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Effect Analysis of Muscle Strength Training in Sports Rehabilitation for Patients with Knee Joint Injuries

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Abstract: In this study, the theoretical relationship between knee joint injury and muscle strength training is explored, and the biomechanical changes caused by injury, the role of muscle on joint stability, and the physiological basis of training are clarified. The implementation strategies of personalized training programs based on injury type and stage, scientific training intensity control, and coordinated use of diversified training types are explained. Multi-dimensional evaluation is conducted from the aspects of joint function recovery, muscle strength and morphological recovery, and improvement of knee joint biomechanical properties, providing theoretical and practical references for muscle strength training in knee joint injury rehabilitation.

Keywords: Knee joint injury; Muscle strength training; Rehabilitation strategy; Effect evaluation; Biomechanics

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1. Introduction

The knee joint is the hub of human movement, but it is prone to injury in daily activities and competitive sports. The biomechanical imbalance and decreased stability of the knee joint after injury seriously affect limb function and quality of life. Muscle strength training, as the core means of rehabilitation, can reshape muscle structure from a physiological level and promote functional recovery through scientific strategies. In-depth exploration of its theoretical basis, implementation methods, and effect evaluation is not only related to the quality of patient rehabilitation, but also provides a key path for optimizing knee joint injury rehabilitation programs.

2. Theoretical relationship between knee joint injury and muscle strength training

2.1. Biomechanical changes caused by knee joint injury

As a complex and critical joint in the human body, the knee joint frequently bears pressure and stress in daily activities and sports. Once damaged, its biomechanical environment will change significantly. After anterior cruciate ligament injury, the anterior-posterior laxity of the knee joint increases. When the tibia is completely ruptured, the forward displacement of the tibia can increase by 5 to 10 mm compared with the normal state, resulting in uneven distribution of pressure on the joint surface. The load originally borne by ligaments, muscles, and articular cartilage is transferred, the movement trajectory is offset, and the local wear of articular cartilage is aggravated, increasing the risk of traumatic arthritis. Meniscus injury also changes the biomechanical properties of the knee joint, and its function of buffering shock and dispersing load is lost. Injury to the medial meniscus will increase the pressure in the medial compartment, accelerate the wear of articular cartilage, change the mechanical conduction path, and increase the risk of injury to other structures. At the same time, knee joint injury will also cause pressure imbalance in the joint cavity, destroy the normal circulation of synovial fluid, further affect joint lubrication and nutrient metabolism, and aggravate the process of joint degeneration.

2.2. The key role of muscles in maintaining knee joint stability

The quadriceps, hamstrings, and gluteal muscles around the knee joint are important power structures for maintaining joint stability. The quadriceps, as an extensor, drives the calf to extend when contracted, ensures the normal position of the patella through the patellar tendon, and ensures the flexion and extension of the knee joint. Studies have shown that every 1 Newton increase in quadriceps muscle strength can reduce the pressure on the knee joint during daily activities. The hamstrings, as flexors, work together with the quadriceps to buffer the ground reaction force through eccentric contraction when running and jumping, reducing the risk of meniscus injury. The gluteal muscles are involved in maintaining the force line of the lower limbs. When walking, the gluteal muscles contract to stabilize the pelvis, reduce the additional torque of the knee joint in the support phase and swing phase, and lower the chance of joint injury [1]. In addition, in actions such as going up and down stairs and squatting, these muscle groups need to work together to maintain the dynamic balance of the knee joint at different angles through fine force regulation to avoid secondary injuries due to uneven force.

2.3. Physiological basis of muscle strength training

From a physiological perspective, muscle strength training is of great significance to the rehabilitation of knee joint injuries. Training promotes muscle hypertrophy and increases muscle cross-sectional area. After repeated stimulation of muscle fibers, protein synthesis increases, myofibrils increase in number and size, and muscle contraction force is enhanced. Strength training can also improve the distribution of muscle fiber types. The human body's slow muscle fibers have strong endurance, and fast muscle fibers have high explosive power. Targeted training can transform some slow muscle fibers into fast muscle fibers to meet the needs of movement function recovery in knee joint rehabilitation. In addition, training improves neuromuscular coordination and enhances the precision of muscle control by the nervous system. During knee joint movement, muscles can respond quickly to mechanical changes, maintain dynamic stability of the joint, and reduce the risk of re-injury. Long-term and regular muscle strength training can also activate muscle satellite cells, promote muscle tissue repair and regeneration, optimize muscle metabolic capacity, and provide more lasting and stable mechanical support for the knee joint.

