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Functional recovery of athletes through rehabilitation training after anterior cruciate ligament reconstruction

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Abstract:
Purpose: This paper aims to introduce neuromuscular electrical stimulation into rehabilitation training following anterior cruciate ligament reconstruction and to assess its impact on the functional recovery of the knee joint.
Methods: Twenty athletes undergoing anterior cruciate ligament reconstruction were allocated into the neuromuscular electrical stimulation group (neuromuscular electrical stimulation + rehabilitation training) and the conventional group (conventional rehabilitation training) for a ten-week training program. Indicators such as Lysholm scores and thigh circumference were assessed before and after the training for comparison.
Results: After the training, the neuromuscular electrical stimulation group demonstrated a Lysholm score of 86.56 ± 11.67 points, a thigh circumference on the affected side of 47.15 ± 2.56 cm, and an active knee flexion angle of 105.12 ± 9.87°. Moreover, the score of the Y-balance test under left and right foot support was 93.67 ± 0.43 points and 91.72 ± 0.48 points, respectively. It achieved a ten-meter walk speed of 1.01 ± 0.15 m/s. It achieved a performance of 264.39 ± 29.36 cm in three consecutive single-leg jumps on the healthy side and a performance of 178.16 ± 21.26 cm on the affected side. Its anterior cruciate ligament-return to sport after injury scale score was 84.21 ± 5.32 points. These outcomes were significantly superior to those of the conventional group.
Conclusion: Neuromuscular electrical stimulation combined with rehabilitation training yields positive effects on post-anterior cruciate ligament reconstruction functional recovery, surpassing the outcomes of conventional rehabilitation training. This approach holds promise for practical application.
Keywords: rehabilitation training, anterior cruciate ligament reconstruction, functional recovery, knee joint

1. Introduction

Knee injuries are a common occurrence among athletes [21], and anterior cruciate ligament (ACL) injuries are a particularly severe type of knee injury and prevalent in sports such as basketball, soccer, and skiing [11]. ACL injuries can significantly impact knee joint function, resulting in symptoms such as swelling and instability [18]. ACL reconstruction is a treatment for ACL injuries [7], and its post-surgical recovery is quite important. Hsu et al. [16] explored the effects of progressive resistance training on kinematics, kinetics, and muscle strength in patients with anterior cruciate ligament reconstruction (ACLR). They found that this training could significantly improve the symmetry of knee extensors, the vertical jump height of a single leg, and the maximum knee flexion angle after landing, and it was superior to the control group in all indicators. Curley et al. [6] analyzed the effectiveness of early use of blood flow restriction training (BFRT) combined with low-intensity exercises in the rehabilitation period following ACLR. Through a randomized controlled trial, they found that BFRT might accelerate the rehabilitation after ACLR, improve quadriceps strength, and relieve postoperative pain. Niederer et al. [23] explored the effects of neuromuscular performance intervention (Stop-X) on late-stage recovery following ACLR, reporting increased confidence in returning to the sport, reduced knee-related pain issues, and improved daily activity performance in the Stop-X group. Ananias et al. [2] investigated the use of electromyographic biofeedback in ACLR rehabilitation. Through systematic review and meta-analysis, it was found that electromyographic biofeedback can improve knee extension and balance. Postoperative rehabilitation training has a great impact on the functional recovery of the knee joint [24]. Neuromuscular electrical stimulation (NMES), a rehabilitation technique that involves stimulating muscle groups via electrodes to induce muscle contractions and enhance functional recovery, has been widely used in the rehabilitation field [1]. This study introduced NMES into post-ACLR rehabilitation training to examine its impact on post-ACLR functional recovery in athletes, providing a theoretical foundation for ACLR rehabilitation and some references for future applications of NMES in sports rehabilitation.

2. Study subjects and methods

2.1 Study subjects

Athletes who attended an orthopedic hospital in Hainan Province and underwent ACLR from 2023 to 2024 were used as experimental subjects, and the specific screening criteria were as follows.

(1) Inclusion criteria

① Unilateral knee ACL injury caused by sports;

② Positive drawer test and Lachman test results [25], ACL injuries under magnetic resonance imaging (MRI);

③ Undergoing arthroscopic autologous hamstring tendon reconstruction of ACL completed by the same physician;

④ Sign the informed consent.

(2) Exclusion criteria

① History of previous ACL injury;

② Presence of other knee injuries;

③ Serious postoperative complications such as infection;

④ Serious cardiopulmonary disease or combination of fractures in other parts of the body;

⑤ Inability to obey the training arrangement.

(3) Dropout criteria

① Re-injury during the experiment;

② Unable to adapt to rehabilitation training;

③ Take the initiative to withdraw.

