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Article

Bioelectrical stimulation therapy for muscle injuries in aerobics athletes

Jian Chen

Department of Physical Education, College of Engineering and technology, Chengdu University of Technology, Leshan 614000, China; chenjian_1124@163.com

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Abstract: This article aims to explore the recovery effect of the bioelectrical stimulation therapy on muscle injuries in aerobics athletes. Non-invasive medical techniques are adopted to activate muscle tissue through electrical currents, promoting muscle contraction ability and functional recovery. This article selects 100 aerobics athletes with muscle injuries through questionnaire surveys and interviews. The Modulo Plus electrical stimulation device is used, and personalized treatment plans are set. Muscle changes before and after treatment are monitored using electromyography and ultrasound technology. In the single-blind experiment, in the fourth week, the pain score of the experimental group decreases to 2.4 points; the functional recovery score increases to 75.2 points; the flexibility measurement reaches 19.2 cm. In the case-control study, the bioelectrical stimulation therapy cures all athletes in the sixth week, exceeding the conventional therapy's 35 patients, and has a lower recurrence rate. In the cohort study, athletes who use the bioelectrical stimulation therapy for a long time have a shorter average recovery time of 15.3 days and a recurrence rate of 16%. In the muscle recovery experiment, in the eighth week after treatment, the electromyographic activity level of the experimental group increases to 58.6 μV; the muscle thickness increases to 4.3 mm; the echo intensity increases to 63.1 dB; the fatigue characteristic score drops to 2.1. These data indicate that the bioelectrical stimulation therapy has significant effects in reducing pain, promoting functional recovery, improving flexibility, shortening recovery time, and reducing recurrence rates and pain scores, thereby providing an effective treatment option for the recovery of muscle injuries in aerobics athletes.

Keywords: bioelectrical stimulation therapy; muscle injury; functional recovery; pain score; recurrence rate

1. Introduction

Muscle injury is a common challenge faced by aerobics athletes, which not only affects their training quality but may also have a negative impact on their performance in competitions. As a non-surgical treatment method, bioelectrical stimulation therapy has begun to receive attention due to its potential in promoting muscle healing and relieving pain. However, current research has limitations in sample size, study design, and efficacy evaluation, which restrict the comprehensive validation of the clinical efficacy and safety of the bioelectrical stimulation therapy. Therefore, there is an urgent need for more rigorous and systematic research to establish the effectiveness of the bioelectrical stimulation therapy. This article explores the clinical effect of the bioelectrical stimulation therapy on the recovery of muscle injuries in aerobics athletes and analyzes and verifies its therapeutic potential and effectiveness. Although this study focused on aerobic athletes, the principles and effects of bioelectrical stimulation therapy may be equally applicable to athletes with other forms of exercise and patterns of muscle use. Future studies should consider individuals with different motor backgrounds to assess the broad applicability of this therapy.

The contribution of this article is to systematically evaluate the therapeutic effect of the bioelectrical stimulation therapy on muscle injuries in aerobics athletes. Through large-scale sample studies, precise injury assessments, and multidimensional data analysis, scientific evidence of the effectiveness of the bioelectrical stimulation therapy is provided, supporting clinical applications and promoting further research and development in the field of bioelectrical medicine.

The structure of this article is as follows: firstly, the introduction section outlines the prevalence of muscle injuries among aerobics athletes and the importance of the bioelectrical stimulation therapy; related works are reviewed, and the findings and limitations of previous research are summarized; the implementation steps of the bioelectrical stimulation therapy is introduced in detail, including case screening, equipment setup, personalized adjustment, and physiological mechanism research; the efficacy of the therapy is comprehensively evaluated through single-blind experiments, case-control studies, cohort studies, and muscle recovery experiments; finally, based on the comprehensive analysis of the experimental results, a conclusion is drawn, and the application prospects of the bioelectrical stimulation therapy in muscle injury recovery are discussed.

2. Related work

In aerobics, athletes often suffer muscle injuries during training and competition, which have a serious impact on their career and athletic performance. There are numerous studies on muscle injuries, and researchers have made various explorations for the health of athletes [1–3]. Boivin [4] discovered that platelet-rich plasma could promote muscle injury repair by releasing growth factors and exosomes. Therefore, he summarized some recent studies on the use of platelet-rich plasma in vitro and clinical fields related to muscle healing, aiming to explore repair methods for muscle injuries. Farrell [5] systematically evaluated the diagnosis, treatment, and prevention of acute adductor muscle injury and found that both non-surgical and surgical treatments were acceptable, emphasizing the importance of the physical therapy in restoring athlete function. Contreras [6] revealed that the combination of muscle precursor cell transplantation and early exercise training could significantly promote the recovery of skeletal muscle injury in rats, providing a new strategy for the treatment of human muscle injury. Ostrowski et al. [7] explored the diagnostic challenges of drug-induced myopathy and proposed a biomarker-based monitoring strategy to improve drug safety and early identification of muscle injuries. Xu [8] explored multiple possible causes of elevated transaminase levels in patients with COVID-19, suggesting that heart and muscle injuries might be factors leading to elevated transaminase levels, providing a new perspective for clinical evaluation and treatment. Adidharma [9] reviewed the mechanisms of muscle sensory nerve regeneration and reinnervation, as well as their applications in clinical treatment, with the aim of promoting motor control recovery and improving muscle function. Ekstrand [10] revealed that the incidence and burden of hamstring injuries in professional football players increased over time, and analyzed the trend, location, mechanism, and recurrence rate of injuries, providing a basis for prevention and treatment. Chan et al. [11] explored the effects of smoking on skeletal muscle injury and repair processes in patients with chronic obstructive pulmonary disease, and found that smoking exacerbated muscle injury and inflammatory response but had little effect on the recovery process. The above researches have explored the comprehensive study of muscle injuries from different perspectives, providing scientific basis for the prevention, treatment, and functional recovery of muscle injuries in athletes and patients. However, these studies often overlooked the importance of long-term tracking and personalized treatment, and the sample size was small, making it difficult to generalize to a wider range of athlete populations.

