question.

The peak knee flexion and extension torque values were much greater in both groups compared to pre-intervention values. It is important to notice that the eccentric group was superior in improvement ($P < 0.05$). These results show that the use of eccentric muscle strength training in isokinetic mode causes the effect of a stretch reflex to lead to a violent contraction in stretched muscles. The lengthening of muscles in eccentric training opposes the presence of elastic elements like the connective tissues. Therefore, it increases muscle force during eccentric contraction and ultimately increases the torque production. The direction of contralateral movement of muscle activity stimulates the increase of neural to the cerebral cortex and spinal cord, improving the collagen re-adaptation control, facilitating the postoperative rehabilitation, improving training efficiency, and bringing an effective enhancement to the muscle strength of the knee flexor and extensor groups.

To sum up, it is possible to state that isokinetic eccentric muscle training is capable of enhancing muscle strength of flexor and extensor muscles of the knee joint in young male patients during the post-ACL reconstruction time, and regulate the functioning of the knee and maintain its control, as well as alleviate the extent of swelling and pain. Its intervention effect is superior to that of isokinetic concentric muscle training which presents a benchmark value of the post-operative rehabilitation of young male ACL injured patients.

2.3. Manual therapy

Being a significant supplement to post-ACL reconstruction rehabilitation, manual therapy poses a direct effect to the joint and related soft tissues, which, in turn, increases the increase in the range of the joints, models muscle contraction, and improves local blood flow. One of the fundamental methods of manual therapy is known as joint mobilization that involves the passive movement of joint surfaces to increase the intra-articular space, nutrient supply to the joints, and activate proprioceptors that surround the joint thereby enabling the neuromuscular control to recover. Joint mobilization has the potential of improving positional and kinesthetic sensation of the knee joint, increasing the propriofeedback mechanism, and creating neuroregulatory influence by suppressing the exit of nociceptive materials in the spinal cord and brainstem, thus raising the pain threshold and blocking pain symptoms.

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One of the significant therapeutic approaches that has become a prominent technique of manual therapy in treating musculoskeletal issues over the last few years is Fascial Manipulation (FM), which may be applied as a single treatment option as well as in conjunction with other treatment modalities to use them in the treatment of both acute and chronic musculoskeletal conditions. According to the FM theory, the fascial system consists of six fascial sequences and fourteen segments, where each of the latter includes a myofascial unit. Li Xiaomao et al. conducted a meta-analysis to determine the effectiveness of FM in the reduction of pain and disability levels in patients with musculoskeletal pain. The quality was evaluated through the PEDro scale including 8 articles and one alternative with the Level 1 and Level 2 evidence, respectively. Table 1 provides the results and includes nine randomized controlled trials and 680 cases [10]. Out of them nine studies included the effect of FM on musculoskeletal pain; six studies have described its effect on lower back pain; two studies explored the effect of FM on pain in patients with postpartum low back pain and nine studies have reported the effect of FM on the level of disability in musculoskeletal patients. All studies have confirmed that FM has a significant positive impact on relieving pain and improving functional impairment. This study results show that FM as a separate or concomitant physical therapy factor in decrease of pains and disability leads to the enhancement of disability among patients with musculoskeletal disorders. According to the literature, FM is a new manual method, which may be successfully applied to patients undergoing ACL reconstruction and reduce the pain.

Table 1. PEDro scale scores and evidence levels [10]

	Branchin et al. (2016)	Endamli et al. (2019)	Harper et al. (2018)	Priya et al. (2020)	Zhang Mingfeng (2018)	He Tianyi et al. (2022)	Chen Yanmei et al. (2022)	Tashi Tsoom et al. (2021)	Jiang Zhijin et al. (2021)
random allocation, random assortment	1	1	1	1	1	1	1	1	1
allocation concealment	0	0	0	0	0	0	0	0	0
baseline comparability	1	1	1	1	1	1	1	1	1
blinded subject	0	0	0	1	0	0	0	0	0
Therapist blinding	0	0	0	0	0	0	0	0	0
blinded evaluator	1	1	1	0	0	0	0	0	0
Full follow-up	1	0	0	0	0	1	1	0	1
intention-to-treat analysis	0	0	1	1	1	1	1	1	1
comparison among groups	0	1	1	1	1	1	1	1	1
point estimate and variability	0	1	1	1	1	0	0	1	0
PEDro total points	4	5	6	6	5	5	5	5	5
Sample≥50	NO	YES	YES	YES	YES	YES	YES	YES	NO

