

Research Progress on Intervention Strategies for Anterior Cruciate Ligament Reconstruction Surgery-induced Fear of Movement

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Abstract. Kinesiophobia is an impediment to functional recovery and return to previous level of activity following anterior cruciate ligament reconstruction (ACL-R), is estimated at 30-50%, and this paper explores the factors in uencing it (biomechanical, pain perception, psychological), and the main three lines of action regarding ACL-R induced kinesiophobia. CBT and GET, that correct irrational cognition and step by step exercise adaptation, are able to alleviate kinesiophobia. However, no long-term follow-up is given. The utilization of physical therapy including isokinetic, proprioceptive and BFR training and/or preoperative pre-rehabilitation, can increase the muscular power and joint stability but cannot offer an individualization and psychological integration. Smart interventions like VR training, AI-based rehabilitation systems and the APP were proven to reduce kinesiophobia and improve compliance with the rehab; however, they are limited to the inconsistency of equipment parameters and uncertainty of long-term effects. Further studies are needed to explore the relationship between kinesiophobia's determinants, as well as largesample, multi-center long-term randomized trials to fill in gaps with current interventions.

Keywords: Anterior cruciate ligament reconstruction, Kinesiophobia, Intervention strategies.

1. Introduction

The incidence rate for anterior cruciate ligament (ACL) injuries in the knee is high, accounting for approximately 50% of all knee joint injuries. Worldwide, annually over 400 thousand people require health care services for ACL injuries. Among them, The treatment of best choice is ACL-R reconstruction. Researches have shown that 90% of patients with an ACL-R will be able to recover knee joint function but only 65% of them will be able to resume preinjury activity levels. The movement fear (kinesiophobia) generated during the postoperative rehabilitation process is one of the important obstacles affecting the functional recovery of patients. Movement fear specifically refers to the excessive fear of pain or re-injury that patients may experience during movement or activities. In patients after ACL-R surgery, the incidence rate is as high as 30%-50%, manifested as excessive vigilance and avoidance of specific actions (such as jumping, sudden stops). This fear mentality can cause patients to actively avoid rehabilitation training, thereby leading to muscle atrophy, joint stiffness and other complications, ultimately affecting the recovery of knee joint function [1].

In recent years, with the development of sports medicine and psychology, kinesiophobia has gradually been recognized as a result of the combined effects of biomechanical factors, pain perception factors, and psychological factors. In response to this clinical issue, scholars both domestically and internationally have attempted various interventions such as psychological interventions and physical interventions. However, there is still controversy over the evaluation of the effects of different intervention strategies, and there is no systematic summary and analysis of intervention methods. This paper aims at comprehensively reviewing the components and interventions for sportophobia following ACLR. It summarizes three major methods: psychological intervention, physical therapy intervention, and digital and intelligent intervention, providing theoretical basis and scientific guidance for future clinical research.

2. The Concept of Motion Phobia

The term "motion phobia" (kinesiophobia) was first proposed and defined by Lethem et al. in 1983 as the "fear-avoidance" (FAM) model. In 1995, Vlaeyen and his research team significantly expanded the FAM theoretical framework and constructed a cognitive behavioral analysis model of "motion/reinjury-fear" [2]. Due to the long-term pain experienced by patients before the surgery and the traumatic pain during the operation, they lack confidence during the postoperative rehabilitation exercise and worry about getting injured again, thus developing catastrophic cognition, which makes them more prone to motion phobia [3]. It is worth noting that motion phobia is different from the general postoperative pain fear. Its core feature is a pathological fear reaction to movement itself. A study involving 50 patients who underwent anterior cruciate ligament surgery and were followed up for six months concluded that preoperative exercise phobia may affect functional recovery scores. If the postoperative motion phobia cannot be effectively and timely psychologically intervened, it will have a long-term impact on the patient's performance in returning to exercise.

