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Article

Rehabilitation management of sports athletes' muscle injury based on OpenSim technology

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Abstract: Due to the rapid development of sports and people's love for sports, athletes often perform resistance training beyond the body to achieve better results, resulting in frequent muscle injuries. After the injury, the athlete cannot return to the state before the injury in time, which destroys the previous training results and hinders the athlete from improving to the professional level. Therefore, the research of athletes' post-injury rehabilitation is the central subject of modern sports science research. This paper used OpenSim technology to study the rehabilitation management of sports athletes' muscle injury. In this paper, the OpenSim skeletal muscle model was first established, followed by muscle modeling and characteristic analysis, and then a muscle rehabilitation system was constructed. The experimental part used the limb rehabilitation device model of this paper to carry out muscle rehabilitation training for patients with muscle injury, and compared it with conventional rehabilitation training. The experimental results showed that the limb rehabilitation device in this paper had a better rehabilitation effect. Compared with the traditional rehabilitation training, the excellent rate of the total active range of motion of the joints and the satisfaction of rehabilitation nursing were both increased by 10%.

Keywords: rehabilitation management; muscle injury; sports athletes; OpenSim technology

1. Introduction

In competitive sports, high-intensity training and high-frequency competition are very common. Many top athletes suffer different types of injuries due to different training programs and different training phases, and this type of physical injury mainly involves muscle damage. Common muscle injuries are mainly related to muscle injuries caused by incorrect movements or inconsistent training volumes during various physical exercises. Rehabilitation strategies for muscle injuries should therefore be explored to minimize the occurrence of these unnecessary injuries.

There are many studies on muscle injury rehabilitation. Ehiogu et al. conducted a study on the rehabilitation methods of climbers with acute hamstring tendon injuries [1]. Zhao discussed the mesoporous multifunctional nanomaterials based on sports rehabilitation training for the treatment of muscle injury in bodybuilding [2]. Sun discussed future rehabilitation measures for rhomboid muscle injury in weightlifters [3]. Yu and Li conducted research on the prevention and rehabilitation of hamstring strain [4]. Baker studied how aging affects skeletal muscle responsiveness to strain [5]. Although there are many studies on the rehabilitation of muscle injury, but the frequent occurrence of muscle injury in sports athletes, further research is needed on the rehabilitation management of muscle injury.

OpenSim technology is often used in medical research. Lu and Li used the

OpenSim musculoskeletal model to study and compare the biomechanics of the lower limbs during barbell squatting between normal feet and valgus patients [6]. Renganathan et al. used OpenSim simulation software to study how over-the-counter running shoes improve gait patterns in patients with flat feet [7]. Alexander et al. studied the effect of walking speed on joint and muscle strength estimates in the AnyBody and OpenSim musculoskeletal models [8]. In order to control the characteristics of human biomechanical models, Mahadas et al. developed a series of model simulation programs in OpenSim [9]. Inchan used the OpenSim biomechanical simulator to propose a method for detecting muscle fatigue during elbow flexion and extension based on surface EMG signals [10]. Although OpenSim technology is widely used in medical research, no scholars have applied it to the rehabilitation management of sports athletes' muscle injury.

In this paper, OpenSim technology is used to study the rehabilitation management of sports athletes' muscle injury. In this paper, OpenSim is used to establish a skeletal muscle model, followed by muscle modeling, including muscle Hill model, muscle path setting, muscle fiber-tendon model, and muscle fiber model. Finally, a limb rehabilitation device is designed to build a limb rehabilitation system. In the experimental part, the limb rehabilitation device model of this paper is used to carry out muscle rehabilitation training for people with muscle damage, and the results of traditional muscle rehabilitation training are compared to analyze the feasibility of the research.

2. OpenSim skeletal muscle model

OpenSim is an open-source simulation software platform with visual simulation models that can create custom skeletal muscle models for different people. Firstly, a human skeletal muscle model is prepared, the position and trajectory of each muscle of the limb is fixed by selecting the muscle attachment point, and the human skeleton parameters are obtained, and the individualized skeletal muscle model is obtained by scaling. Then, the muscle moment arm at the joint is obtained through kinematic analysis, and the trajectory coordinates of each marked point of the moving limb are given, and the inverse kinematics module is used to calculate the motion angle of each lower limb joint. It then uses dynamic analysis to find joint torque, and optimizes the obtained results to find the strength and muscle activation of the current movement [11]. **Figure 1** shows the OpenSim simulation analysis process.