The bioelectrical stimulation therapy is an innovative non-invasive medical technique that uses electrical currents to activate nerve or muscle tissue, thereby promoting muscle contraction and functional recovery. Compared with conventional physical therapy methods, the bioelectrical stimulation therapy has demonstrated several significant advantages, such as precise targeting, promoting blood circulation, and improving safety and comfort [12–14]. Lee [15] reviewed the potential and applications of microcurrent stimulation in bioelectronics medicine, emphasizing its effectiveness and innovation in promoting physiological processes and treating various diseases. Lee [16] explored the potential of bioelectrical medicine in treating various diseases, emphasizing the importance of closed-loop systems and personalized treatment, and looking forward to the future development of this field. Zulbaran [17] preliminarily confirmed the effectiveness, feasibility and high compliance of home electrical stimulation therapy as an auxiliary therapy in accelerating the healing of chronic diabetic foot ulcers. Zhao [18] discussed the current status and challenges of the application of electrical stimulation in the biomedical field, pointing out the importance and potential of understanding its cellular mechanisms and optimizing clinical applications. Madane [19] explored the potential application of bioelectronics medicine in non-pharmacological treatment fields, emphasizing its innovative treatment methods that went beyond symptom management and utilized the body's self-healing mechanisms. Gao [20] evaluated the clinical efficacy of the biomimetical electrical stimulation therapy in the treatment of postpartum diastasis recti abdominis, providing a potential effective treatment for this condition. Xu [21] explored the effects of biofeedback electrical stimulation therapy combined with pelvic floor muscle training on postpartum pelvic floor muscle tissue status and functional rehabilitation. The results showed that this therapy could effectively improve tissue status and pelvic floor muscle function. Wu Fei's research [22] confirmed that the combination of electrical stimulation biofeedback and comprehensive exercise therapy had significant therapeutic effects on middle-aged and elderly women with mild to moderate stress urinary incontinence, effectively improving their quality of life and pelvic floor muscle strength. The bioelectrical stimulation therapy has shown significant effects and potential applications in promoting muscle contraction, accelerating wound healing, improving pelvic floor muscle function, and enhancing quality of life, providing a new treatment option for the recovery of muscle injuries in aerobics athletes.

3. Specific implementation of the bioelectrical stimulation therapy

3.1. Case screening and statistics

Among the group of aerobics athletes participating in the study, athletes with muscle injuries are selected through questionnaire surveys and face-to-face interviews. The questionnaire survey provides detailed records of athletes' injuries during recent training and competitions, including the injured part, the specific environment in which the injury occurred, and the level of pain. The interview session is conducted by professional physicians to further confirm the reported injuries in the questionnaire, ensure their authenticity, and assess their severity. A total of 100 aerobics athletes are selected for this study, and their injured part and injury environment statistics are shown in **Table 1**.

Table 1. Statistics of the injured part and the injury environment.

Injured part	Number of people	Injury environment	Number of people
Waist	31	Injured in back bend movements during the training	18
Shoulder	19	Injured while performing handstands during the competition	28
Leg	28	Sprained in the warm-up running during the training	13
Abdomen	12	Injured while rotating during the competition	26
Back	10	Activity-related strain during the training	15

From **Table 1**, it can be seen that among the 100 aerobics athletes in this study, the highest number of athletes with waist injuries is 31. This is one of the more common part of injury in aerobics and is associated with high-intensity back bend movements. The number of injuries to the abdomen and back is relatively small, with 12 and 10 people respectively. In the statistics of injury environments, handstands and rotations during competitions are the main environments in which athletes are injured, with 28 and 26 injured respectively. Overall, the high-difficulty movements in competitions are the main cause of muscle injuries for aerobics athletes, with the waist and legs being the high-risk parts for injuries.

The visual analogue scale method is used [23,24], and the pain level of athletes after injury is statistically analyzed. The statistical results are shown in **Figure 1**.