3. Factors Influencing Postoperative Fear of Movement after ACL-R Surgery

The influencing factors of sports fear after ACL-R surgery may involve the following three aspects: biomechanical factors, pain perception factors, and psychological factors.

3.1. Biomechanical Factors

From a biomechanical perspective, the decline in neuromuscular control and the impairment of proprioception can cause patients to lack confidence in joint stability, thereby increasing their perception of movement risks [4]. Within several months after the surgery, patients may exhibit symptoms of gait asymmetry. Abnormal biomechanics during lower limb walking is an important factor leading to knee osteoarthritis (KOA) in patients with ACL-R and its progression. The incidence of KOA in ACL-R patients is 57%, which is three times that of healthy individuals. Studies have shown that persistent gait abnormalities within 2 years after the surgery can even affect the normal function of the knee joint in the next 10 years [5]. Fear of movement will further intensify, causing patients to avoid or refuse to participate in any activities and physical exercises, thereby triggering the occurrence of joint stiffness, swelling, quadriceps muscle atrophy, and persistent weakness symptoms. The outcome, as well the patient's quality of life is adversely affected.

3.2. Pain Perception Factors

In terms of pain perception, one component of sports phobia is the fear associated with pain. Patients may experience increased sympathetic nerve excitation due to injury or pain, which exacerbates their perception of pain. Once patients engage in pain-exposure behavior, it can lead to learning-based avoidance, further exacerbating symptoms [4]. The correlation between fear of pain with landing technique was investigated in a sample consisting of 32 women patients that underwent ACL-R. The results showed that pain fear can reduce the knee joint, hip joint, and body flexion during jumping and landing in ACL-R patients. At the same time, to avoid pain, patients may limit joint movement, potentially leading to harmful actions until they feel pain again, thereby exacerbating symptoms [4]. Therefore, pain perception may also affect biomechanical aspects. However, research on pain perception is limited, so future exploration is needed from multiple perspectives and levels.

3.3. Psychological Factors

The psychological state is usually one of the important influencing factors that affect athletes' return to their original activities in the early stage after ACL-R surgery. Although psychological preparedness is not the core part of ACL-R rehabilitation, It could affect the prognosis of the patient greatly. However, it is often overlooked in clinical practice. A meta-analysis included 16 studies (n = 3744), ACL-RSI scale score was significantly increased in subjects resuming sport (MD,20.8; P<0.001) and decreased significantly for the TSK/TSK-11 items (MD,10.1%; with 95% CI ranging

from -12.1% to -8.2%; $P < 0.005$) [6]. Psychological factors are also related to knee joint biomechanics. Some scholars analyzed 9 studies on the influence of psychological factors on knee joint biomechanics and found that the overall movement level would decrease 2-5 years after ACL injury but the symmetrical movement function remained normal. The average limb symmetry index (LSI) was 90%, and it was pointed out that patients with undamaged symmetrical muscle function had a lower overall quality of life and movement level than those with restored symmetrical function. At the same time, fear of movement is closely related to negative emotions such as anxiety and depression. It may be caused by the negative emotions such as fear of ACL-R patients, which makes them more likely to resist and avoid movement behaviors. Excessive worry about pain and fear of re-injury form a vicious cycle that also leads to patients having excessive movement sensitivity. These complex factors mean that we should adopt a multi-faceted treatment approach to deal with this issue and fully consider various factors such as physiology, psychology, and society.