Based on the aforementioned criteria, a total of 20 eligible athletes were included in the study and randomly divided into two groups. The first group underwent rehabilitation training supplemented with NMES, referred to as the NMES group. In contrast, the second group received only conventional rehabilitation training, designated as the conventional group. The baseline characteristics of the participants are presented in Table 1, showing no statistically significant differences ($p > 0.05$), i.e., the results were comparable.

Table 1 Basic information of athletes

	NMES group (n=10)	Conventional group (n=10)
Gender	Male = 4, Female = 6	Male = 5, Female = 5
Age/year	21.23 ± 1.68	21.26 ± 1.71
Height/cm	175.62 ± 5.68	176.15 ± 6.02
Weight/kg	72.36 ± 12.36	73.29 ± 11.78
Training time/year	5.69 ± 2.23	5.77 ± 2.19

2.2 Rehabilitation training program

After ACLR, the effectiveness of conventional rehabilitation training is often limited due to pain, swelling, and nerve control disorders. As a non-invasive peripheral intervention, NMES can activate the peripheral nerves that innervate the target muscles through electrical pulses, triggering involuntary muscle contractions, thereby breaking muscle inhibition. That is to say, NMES can make up for the limitations of conventional rehabilitation training and is easy to implement clinically. Li et al. [19] found through a systematic review and meta-analysis that for quadriceps weakness after ACL surgery, rehabilitation using NMES can significantly enhance the strength of the quadriceps compared with simple rehabilitation. Currently, there are still relatively few studies on the rehabilitation training effect of NMES after ACLR. The synergistic effect of NMES in the systematic rehabilitation of ACLR athletes still requires high-quality evidence support. Therefore, it is necessary to further prove the role of NMES through experiments. For this reason, this paper selects NMES on the basis of conventional rehabilitation training. Both groups of athletes participated in a ten-week rehabilitation training program, starting from the 3rd week postoperatively and ending at the 12th week postoperatively. The conventional group followed the Postoperative Orthopaedic Rehabilitation Guidelines for their rehabilitation training (Table 2).

Table 21 Rehabilitation training program for the conventional group

Time	Content	Number of groups
Week 2-6 after surgery	Walking exercise; resistance straight-leg raising exercise; weight transfer exercise; stair climbing exercise; weighted knee extension exercise; elastic band-assisted leg curl exercise	10-15 min for each exercise, twice each day
Week 6-12 after surgery	Static squatting exercise; stair descending exercise; split-leg squatting exercise; Balance exercise	10-15 min for each exercise, twice each day

The NMES group utilized the Compex Neuromuscular Electrical Stimulator 8.0 for training, five times a week, each lasting 120 minutes (Table 3).

Table 3 Rehabilitation program for the NMES group

Time	Content	Program	Position of electrical stimulation patch	Duration
Week 2-4 after surgery	Knee mobility training	Sliding wall exercise	The front of the thigh	5 min
		Knee flexion and extension exercises	The front of the thigh	25 min
	Leg muscle strength training	Squatting	The front of the thigh	20 min
		Prone backward and upward calf curl exercise	The back of the thigh	20 min
		Seated resistance	The front of the thigh	15 min

		bicycle exercise		
		Squatting against the wall	The front of the thigh	5 min
	Functional training for adjacent joints	Prone leg raise exercise	Hip	10 min
		Standing heel raise exercise	Calf gastrocnemius	10 min
		Core exercise	Lower back & abdominals	10 min
Week 4-8 after surgery	Knee mobility training	Seated resistance bicycle exercise	The front of the thigh	30 min
	Leg muscle strength training	Lunge squat exercise	The front of the thigh	20 min
		Bridge leg curl exercise	The back of the thigh	20 min
		Squatting against the wall	The front of the thigh	10 min
	Functional training for adjacent joints	Hip bridge exercise	Hip	20 min
		Heel lifts	Calf gastrocnemius	10 min
		Core exercise	Lower back & abdominals	10 min
Week 8-12 after surgery	Knee mobility training	Seated resistance bicycle exercise	The front of the thigh	30 min
	Leg muscle strength training	Lunge squat exercise	The front of the thigh	20 min
		Supine suspension knee curl	The back of the thigh	20 min
		Squatting against the wall	The front of the thigh	10 min
	Functional training for adjacent joints	Weighted hip bridge exercise	Hip	20 min
		Weighted heel lift	Calf gastrocnemius	20 min
		Core exercise	Lower back & abdominals	10 min

2.3 Functional recovery indicator tests

(1) Lysholm score [4]

Test method: Athletes filled out the Lysholm scale to assess knee function.