3. Implementation strategies of muscle strength training in knee injury rehabilitation

3.1. Development of personalized training programs based on injury types and stages

There are various types of knee injuries, such as ligament injuries (anterior cruciate ligament, posterior cruciate ligament, medial and lateral collateral ligaments, etc.), meniscus injuries, cartilage injuries, etc. Different types of injuries have varying effects on knee stability and function, and rehabilitation training programs need to be accurately adapted. Taking ligament injuries as an example, in the early stage after anterior cruciate ligament reconstruction (0–2 weeks), in order to protect the graft, isometric contraction exercises of the quadriceps and hamstrings should be performed under brace fixation, such as static contraction of the quadriceps, multiple times a day, each time for 5–10 seconds, to prevent muscle atrophy; At 2–6 weeks, patients can gradually carry out active knee flexion and extension training, such as sitting knee flexion exercises, each flexion and extension range of motion is determined according to the progress of rehabilitation, and gradually increase the range of motion of the joint. During the rehabilitation of meniscus injury, if it is a mild injury, ankle pump exercise can be used to promote blood circulation in the lower limbs in the early stage. Lie flat on the bed and flex and extend the ankle joint slowly and evenly. Each flexion and extension should be maintained for 3–5 seconds, 10–20 times as a group, 3–4 groups per day; as recovery, straight leg raising training can be performed, supine position straighten the knee joint, slowly raise the lower limb to 30–60 degrees, hold for 5–10 seconds and then slowly put it down, 10–15 times as a group, 3–4 groups per day, to strengthen the quadriceps strength and reduce the pressure on the meniscus [2]. At the same time, according to the dynamic adjustment plan of the injury recovery stage, transition from the early joint range of motion and muscle basic strength recovery to the mid-term strength strengthening and stability training, and then to the later functional recovery and sports ability training.

3.2. Scientific and reasonable control of training intensity

Training intensity is a key element of muscle strength training in knee injury rehabilitation. In the initial stage, low-intensity training should be used to avoid increasing the burden on the injured part. For example, when performing isometric muscle contraction training in the early stage of injury, the contraction force should be controlled at 20–30% of the maximum muscle strength. The duration of each contraction should not be too long, 3–5 seconds is adequate, and each set should be repeated 10–15 times, 3–4 sets per day, to allow the damaged knee joint to adapt. As the rehabilitation process progresses, the training intensity is gradually increased. In the middle term, resistance training can be introduced, such as using elastic bands to perform simple knee flexion and extension resistance exercises. The resistance provided by the elastic band should start at a lower level, such as choosing an elastic band with a smaller elastic coefficient. Initially, perform about 10 times per set. As muscle strength increases, gradually increase to 15–20 times per set. At the same time, appropriately increase the resistance level of the elastic band, but make sure that there is no obvious pain or discomfort in the knee joint during training. When entering the late stage of rehabilitation, more challenging training can be carried out, such as moderately weighted leg strength training with the assistance of equipment. The weight is determined according to the individual's recovery situation. Generally, it starts from 10–20% of one's own body weight and gradually increases. The number of training times per set is maintained at 8–12 times. By scientifically adjusting the intensity, it can effectively promote muscle strength improvement and ensure the safe recovery of the knee joint.

3.3. Coordinated use of diverse training types

In order to comprehensively promote the rehabilitation of knee joint injuries, a variety of training types need to be used in combination. Isometric training plays an important role in the early stage. For example, isometric contraction of the quadriceps can enhance muscle strength and maintain basic physiological functions of muscles without obvious displacement of the joints. In the middle stage of rehabilitation, isotonic training can effectively improve muscle contraction and relaxation ability. For example, using dumbbells for leg curl exercises, choose dumbbells of appropriate weight, such as 2–3 kg, and perform 10–15 times per set, 2–3 sets of training to enhance leg muscle strength and explosive power [3]. Isokinetic training uses a special isokinetic muscle training device to provide precisely controlled resistance, which can effectively exercise muscles at different joint movement angles. For example, setting a specific angular velocity and performing knee flexion and extension exercises can significantly improve the coordination and strength balance of muscles around the knee joint. In addition, balance training cannot be ignored. For example, when standing on one leg, start with eyes open and gradually transition to eyes closed. Each standing time starts from 30 seconds. As the balance ability improves, the time is extended, which can effectively improve the proprioception and stability of the knee joint. Different types of training work together to help the recovery of knee joint function and muscle strength reconstruction in all directions.