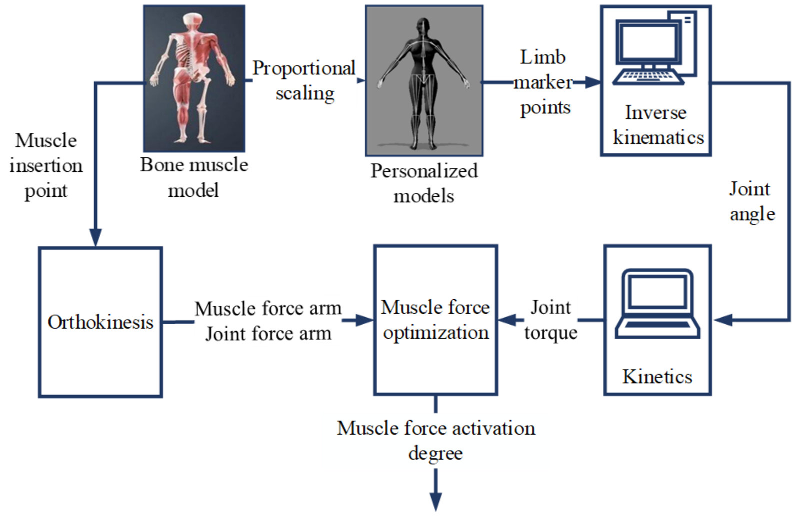

Figure 1. OpenSim simulation analysis process.

In the rehabilitation management of athletes' muscle injury, the creation and use of OpenSim technology's skeletal muscle model is quite complex, involving many parameters and calculations. This is indeed a challenge for practitioners who lack a background in biomechanics. In order to overcome this problem, integrating OPSIM with other biomechanical analysis tools is a feasible solution.

The integration process first involves the export and transformation of the OPSIM model data so that other tools can read and use it. This is usually achieved through a dedicated interface or plug-in to ensure the accuracy and completeness of the data. Next, select appropriate biomechanical analysis tools according to specific needs, such as motion capture systems, EMG analyzers, etc., to obtain more detailed muscle activity and exercise data.

In the integration process, the key is to ensure that the data flow between OPSIM and other tools is smooth and seamless. This may require certain technical support and expertise to ensure the stability and reliability of the entire system. By integrating different biomechanical analysis tools, it can make up for the shortcomings of a single method and provide a more comprehensive and accurate muscle injury assessment and rehabilitation management plan.

3. Muscle modeling and characteristic

3.1. Muscle hill model

The overall input to the muscle model is activation and the output is muscle strength. The Hill muscle model has been continuously improved and has been gradually improved. The Hill muscle model is shown in **Figure 2**.

Models of muscle fibers are represented by parallel elastic elements (PE) and contractile elements (CE), while tendons and some elastic tissues are represented by sequential elastic elements (EE).

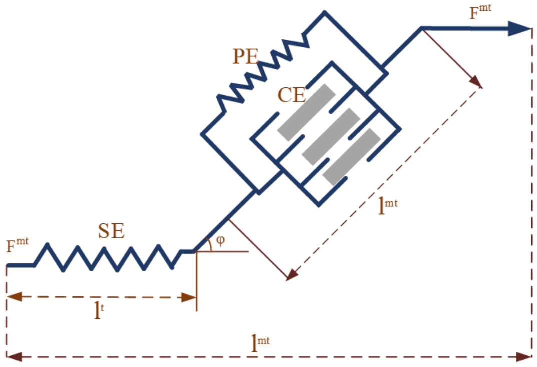

Figure 2. Hill muscle model.

The parameters used to create the muscle mathematical model should be standardized, otherwise it is only applicable to the human individual and is not universal. The concept of normalization is easy to use and works for everyone, so parameters that affect muscle strength, such as activation, muscle length, and muscle contraction rate, need to be standardized [12].

In fact, the force produced by muscle fibers is not the same as the force acting on the bones in skeletal muscle. In the muscle model established in this paper, the force transmitted by the tendon to the bone is compared to the muscle force, and the force generated by the muscle belly is compared to the muscle fiber force. Muscle fiber strength F_f is:

$$F_f = F_{CE} + F_{PE} \tag{1}$$

In Equation (1), F_{CE} represents the active force of the muscle fiber, and F_{PE} represents the passive force of the muscle fiber.

Due to the special structure of muscles, the relationship between muscle force F_M and muscle fiber force F_f and tendon force F_T is as follows:

$$F_M = F_T = F_f \cdot \cos\emptyset \tag{2}$$

In Equation (2), ∅ represents the feather angle.