4. Main Intervention Strategies for Sports Phobia after ACL-R Surgery

4.1. Psychological Therapy

4.1.1. Cognitive behavioral therapy (CBT)

CBT is widely applied in clinical psychology and research. This type of intervention can be an effective method for reinforcing mental structure, improving emotional states and increasing the confidence level of individuals. Its core lies in identifying and correcting irrational cognitions and catastrophizing thinking related to fear of movement [7]. Cognitive behavioral therapy identifies and corrects patients' irrational fears and incorrect cognitions about pain, re-injury, and movement ability, establishing adaptive thinking and behavioral patterns. Additionally, cognitive behavioral therapy employs behavioral strategies such as activity rhythm planning and goal setting to help patients gradually increase their activity levels without causing serious problems, proving that injury is not inevitable. A randomized controlled study implemented a 6-month cognitive therapy intervention through an interactive multimedia project. The experimental group ($n=34$) watched videos to learn about the knee joint anatomy and physical therapy for anterior cruciate ligament tear, while using an electronic rehabilitation diary to set goals; the control group ($n=35$) received a manual on knee ligament injury and treatment. Both groups were required to fill out relevant scales and return to the hospital within the first five months, and were re-evaluated in the sixth month. The results showed that after 6 months of intervention, the experimental group significantly improved their fear of movement and pain compared to the control group (pain score decreased by 92.0% vs. 43.2%; TSK score decreased by 30.2% vs. 16.1%), confirming that the potential viability and acceptability of CBT in the management of psychological risk factors following ACLR is unquestionable [7]. Another research investigations incorporated 61 participants scheduled for ACL-R procedures, with random allocation into two distinct cohorts: a standard treatment arm ($n=32$) and a cognitive behavioral therapy intervention group ($n=29$). It was found that at the 6th week after surgery, the knee joint function of the CBPT group had an advantage over the control group, with an increase of 4.2 points in ACL-RSI scores; the advantage was even more pronounced at 12 and 24 weeks: the scores increased by approximately 6 points at 12 weeks and 5 points at 24 weeks compared to the control group ($P < 0.05$). It confirmed that cognitive behavioral therapy facilitates the improvement of the knee joint function and hence allows the patient's return to sport [8]. However, the current research data are limited and lack long-term follow-up, so future studies need to explore different modes of cognitive intervention methods and the optimal duration for prognosis to quickly restore patients' movement ability and prevent further deterioration of the patients.

4.1.2. Gradual exposure therapy (GET)

GET grades the intensity of exercise programs, allowing patients to start with exercises that evoke minimal fear and gradually increase the intensity of training as they adapt. For patients with ACL-R, this process may begin with imagining tightening the thigh muscles, followed by actual tightening,

light weight-bearing, full weight-bearing, walking, lunging, jumping, and ultimately sports-specific movements. Studies have shown that it can directly enhance patients' confidence in knee joint function, leading to substantial improvements in indicators such as landing technique that predict safe return to sports and reduce the risk of re-injury. A graded exposure intervention program was designed for female ACL-R patients (n=12) with a duration of 5 weeks. In the first week, patients watched videos about exposure therapy and learned about active and passive coping modes; from the second week onwards, patients were gradually exposed to situations that evoke fear of movement and performed corresponding exercises, while being encouraged to adopt positive self-talk and fill out a rehabilitation diary weekly. The results showed that the intervention program could reduce patients' fear of movement (TSK-11 score decreased by 12.3%) and improve patients' adherence [9]. GET provides a way to show how motion doesn't necessarily lead to pain and injury, thus disrupting the cycle of fear avoidance. To demonstrate its lasting effect, further study of larger cohorts and longer follow up are needed.

4.2. Physical Therapy

The importance of physical therapy in recovery from patients undergoing ACL-R has proven. ACL-R Patients may exhibit a series of symptoms such as gait asymmetry, quadriceps atrophy, and decreased muscle strength. Proper rehabilitation training can not only enhance patients' self-efficacy but also reduce the recurrence of injury, accelerate patients' return to sports, and alleviate their fear of sports.