Test time: before and after rehabilitation training

(2) The thigh circumference of the affected side

Test method: Athletes lay on their backs on a hospital bed. A mark was made at 15 cm above the midpoint of the patella, and the thigh circumference was measured using a tape measure. This process was repeated three times, and the average value was calculated.

Testing time: before and after rehabilitation training

(3) Active knee flexion angle of the affected side

Test method: Athletes lay prone on the hospital bed and actively flexed the knee of the affected side. The joint angle was measured using a . This process was repeated three times, and the average value was calculated.

Test time: before and after rehabilitation training

(4) Y-balance test [14]

Test method: Athletes stood with one foot in the center of the Y-Balance test instrument while pushing the opposite foot out to the front, rear medial, and rear lateral sides. The distances in each direction were recorded. This process was repeated three times, and the best performance was taken.

Test time: After rehabilitation training

(5) Ten-meter walk

Test method: Athletes stood at the starting point of a ten-meter track and began walking upon hearing the starting cue. The timer started counting when the toe of the foot crossed the two-meter mark and stopped when the toe crossed the eight-meter mark. This process was repeated three times, and the best performance was recorded.

Test time: After rehabilitation training

(6) Three consecutive jumps on one leg

Test method: Athletes stood at the starting point and performed three consecutive single-leg jumps with both the affected leg and the healthy leg. The distance jumped was recorded. This process was repeated three times, and the best performance was taken.

Test time: After rehabilitation training

(7) ACL-return to sport after injury (ACL-RSI) scale [15]

Test method: Athletes filled out the ACL-RSI scale to assess their psychological status after returning to sport.

Testing time: After rehabilitation training

2.4 Statistical analysis

The test results were recorded as mean ± standard deviation, and statistical analysis was conducted using SPSS 20.0. Inter-group comparisons were analyzed using an independent samples t-test [22], while intra-group comparisons were analyzed using a paired samples t-test [13], with a significance level set at 0.05.

3. Study results

Table 4 shows no significant difference in the baseline scores between the NMES group and the conventional group, indicating comparability before the intervention. After the intervention, the scores of both groups were significantly higher than those before the training, and the effect size between the groups was extremely large. The inter-group comparison showed that the Lysholm score of the NMES group after training was significantly higher and the effect size between the groups was large.

Table 42 Comparison of Lysholm scores

	Before training	After training	P value	Cohen's d
NMES group	19.56 ± 5.87	86.56 ± 11.67	0.001	7.61
Conventional group	19.89 ± 5.64	74.12 ± 12.03	0.001	6.16
P value	0.146	0.026		
Cohen's d	0.06	1.05		

Table 5 also shows insignificant difference in the circumference between the two groups before training.

After training, the thigh circumference of the NMES group increased significantly compared with that before training, and the inter-group effect size was extremely large. The inter-group comparison showed that the thigh circumference of the NMES group after training was significantly larger, and the inter-group effect size was extremely large.

Table3 5 Comparison of thigh circumference on the affected side (unit: cm)

	Before training	After training	P value	Cohen's d
NMES group	42.36 ± 2.68	47.15 ± 2.56	0.001	1.83
Conventional group	43.01 ± 2.94	43.26 ± 2.77	0.069	0.09
P value	0.089	0.044		
Cohen's d	0.23	1.46		

Table 6 suggests no significant difference in the angles between the two groups before training. After training, the active flexion angle of the affected knee joint in the NMES group increased significantly compared with that before training, and the inter-group effect size was extremely large. The inter-group comparison demonstrated that the active flexion angle of the affected knee joint in the NMES group was significantly larger than that in the conventional group after training, and the inter-group effect size was large.

Table4 6 Active flexion angle of the affected knee joint (unit: °)

	Before training	After training	P value	Cohen's d
NMES group	28.79 ± 8.94	105.12 ± 9.87	0.001	8.11
Conventional group	28.16 ± 8.69	90.21 ± 18.64	0.003	4.48
P value	0.084	0.018		
Cohen's d	0.07	1.01		

In Table 7, the Y-balance test performance of the NMES group were significantly higher than those of the conventional group, and the effect size between the groups was extremely large. There were no significant differences in the performance within the NMES group and the conventional group between the two support conditions.

Table 7 Y-balance test performance

	NMES group	Conventional group	P value	Cohen's d
Left-leg support	93.67 ± 0.43	84.46 ± 0.56	0.002	8.21
Right-leg support	91.72 ± 0.48	83.37 ± 0.62	0.001	8.33
P value	0.067	0.082		
Cohen's d	0.05	0.07		

As shown in Table 8, the ten-meter walking speed of the NMES group was significantly faster than that of the conventional group, and the effect size between the groups was extremely large.