3.2. Muscle path setting

According to anatomical knowledge, the tendons and belly of the abdomen make up the muscles. The muscle belly is located in the center of the muscle, and the tendons are located at the ends of the muscle, usually attached to the bone. When analyzing a muscle, the spatial location of the muscle can first be determined. Muscle is composed of muscle fibers and connective tissue, and the distribution of muscle fibers is uneven. For the convenience of modeling, muscles are simplified as muscle lines [13].

There are two situations for adjusting the muscle line trajectory:

1) The muscle line is directly connected to the insertion point, and has a starting point and an ending point. In this case, the movement of the joints has little effect on the movement of the muscles, and there are fewer muscles in this condition.

2) The motion trajectories of most muscles change greatly during joint movement. These muscles usually cover the surface of bones or other muscles.

If the person changes the angle of the joint during the simulation, that part of the muscle will be buried in the bone or overlap with other muscles, causing the muscle to move incorrectly. Therefore, in order to ensure the correct movement of the muscles during joint movement, certain modules must be set up to attach to the surface of this type of muscle.

3.3. Muscle fiber-tendon model and analysis

3.3.1. Analysis of the structural characteristics of muscle fibers and tendons

According to the kinematic analysis and the constructed limb model, the muscle fiber-tendon length (l_{M-T}) and the muscle fiber-tendon speed (v_{M-T}) during training can be obtained. Muscle strength, muscle (or tendon) length and velocity can be derived from the Hill model.

Tendon length:

$$l_T = l_{T1} + l_{T2} \tag{3}$$

l_T represents the length of the tendon, and l_{T1} and l_{T2} represent the length of the tendon at both ends of the muscle fiber.

Muscle length:

$$l_{M-T} = l_M \cdot cos\varphi + l_T \tag{4}$$

l_M is the muscle fiber length.

Muscle fiber length planning processing:

$$L_M = \frac{l_M}{L_{CEopt}} \tag{5}$$

L_M represents muscle fiber length after planning.

In skeletal muscle, the length of the tendon consists of two parts. Generally speaking, it is assumed that the distance between the common vertical lines of the muscle belly at both ends remains unchanged during the process of muscle contraction and relaxation, that is, the thickness (H) of the muscle belly remains unchanged. In the optimal case, the length of the muscle fiber is L_{CEopt}, and the feather angle usually takes a smaller value. For example, the feathered angle of the long head of the biceps usually takes the 0^o when displaced at the joint. At a given moment of movement, the length of the muscle fiber is l_M and the feather angle is $\emptyset$, and the mathematical relationship is:

$$l_M sin\varphi = L_{CEopt} \sin\varphi_o = H \tag{6}$$

The velocity formula of the muscle fiber-tendon:

$$v_{M-T} = v_T + v_{CE} \cos\varphi - l_w \cdot w \cdot \sin\varphi \tag{7}$$

v_{CE} is the muscle fiber contraction velocity, v_T is the tendon contraction velocity, and w is the change in the angular feather angular velocity.

3.3.2. Analysis of tendon force characteristics

According to the Hill model of muscle, the relationship between the strengths of muscles, tendons, and muscle fibers can be transformed into the following forms:

$$F_M = f_1(L_M) = f_2(L_T) \tag{8}$$

$$F_T = \begin{cases} \dfrac{F_{toe}^T}{e^{K_{toe}} - 1}\left(e^{\frac{k_{toe} \cdot \varepsilon^T}{\varepsilon_{toe}^T}} - 1\right), & \varepsilon^T \le \varepsilon_{toe}^T \\ k_{lin}(\varepsilon^T - \varepsilon_{toe}^T) + F_{toe}^T, & \varepsilon^T > \varepsilon_{toe}^T \end{cases} \tag{9}$$

$$\varepsilon^T = \frac{L_T - L_{T_O}}{L_{T_O}} \tag{10}$$

F_T represents the planned tendon force; ε_{toe}^T represents the tendon strain under linear conditions; ε^T represents the tendon strain. F_{toe}^T represents the ideal tendon force after planning, with a value of 0.33; k_{lin} is a linear coefficient, with a value of 42.8; K_{toe} represents an exponential factor, with a value of 3.

3.4. Muscle fiber model and analysis

3.4.1. Kinetic model of muscle activation

There are approximately 600 skeletal muscles in the human body, and once normalized, the excitation signal applies to all skeletal muscles [14]. The conversion of EMG signals to activation levels in the muscle model is shown in **Figure 3**.