In general, physical therapy techniques are currently directed at regaining range of motion in the knee joint. Exercise intervention and strength training are the most effective methods and foundations. Researches indicate that isokinetic exercises and resistance training contribute significantly to rebuilding quadriceps strength and improving knee joint functionality in patients. A meta-analysis examined 11 research investigations analyzing the impact of isokinetic and eccentric exercise protocols on ACL reconstruction. The results showed that two training methods had significant effects in restoring the strength of the quadriceps femoris and the symmetry of the limb (SMD=0.64; $P<0.01$) [10]. Proprioceptive training is one of the most important elements in functional rehabilitation because it plays an integral role in increasing dynamic stability as well as joint position sense. The effects of incorporating proprioceptive training into standard rehabilitation therapy programs on knee joint function have been investigated by researchers, pain and the dynamic balance of patients with ACL-R. They included 48 patients and divided them into a control group and an experimental group. The results showed that at 12 weeks after the surgery, not only did the functional status of the experimental group significantly improve, but the treatment group exceeded the comparison group by 5.4 points in the ACL-RSI score ($P = 0.04$) and by 3% in the Y balance index ($P < 0.05$) [11]. Proprioceptive training was found to be more efficient than conventional rehabilitation on restoration of knee joint function and dynamic balance, but it doesn't alleviate pain.

However, patients may be reluctant to undergo training or even develop a fear of movement due to joint pain during the initial stages of surgery when undergoing high-intensity strength training. Therefore, Blood Flow Restriction (BFR) training, as a relatively balanced combination of exercise training and low-intensity load training, may improve muscle strength. A randomized controlled trial involving 23 subjects was equally divided into three groups. The control group received conventional quadriceps training, while the other two groups underwent conventional training combined with 40% Arterial Occlusion Pressure (AOP) and 80% AOP. The intervention consisted of eight weeks with a frequency of two sessions per week for 60 minutes. The results showed that the indicators in the 40% AOP group and the 80% AOP group were significantly improved compared to the control group. In terms of the thickness of the rectus femoris and intermuscular septum, the 80% AOP group was superior to the 40% AOP group (thickness: 6.26cm vs. 5.23cm, $P<0.01$). In terms of peak torque/body weight (at angular velocities of 60°/s and 180°/s) of the quadriceps, the 80% AOP group showed higher improvement efficiency than the 40% AOP group (improvement at 60°/s: 44.51N.m/s vs. 30.92N.m/s; improvement at 180°/s: 58.96N.m/s vs. 27.33N.m/s) [12]. However, the sample size in

this study was small and no blinding screening was conducted, which may have led to less rigorous data. Overall, BFR has a significant effect on muscle and functional recovery and is suitable as an auxiliary training intervention.

Although these methods are effective in improving muscle strength and balance, they have limitations in restoring the neural-muscular control required for complex movements. Therefore, preoperative "pre-rehabilitation" seems to be more effective [12]. This method enhances body control through resistance load training and neuromuscular training (balance, stability, proprioceptive exercises), and through movements on unstable surfaces, anti-interference training, and balance exercises, improving joint position perception, dynamic stability, and rapid response ability. Therefore, physical therapy should strictly follow the principle of "gradual progression", dynamically adjusting the training intensity and difficulty according to the patient's recovery situation, avoiding pain or injury caused by excessive training, and ensuring that functional recovery and psychological reconstruction proceed simultaneously.

4.3. Intelligent Rehabilitation Intervention

4.3.1. Sports training based on virtual reality (VR) technology

With constant technological advances, virtual reality technology was introduced and later on has found its application in treating patients after ACL-R. Studies have found that this technology can not only improve fear of movement and enhance knee joint function but also increase joint range of motion. A Meta-analysis of 9 RCTs with a total of 330 patients that reported information regarding the impact of VR technology on functional recovery following ACL-R, found that there was no statistically significant improvement of VRBT on the proprioception of knee joints but demonstrated significant efficacy in pain reduction (standardized mean difference = -1.15 , with 95% CI ranging from -1.85 to -0.45 ; $P = 0.001$, heterogeneity $I^2 = 0\%$) while also improving range of motion for knee flexion (SMD = 0.7 , 95% CI $0.37-1.01$; $P < 0.001$, with no observed heterogeneity $I^2 = 0\%$) [13]. A randomized controlled trial involving 56 patients explored the effect of virtual reality-based exercise on the functional condition after ACL-R. The conclusion shows that VR motion training enables patients to consciously make methodological changes and timely adjustments in response to various changes in the task. Continuously reinforcing sensory information input can enhance the adaptability of the patient's knee joint to complex situations, improve the effectiveness of movement responses, thereby reducing the fear of movement, and thereby increasing their movement output level. It also improves the flexibility and stability of the knee joint's movement and enhances the movement function of the knee joint. However, the above two studies also have limitations. Differences in equipment usage parameters, small sample sizes and so on can cause errors in results and impacts. Therefore, future studies need to conduct high-quality randomized controlled experiments with large amounts of data to further explore the effect of virtual reality technology in improving the function of ACLR patients.