Table 8 Ten-meter walking speed (unit: m/s)

	NMES group	Conventional group	P value	Cohen's d
Ten-meter walking speed	1.01 ± 0.15	0.84 ± 0.12	0.001	5.56

In Table 9, there was no significant difference between the two groups in the healthy-side jump. In the affected-side jump, the performance of the NMES group was significantly better than that of the conventional group, with a large effect size between the groups. The intra-group comparison showed that the performance of the healthy side was better than that of the affected side in both groups, and the intra-group effect was extremely large.

Table5 9 Comparison of three consecutive jumps on one leg (unit: cm)

	NMES group	Conventional group	P value	Cohen's d
Healthy side	264.39 ± 29.36	261.37 ± 29.87	0.067	0.11
Affected side	178.16 ± 21.26	150.36 ± 30.77	0.033	1.05
P value	0.002	0.003		
Cohen's d	8.77	5.45		

As shown in Table 10, the ACL-RSI scale score of the NMES group was significantly higher than that of the conventional group, and the effect size between the groups was extremely large.

Table 10 Comparison of ACL-RSI scale scores

	NMES group	Conventional group	P value	Cohen's d
ACL-RSI scale score	84.21 ± 5.32	68.97 ± 4.17	0.001	7.64

4. Discussion

Joint pain and functional limitations are common after ACLR [12]. For athletes who want to return to the playing field as soon as possible, the rehabilitation training after ACLR is particularly important [17]. The goal of rehabilitation after ACLR is to help the transplanted ligaments adapt to the athlete's body environment and restore the function of the knee joint.

The Lysholm score can comprehensively evaluate the knee joint function after ACLR [10]. After ACLR, due to inflammation, limited mobility, and other factors, there will be a certain degree of atrophy in the muscles around the knee joint [26]. Measuring the thigh circumference can reflect the recovery status of the thigh muscles. After ACLR, the internal environment of the knee joint is disrupted. Under the influence of inflammation, the range of motion of the knee joint is restricted [5]. The Y-balance test can well reflect the body's dynamic balance ability. It is applied in the assessment of ankle instability and other conditions and can effectively reflect the flexibility and stability of joints. Walking speed reflects the body's walking function. After ACLR, under the influence of joint pain and decreased control ability, the body's gait will be abnormal [3], and the walking speed will slow down. Jumping ability is also an important function of the human body, and the ACL-RSI scale score can reflect the athletes' confidence in returning to sports. The experimental results demonstrated that the NMES group showed significant advantages in multiple functional indicators. This finding is somewhat similar to the research conclusions in existing literature regarding the role of NMES in post-orthopedic surgery rehabilitation.

The research by Mintken et al. [20] shows that early postoperative NMES can relieve quadriceps weakness after total knee arthroplasty (TKA). Compared with single rehabilitation training, it can more effectively reduce the loss of quadriceps torque. The research by Delanois et al. [8] also indicates that receiving NMES after TKA can significantly relieve pain and improve knee joint function. Durigan et al. [9] evaluated the effect of NMES on the extracellular matrix remodeling of the quadriceps femoris after ACL disruption in rats and proved the benefits of NMES. Zhang et al. [28] evaluated the role of NMES in post-shoulder-surgery rehabilitation and found that NMES has advantages in pain management. Windley [27] pointed out that NMES can be used as an effective tool to enhance the muscle strength of athletes during orthopedic injury rehabilitation. The results of this study showed that the NMES group achieved significantly better results than the conventional group in terms of Lysholm score, thigh circumference, and knee joint range of motion, which further verifies the role of rehabilitation training combined with NMES and also demonstrates the effectiveness of this training program in the rehabilitation of athletes after ACLR.

However, the research in this paper also has some limitations. For example, the small sample size restricted the generalizability of the research results. The individualized optimization of NMES parameters, such as frequency and pulse width, was not explored in depth in the research, which affects the maximization of the intervention effect. Moreover, the follow-up time was short, resulting in a lack of medium- and long-term follow-up data. It is unclear whether the rehabilitation protocol combined with NMES can bring more lasting curative effects, and the potential physiological mechanism of the curative effect produced by NMES was not explored in depth. Therefore, in future work, these aspects need to be improved to further explore the curative effect of NMES on knee joint function recovery.

5. Conclusion

This study examined the impact of combining NMES with rehabilitation training on post-ACLR knee function recovery in athletes. After ten-week rehabilitation, it was observed that the NMES group exhibited a higher Lysholm score, an improved thigh circumference, an increased knee flexion angle, an enhanced balance, walking, a better jumping ability, and a higher ACL-RSI scale score compared to the conventional group. These findings highlight the positive impact of NMES in combination with rehabilitation training on functional recovery, suggesting its application potential in rehabilitation programs.

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