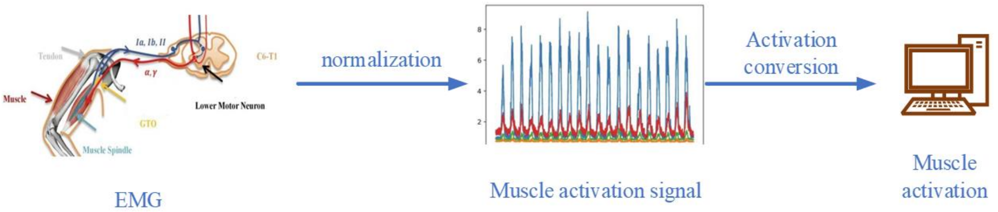

Figure 3. Transformation of EMG Signals to Activation in Muscle Models.

First-order nonlinear processing was used to establish the relationship between muscle activation and normalized excitation signal.

$$\frac{da}{dt} = \frac{u - a}{\tau_a(a, u)} \tag{11}$$

$$\tau_a(a, u) = \begin{cases} \tau_{act}(0.5 + 1.5a); & a < u \\ \tau_{deact}/(0.5 + 1.5a); & a \geq u \end{cases} \tag{12}$$

In the formulas, a represents the degree of muscle activation, u represents the muscle excitation signal; $\tau_a(a, u)$ represents the time cost associated with increasing and decreasing muscle levels. τ_{deact} represents the time constant of the degree of muscle inactivation, usually 50 ms; τ_{act} represents the time constant of muscle activation, usually 15 ms.

The degree of muscle activation is determined by the ratio of fast-twitch to slow-twitch fibers in the muscle and depends on the concentration of calcium ions. In the process of muscle activation and inactivation, there is a certain time interval between the release of calcium and sodium ions from nerve endings and the stimulation of muscle movement. Generally speaking, this time interval is related to the physiological condition of the human body. Depending on the body type of each person, it will be different. The differences are usually small, but become more pronounced as the body ages and the physiological environment changes.

3.4.2. Analysis of the active force of muscle fibers

The conversion relationship between muscle fiber active force strength and muscle activation, muscle fiber length, and muscle fiber contraction rate is shown in **Figure 4**.

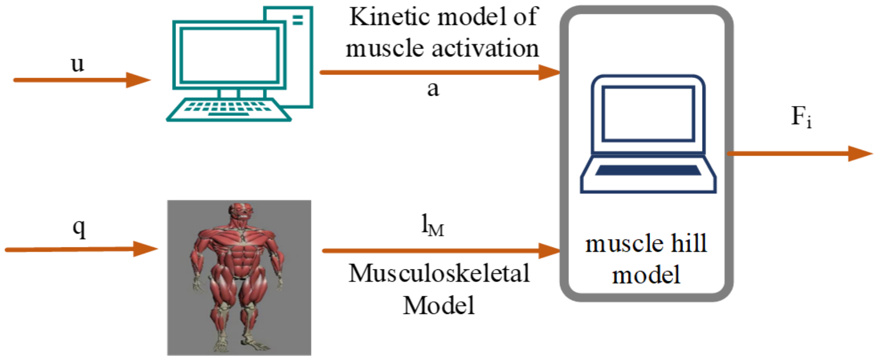

Figure 4. Muscle force export process.

A given muscle activation signal can be converted into muscle activation using a dynamic model of muscle activation. According to the theory of sports biomechanics, the model determines the muscle fiber length according to the angle change of the joint, and then the muscle activation, muscle fiber length and muscle fiber contraction rate are imported into the muscle Hill model to obtain the muscle fiber active force.

The mathematical model of muscle fiber active force F_{CE} is:

$$F_{CE} = a \cdot f_{1-F} \cdot f_{v-f} \cdot F_0^M \tag{13}$$

f_{1-F} is the correlation coefficient between muscle fiber length and muscle fiber activity, and f_{v-f} is the correlation coefficient between muscle fiber contraction rate and muscle fiber activity.

Regardless of changes in muscle fiber length and muscle contraction rate, it is assumed that under joint activity, the degree of muscle activation is roughly proportional to the strength of the active muscle fibers.

$$f_{1-F} = e^{\frac{-(L_M-1)^2}{\gamma}} \tag{14}$$

From the perspective of the physiological structure of the muscle, the maximum isometric force of the muscle fiber is mainly affected by the physiological part of the muscle. The relationship between the maximum isometric force of a muscle fiber and the physiological cross-section of the muscle is expressed as follows:

$$F_0^M = \sigma \cdot PSCA \tag{15}$$

PSCA is the physiological cross-sectional area of the muscle fiber, and σ is the maximum load applied to the muscle fiber.