4.3.2. Intervention based on digital technology

A study conducted a six-week randomized controlled experiment on ACL-R patients by using the mobile health (MHealth) intervention app "MHI". This platform, while promoting the importance of rehabilitation exercises, teaches patients how to measure knee joint range of motion and circumference through graphical exchange format, as well as the standards for exercise movements, and reminds patients of daily exercise content and follow-up dates. The results showed that MHealth-based education further promoted the improvement of clinical indicators, but did not significantly improve the subjective outcomes after anterior cruciate ligament reconstruction. Moreover, it only focused on early knee joint function and required patients to learn smartphone software, thus having certain limitations [14]. A separate research project involved 80 participants undergoing rehabilitation therapy directed by an AI-powered evaluation and adjustment platform. These individuals were randomly allocated between a reference cohort and an experimental cohort. The test group underwent intervention in a closed loop of assessment-rehabilitation prescription training feedback and

stretching movement analysis or guidance including warming up movement analysis, accurate motion analysis, exercise recommendation, AI-based training etc. Starting one month after surgery, the duration of the treatment was 12 weeks (three sessions per week). The findings demonstrated that the AI-driven evaluation and adjustment framework for rehabilitation therapy significantly enhanced the restoration of knee functionality, mobility range, and equilibrium control, but significantly improved adherence to rehabilitation exercises (experimental group: 63.10 ± 3.13 vs. 61.18 ± 3.07 , $P < 0.05$, with higher scores indicating better adherence) [15]. In summary, digital intervention can effectively improve patients' knee joint function and enhance their adherence to rehabilitation, but related research is limited and the follow-up period is short, presenting certain limitations. Further study needs to focus on longer term follow up and multi-center trials evaluating effectiveness of digital intervention.

5. Conclusion

Anterior cruciate ligament injury not only affects the patient's motor function, but also the fear of pain caused by exercise can have a significant impact on the patient's mental health. The various intervention methods introduced in this article each have their own advantages: cognitive behavioral therapy and graded exposure therapy are both classic psychological intervention methods. The former improves the patient's fear of movement through treatment, while the latter helps the patient gradually adapt to the challenges of exercise. However, they lack long-term follow-up and unified intervention norms. Physical therapy intervention is the foundation. Isokinetic and eccentric training, as well as proprioceptive training, can effectively improve muscle strength and stability. Preoperative "pre-rehabilitation" can reduce the movement fear caused by postoperative trauma stress, but the existing training mostly focuses on the recovery of a single function and lacks individualized adjustment, and the combination with psychological intervention is insufficient. Virtual reality technology can reduce movement fear through immersive experience, and the artificial intelligence assessment system can achieve precise rehabilitation guidance. Digital and intelligent intervention provides a new path for clinical practice, but such research has problems such as inconsistent equipment parameters and a single research subject. Some methods have application barriers, and the long-term effect is not yet clear. Therefore, future research needs to further explore the mechanism and interaction rules of each influencing factor of movement fear, conduct multi-center randomized controlled trials with large samples and long-term follow-up, and clarify the best plan, combination form and intervention timing of various intervention methods. By leveraging the advantages of multidisciplinary integration, it can better guide clinical practice and provide reasonable suggestions. This will improve the cure rate and quality of life of patients.

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