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3. Assistive device use

Scientific and rational application of assistive devices may be crucial during the rehabilitation process following the ACL reconstruction. Other types of assistive devices like braces give the knee joint stability, limit unnecessary movements, prevent the secondary destruction of the reconstructed ligament through incorrect activities, and protect the surgical site, hence facilitating the healing of the ligament. The crutches may help with the distribution of body weight and reduction in the load of the knee joints during the first stage of the recovery of the lower limb strength allowing patients to continue the daily routines and walking safer and gradually recover the lower limb functioning. The use of elastic bandages may ensure active local circulation of blood by providing moderate pressure on the area, reducing swelling and pain, and providing conducive rehabilitation conditions. A systematic literature review of Kinesio Taping (KT) was performed by Wang Zhueting et al. [11]. Through this research, a thorough analysis of both experimental findings and clinical results of several related articles was obtained, which indicated that Kinesio Taping may be successfully used to relieve pain perception in patients, in short-term, especially the decrease and elimination of local swelling in cases of lower limbs injuries. Also, the research suggested that the therapy shows good and significant rehabilitation results in the enhancement of balance dysfunction and proprioception disorders caused by chronic lower limb sporting injuries. In general, KT as a non-invasive therapeutic mode is significant in terms of value of application in sports injury rehabilitation.

Another study by researcher Luca Labianka included 52 male participants aged 18 to 45 who underwent anterior cruciate ligament reconstruction (ACLR) using dual bundle autografts and semitendinosus muscle (DGST) autografts [12]. The patients were randomly separated into two groups (Group A: control; Group B: experimental) that had the standard rehabilitation protocols implemented in them and those that had the standard rehabilitation protocols in addition to KT. During the follow-up at 2 and 4 weeks postoperatively, the researchers measured pain levels, range of motion, edema levels, thigh circumference, scores on the Tegner-Lysholm Scale, and the Knee Osteoarthritis Outcomes Score (KOOS). The findings revealed that the experimental group depicted noticeable changes in pain relief and edema reduction in 2 weeks after surgery ($p < 0.05$). During the in-hospital rehabilitation period at 4 weeks, the two groups showed no significant difference in pain intensity (n.s.), but the experimental group showed greater edema decrease ($p < 0.05$). As one of the results of the study, it was revealed that KT use in the postoperative rehabilitation period was effective in removing the pains and edema.

4. Conclusion

To conclude, postoperative rehabilitation following anterior cruciate ligament (ACL) reconstruction constitutes an extensive, multi-faceted, and patient-centered systematic process that integrates a synergistic combination of evidence-based rehabilitation techniques and judicious use of assistive devices. Physical factor therapy, exercise therapy, and manual therapy have each proven to be indispensable pillars in optimizing joint functionality, enhancing muscle strength, expanding joint mobility, and alleviating pain, thereby laying a solid foundation for patients' return to normal life and athletic pursuits. Notably, the innovative integration of emerging approaches, such as isokinetic eccentric muscle strength training, targeted joint mobilization, and acupuncture-integrated therapies, has opened new avenues for refining rehabilitation outcomes, offering more tailored and effective solutions to address the unique challenges of ACL recovery.

Furthermore, assistive tools including braces, crutches, and Kinesio Taping play an invaluable role in safeguarding the surgical site, reducing knee joint load, promoting local blood circulation,

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and mitigating discomfort throughout the rehabilitation journey. These devices not only enhance safety but also boost patient confidence, facilitating consistent engagement in rehabilitation protocols. Successful rehabilitation hinges on the seamless coordination of these interventions, aligned with individual patient characteristics, functional goals, and physiological recovery trajectories.

In essence, the development and implementation of a scientifically rigorous, personalized rehabilitation plan—one that harmonizes diverse rehabilitation technologies and supportive aids—is paramount to fully restoring knee joint performance, improving patients' quality of life, and minimizing the long-term risks associated with ACL injury. By embracing a holistic and adaptive approach, clinical practitioners can optimize recovery pathways, empower patients to regain functional independence, and achieve sustainable outcomes that extend beyond mere anatomical healing to comprehensive physical resilience.

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