The physiological cross-sectional area of a muscle is equal to the volume of the muscle fiber divided by the length of the muscle fiber, which is related as follows:

$$\text{PSCA} = \frac{V}{l_M} \tag{16}$$

In the equation, V represents the muscle fiber volume.

3.4.3. Analysis of the passive force of muscle fibers

$$F_{PE} = \frac{e^{\frac{k^{PE}(L_M-1)}{\varepsilon_0^M}} - 1}{e^{k^{PE}} - 1} \tag{17}$$

In the equation, k^{PE} represents the passive force-length exponential factor, which takes a value of 5; ε_0^M represents the maximum passive muscle tension load, which takes a value of 0.6.

When building a muscle model according to the characteristics of the muscle, the strength of the muscle fiber is divided into two parts: The active strength of the muscle fiber and the passive strength of the muscle fiber. The strength of the muscle fiber is the sum of the strength of the active muscle fiber and the strength of the passive muscle fiber. When the muscle fiber length is shorter than the ideal muscle fiber length, the active strength of the muscle fiber gradually increases with the increase of the muscle fiber length. When the muscle fiber length is equal to the ideal muscle fiber length, the active strength of the muscle fiber is equal to the maximum isometric force. Passive muscle fiber strength is approximately zero when the muscle fiber is elongated, and in this case, the strength of the muscle fiber is approximately equal to the contractile force of the muscle fiber. If the muscle fiber length is greater than the ideal muscle fiber length, active strength decreases gradually with increasing muscle fiber length, whereas passive strength increases approximately exponentially with increasing muscle fiber length [15].

4. Construction and control method of limb rehabilitation system

4.1. Design requirements for limb rehabilitation devices

Muscle rehabilitation training should include the movement of each joint as much as possible. This article mainly analyzes the muscle characteristics of the biceps and triceps. Because the muscles of the elbow, biceps, and triceps are primarily used, rehabilitation training focuses primarily on elbow movements, including wrist movements as well as shoulder movements.

4.2. Design of limb rehabilitation device

4.2.1. Selection of the motor

The motor used in this paper is a rare earth permanent magnet wide-speed DC motor. The motor has a higher torque-to-inertia ratio, which makes the system respond faster and generate greater acceleration, with external load balancing [16]. The motor parameters used in this paper are shown in **Table 1**.

Table 1. Motor parameters.

Name	**Rare earth permanent magnet wide speed control DC motor**
Model	82SYXB
Power (W)	250
Rated voltage (V)	48
Rated torque (N·m)	0.83
Rated speed (r/min)	3000
Current (A)	7

4.2.2. Analysis of limb rehabilitation device model

In the rehabilitation system, the output torque of the DC motor is driven by the armature current. The rehabilitation system is mainly composed of the motor armature circuit model and the force balance formula of the transmission mechanism [17].

A. The armature circuit model of the motor

The voltage formula is:

$$L_a \frac{di_a}{dt} + R_a i_a + e = U \tag{18}$$

$$e = C_e \dot{\theta_m} \tag{19}$$

e is the back electromotive force, U is the armature voltage, i_a is the armature current, and $\dot{\theta_m}$ is the angular velocity of the DC servo motor shaft.

B. Moment formula

$$T_m = C_m \cdot i_a \tag{20}$$

C_m is the torque constant of the DC servo motor; T_m is the driving torque.

C. Force Balance formula

$$T_m - T_L = J_m \cdot \ddot{\theta_m} + B_m \cdot \dot{\theta_m} \tag{21}$$

T_L is the load moment.

Equations (18) and (19) can be combined for pull transformation to obtain the electric circuit model of the DC motor:

$$I_a(s) = \frac{U(s)}{L_a \cdot s + R_a} - \frac{C_e \cdot \dot{\theta_m}(s)}{L_a \cdot s + R_a} \tag{22}$$

Equations (20) and (21) can be combined to obtain the motor current and speed model:

$$\dot{\theta_m}(s) = \frac{C_m}{J_m \cdot s + B_m} I_a(s) - \frac{T_L}{J_m \cdot s + B_m} \tag{23}$$

According to Equations (22) and (23), the DC motor servo system model can be obtained.

D. Model of screw nut mechanism

The displacement and torque transfer functions of the rehabilitation equipment handle are:

$$L(s) = \frac{L_0}{2\pi} \cdot \frac{T_i(s)}{s \cdot (J_e \cdot s + B_e)} \tag{24}$$

$T_i(s)$ is the torque applied by the motor to the lead screw, andL(s) is the movement displacement of the rehabilitation handle.