4. Multi-dimensional evaluation of the effect of muscle strength training on knee injury rehabilitation

4.1. Evaluation based on joint function recovery

Joint function recovery is a key dimension for evaluating the effect of muscle strength training on knee injury rehabilitation. Knee injury is often accompanied by limited joint mobility, such as reduced range of motion, including flexion, extension, and rotation. During the rehabilitation process, it can be evaluated by measuring the active and passive range of motion of the knee joint. The normal knee extension position is 0 degrees, and the flexion can reach 135 to 150 degrees. If the patient's active knee flexion angle gradually increases from 90 degrees at the beginning of the injury to more than 120 degrees after muscle strength training, and the extension angle is close to 0 degrees, it shows that the training is effective in improving the range of motion of the joint. In addition, the performance of daily life functions is also crucial, such as whether the patient can independently complete walking, going up and down stairs, squatting, and other actions. Taking walking as an example, the patient's stride, step frequency, and knee stability during walking can be monitored. The stride of a normal adult is about 50 to 70 cm, and the step frequency is 80 to 120 steps per minute. If the patient's stride is close to the normal range after training, and there is no obvious pain, jamming, or weakness in the knee joint during walking, it means that the knee joint function has been effectively restored under muscle strength training and can better meet the needs of daily activities.

4.2. Evaluation of muscle strength and morphological recovery

As an important power structure to maintain the stability of the knee joint, the strength and morphological recovery of muscles are the core content of evaluating the rehabilitation effect. In terms of muscle strength, isometric, isotonic, and isokinetic muscle strength tests can be performed with the help of professional equipment. For example, a portable isometric muscle strength test device, such as a handgrip dynamometer, is used to test the isometric contraction strength of the quadriceps [4]. The maximum isometric contraction strength of the quadriceps of normal adult males can reach 500 to 800 Newtons, and that of females is 300 to 500 Newtons. If the patient's muscle strength gradually approaches this range after training, it shows that the training has promoted muscle strength growth. Muscle morphology can be observed through imaging methods such as ultrasound and MRI. Muscle cross-sectional area is a key indicator of muscle morphology. MRI measurement data show that the cross-sectional area of the normal quadriceps in the middle of the thigh is about 50 to 70 square centimeters. Muscle atrophy often occurs after knee injury, and the cross-sectional area decreases. After a period of muscle strength training, if the cross-sectional area of the quadriceps gradually increases and approaches the normal range, it indicates that the muscle gradually recovers to its normal form under the stimulation of training, providing stronger support for the knee joint.

4.3. Evaluation of improvement in the biomechanical properties of the knee joint

The biomechanical properties of the knee joint are of great significance for evaluating the rehabilitation effect. Biomechanical parameters such as the force line of the knee joint and the pressure distribution on the joint surface are abnormal after injury, and muscle strength training aims to correct these abnormalities. The three-dimensional motion analysis system can accurately measure the changes in the force line of the knee joint during movement. Under normal circumstances, the movement of the knee joint in the sagittal, coronal, and horizontal planes follows a specific trajectory. After injury, the trajectory may be offset, such as the abnormal increase in the knee valgus angle during the walking support phase. If, after muscle strength training, the knee valgus angle gradually decreases from more than 15 degrees after injury to the normal range of 5 to 10 degrees, it means that the training has effectively improved the force line of the knee joint. At the same time, with the help of pressure measurement insoles and other equipment, the pressure distribution of the joint surface can be monitored. The pressure distribution of the medial and lateral compartments of the normal knee joint is relatively balanced. After injury, the pressure of the medial compartment often increases significantly. When the pressure ratio of the medial and lateral compartments tends to be normal after training, it indicates that the pressure distribution of the joint surface is optimized, reducing the risk of articular cartilage wear, and further confirming the positive effect of muscle strength training on improving the biomechanical properties of the knee joint.

5. Conclusion

Knee injury rehabilitation is a complex system of engineering, and muscle strength training runs through it. From clarifying the biomechanical changes and muscle action mechanisms after injury to formulating personalized training strategies, and then verifying the effect through multi-dimensional evaluation, each link is closely related. Scientific application of muscle strength training can help improve knee joint function, enhance patients' quality of life, and provide solid theoretical and methodological support for knee joint injury rehabilitation practice.

Disclosure statement

The author declares no conflict of interest.

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