According to the differential formula, the transfer function between the output motion of the rehabilitation device handle and the input armature voltage of the DC motor is:

$$G(s) = \frac{L(s)}{U(s)} \tag{25}$$

4.3. Passive controller design and simulation

Passive training is a relatively mature rehabilitation training program, and the main training method is to fix the patient's limbs on the rehabilitation device [18]. When moving the rehabilitation device, the limbs move along a predetermined path. Commonly used rehabilitation trajectories are straight lines, circles, eight symbols, etc., and the planned trajectory can be reliably tracked through the position closed loop. To improve the responsiveness of the system, passive training uses dual position and velocity controllers. The block diagram of the control system is shown in **Figure 5**.

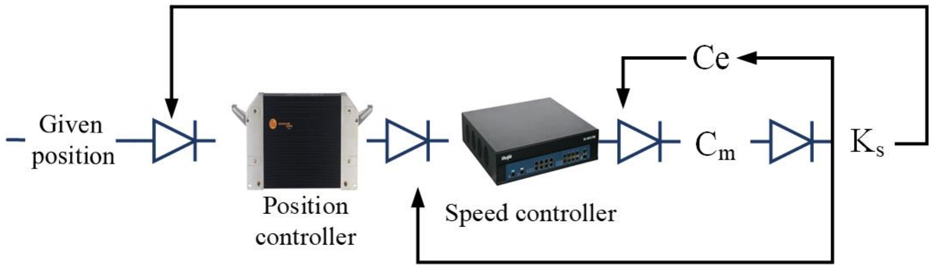

Figure 5. Passive controller control system block diagram.

4.4. Active controller design and simulation

Active training is mainly aimed at patients who can basically achieve a certain degree of voluntary contraction after recovery. The main purpose of this stage is to increase muscle strength and gradually perform some functional movements independently [19]. During active exercise, the limb will actively grasp the end handle of the rehabilitation device, so that the system can provide constant resistance through a closed circuit.

For limb rehabilitation devices, there are direct and indirect methods to achieve force control. The direct method uses a force sensor at the end of the circuit to sense the terminal pressure and then measure the terminal resistance. The indirect method uses a current chip on the control board to determine how the motor works. For a DC motor, the armature current is proportional to the motor torque, so torque can be indirectly controlled through current control. In the limb rehabilitation instrument, the measurement result of the force sensor depends on the position of the active force application, and it is difficult to achieve more control because its accuracy is not as good as that of the current chip. Therefore, an indirect method is used to realize the force closed loop, and the control principle block diagram is shown in **Figure 6**.

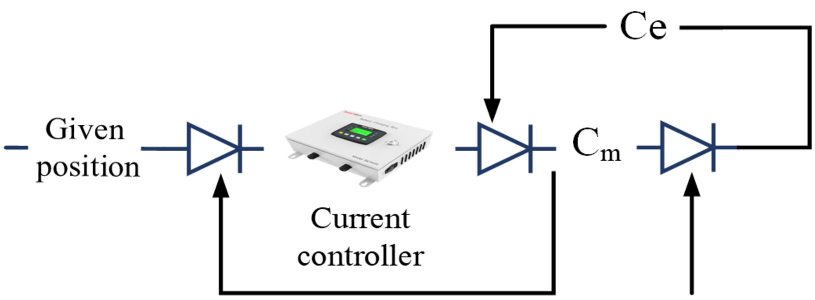

Figure 6. Block diagram of active controller control system.

4.5. Design of synovial variable structure controller

When the handle of the rehabilitation device makes the limbs perform rehabilitation exercises, tension is generated between the limbs and the handle. This part of the tension is very helpful to restore the patient's muscle strength, but at the same time this part of the tension can interfere with the movement of the rehabilitation equipment [20]. The sliding mode rehabilitation device adopts a variable structure control method to ensure the stability of the movement of human limbs. The principle block diagram of the sliding mode variable structure is shown in **Figure 7**.

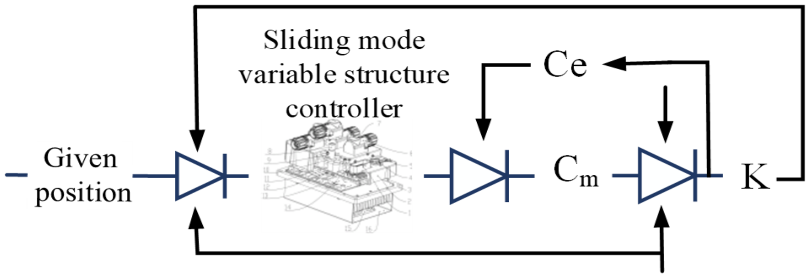

Figure 7. Block diagram of sliding mode variable structure.

5. Muscle rehabilitation training

This paper selects 188 athletes with muscle injuries received by a local top three hospital from October 2022 to December 2023 as research subjects, and uses a blind selection method to divide the experimental group and the control group to ensure that patients and researchers are unaware of the experimental treatment and the control treatment, thereby reducing the interference of subjective bias on the results. First, patients were selected randomly, and then these patients were divided into experimental groups and control groups, with 94 patients in each group. The comparison between the two groups of patients in terms of condition, age, gender, etc. was not significant, and the difference was not statistically significant ($P > 0.05$), which was comparable. During the experiment, the researchers treated and observed in a blind state to ensure the objectivity and reliability of the results. Among them, the experimental group used the limb rehabilitation device model of this paper for muscle rehabilitation training, and the control group used conventional rehabilitation training methods to compare and analyze the differences in the total activity range score and rehabilitation nursing satisfaction rate of the two groups of patients during rehabilitation training.

The total active range of motion scores of the two groups of patients are shown in **Figure 8**.

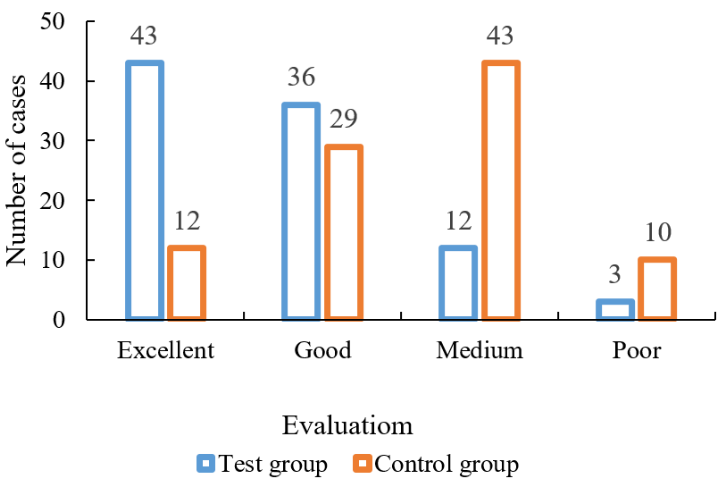

Figure 8. Joint total active range of motion score results.

From the data, it can be seen that 43 patients in the experimental group believed that the rehabilitation status of the total range of motion of the joints was excellent, while 36 patients believed that the rehabilitation status of the total range of motion of the joints was good. 12 patients believed that the total range of motion of the joint was moderate, while 3 patients believed that the recovery of the total range of motion of the joint was poor. The excellent rate of the total active activity range of the experimental group is 84.04%. In the control group, 12 patients believed that the total range of motion of the joints was good, while 29 patients believed that the total range of motion was good. 43 patients believed that the total active range of motion of the joints was moderate, while 10 patients believed that the recovery of the total active range of motion of the joints was poor. The excellent rate of the total activity range in the control group was 43.61%. Comparing the data, it can be found that the excellent rate of the total active range of motion of the experimental group is significantly higher than that of the control group, and the excellent rate of the total active range of motion of the joints has increased by 40.43%, indicating that the limb rehabilitation device designed using OpenSim technology can recover muscle injuries more quickly and effectively.

The rehabilitation nursing satisfaction of the two groups of patients is shown in **Figure 9**.

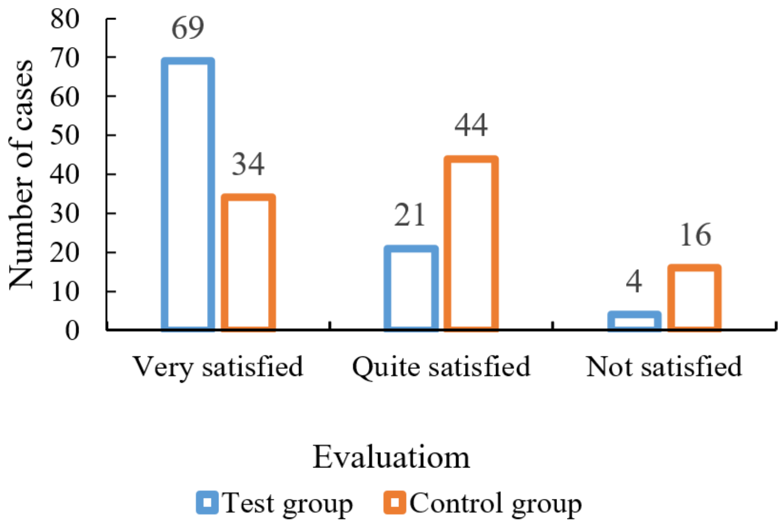

Figure 9. Rehabilitation nursing satisfaction.

From the data, it can be seen that 69 patients in the experimental group were very satisfied with rehabilitation care, while 21 patients were relatively satisfied with rehabilitation care. Four patients were dissatisfied with rehabilitation nursing, and the satisfaction rate of rehabilitation nursing in the experimental group was 95.75%. In the control group, 34 patients were very satisfied with rehabilitation nursing, 44 patients were relatively satisfied with rehabilitation nursing, and 16 patients were dissatisfied with rehabilitation nursing. The satisfaction rate of rehabilitation nursing in the control group was 82.98%. Comparing the data, it can be found that the satisfaction with rehabilitation nursing in the experimental group is significantly higher than that in the control group, with an increase of 12.77% in satisfaction with rehabilitation nursing. The results indicate that the limb rehabilitation device designed using OpenSim technology can provide patients with more comfortable and convenient rehabilitation training, and the training effect is more satisfactory to patients.

6. Discussion

Athlete muscle injury rehabilitation management based on OPSIM technology does have significant advantages in improving the rehabilitation effect and the recovery speed of athletes. However, its cost-effectiveness issues cannot be ignored, especially considering that the required technology and equipment may be quite expensive. For many athletes, especially individuals who lack strong financial support, the high cost of rehabilitation may become a huge obstacle, restricting their access to the latest technology and equipment, thereby affecting the choice and effectiveness of rehabilitation. Therefore, when introducing OPSIM technology or any other new technology, it is essential to conduct a comprehensive cost-benefit analysis. We need to delve into the balance between the long-term benefits of these technologies and short-term investment to ensure that the investment can bring the expected return.

The rehabilitation process does not only rely on technology. Excessive dependence may ignore other important aspects of rehabilitation, such as psychological support, nutritional intake, and manual treatment. These elements also play an important role in the recovery process of athletes. Therefore, when adopting OPSIM technology, efforts should be made to combine it with other non-technical rehabilitation methods to create a comprehensive, multi-dimensional rehabilitation plan. Such a plan can not only make full use of the advantages of technology, but also ensure that athletes receive comprehensive support and attention in psychological, nutritional and physical therapy. It is essential to pay attention to the mental state of athletes in the rehabilitation process. Providing psychological support and counseling can help them better cope with the challenges and difficulties in the rehabilitation process, reduce excessive dependence on technology, and thus improve the overall rehabilitation effect. By considering technical and non-technical methods comprehensively, we can achieve a more comprehensive and effective rehabilitation management of athletes.

7. Conclusion

This paper uses OpenSim technology to design a limb rehabilitation device to study the rehabilitation management of sports athletes' muscle injury. The experimental results show that the limb rehabilitation device is effective, the excellent rate of total active range of motion of joints and nursing satisfaction have been improved, which proves the validity of this research. However, for this research, there is still some work to be improved, including the acquisition of more accurate limb model parameters, the influence of intramuscular environmental factors on muscle force, etc.

In order to better understand the relationship between the muscle environment and muscle strength and recovery, we need to carry out further biochemical and physiological research. Pay attention to the biochemical characteristics of muscle fiber types, metabolic processes, and energy supply. These factors directly affect the production and recovery of muscle strength. By monitoring physiological indicators such as muscle electrical activity, metabolic changes, and mechanical properties in real time, we can more accurately assess the degree of muscle injury and recovery process.

The inflammatory response plays an important role in the recovery process after muscle injury. We need to delve into how the inflammatory response affects the repair and regeneration of muscle tissue, and how to optimize the rehabilitation process by regulating the inflammatory response. Explore the effects of different anti-inflammatory drugs or physical therapy methods on inflammation and muscle recovery, and provide athletes with more effective rehabilitation strategies. We also need to pass more in-depth biochemical and physiological research, we can more comprehensively understand the relationship between muscle environment and muscle strength and recovery, and provide more accurate and effective guidance for athletes' muscle injury rehabilitation management.

Author contributions: Conceptualization, NZ and HH; methodology, NZ; software, HH; validation, NZ and HH; formal analysis, NZ; investigation, HH; resources, HH; data curation, HH; writing—original draft preparation, NZ; writing—review and editing, HH; visualization, HH; supervision, NZ; project administration, NZ; funding acquisition, HH. All authors have read and agreed to the published version of the manuscript.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

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