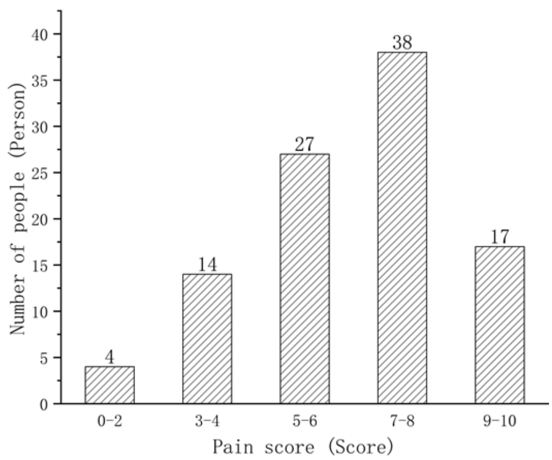

Figure 1. Score statistics of pain severity.

In the visual analogue scale method, 0 points indicate no pain, and 10 points indicate severe pain. According to the statistical data shown in **Figure 1**, it is observed that the number of aerobics athletes with pain levels of 7 to 8 is the highest, with a total of 38. Following closely behind are pain levels of 5 to 6, involving 27 athletes. These data indicate that most injured aerobics athletes experience severe pain.

In the injury assessment of 100 athletes, professional rehabilitation doctors conduct detailed physical examinations using muscle palpation techniques to determine the specific location, scope, and severity of the injury. In imaging examinations, ultrasound technology is used to provide dynamic observation of the part of injury, and magnetic resonance imaging reveals the specific location and severity of the injury in depth. Functional testing includes isokinetic muscle testing and flexibility assessment, quantifying the degree of muscle functional injury and providing scientific basis for the bioelectrical stimulation therapy.

After the injury assessment is completed, a detailed medical history record is compiled for each aerobics athlete. The record includes basic information of the athlete (age, gender, training years), injury details, past injury and rehabilitation history, as well as treatment history (physical therapy, drug therapy and their effects). All information is recorded and managed through an electronic medical record system to ensure data integrity and accuracy, and the privacy is protected through encrypted storage, with regular backups to prevent data loss.

To ensure the accuracy of the experimental results, each aerobics athlete undergoes a comprehensive physical examination, including complete blood count, biochemical tests, and electrocardiogram. Blood tests monitor blood indicators to rule out health problems such as anemia or infection. Electrocardiogram evaluates heart function to ensure no risk of heart disease. These physical examination measures ensure the health status of athletes during the experiment and improve the reliability of experimental data. Neurological examination is performed by a neurologist to examine the athlete’s neural reflexes and sensory function, ensuring that there are no neurological disorders. More in-depth specialized examinations are conducted for athletes with special medical history or abnormal results found during physical examinations. Individuals with abnormal electrocardiogram display need to undergo dynamic electrocardiogram monitoring and cardiac ultrasound examination, and individuals with abnormal complete blood count examination need to undergo further hematological examination.

Before implementing the bioelectrical stimulation therapy, it is necessary to conduct a thorough screening of contraindications for each athlete. Contraindications include the follows:

1) Electronic implants: such as pacemakers, defibrillators, etc., because electrical stimulation may cause the malfunction of these devices.
2) Malignant tumors: Electrical stimulation may promote the growth and spread of tumor cells, so it should be avoided in the tumor area.
3) Serious blood circulation disorders: such as thrombotic phlebitis, because electrical stimulation may aggravate the condition.
4) Infectious diseases: Any local or systemic infection may be aggravated by electrical stimulation and should be avoided at the site of infection or when suffering from systemic infection.

5) Open wounds: Electrical stimulation may cause infection or wound deterioration, so it should be avoided near open wounds.
6) Neurological disorders: such as epilepsy, electrical stimulation may trigger seizures, so it should be used with caution in these patients.
7) Pregnancy: Especially when electrical stimulation is performed in the abdomen and pelvic area, because it may affect the fetus.
8) History of heart disease: including myocardial infarction, arrhythmia, etc., because electrical stimulation may have an impact on heart function.

After a comprehensive evaluation confirms no contraindications, the rehabilitation team develops a personalized treatment plan and conducts pre-treatment and training, including skin cleansing, equipment operation guidance, and psychological preparation.

Prior to the implementation of bioelectrical stimulation therapy, a careful risk assessment is essential to ensure the safety and effectiveness of the treatment process. Equipment failure is the primary concern. Improper maintenance or technical problems that are not identified in time may cause electrical abnormalities, which may cause harm to patients. At the same time, improper operation is also a non-negligible risk, if the operator does not strictly follow the operating guidelines, it may lead to improper electrode position or current setting, increasing the risk of patient discomfort or muscle injury.

In addition, although bioelectrical stimulation therapy is generally considered non-invasive, some patients may be sensitive to the electrode patch or conductive gel components, developing symptoms such as skin swelling, itching, and even developing severe skin inflammation. Therefore, the patient's allergy history needs to be asked in detail before treatment, and the skin condition needs to be closely monitored during treatment to facilitate material replacement or interruption of treatment if necessary.

3.2. Setting of electrical stimulation equipment

According to the needs of muscle injury rehabilitation, it is necessary to choose electrical stimulation equipment with adjustable frequency, adjustable intensity, and diverse waveforms, and the equipment should have overcurrent protection and overheating protection functions. The model selected for this article is Modulo Plus. This equipment has four completely independent stimulation channels, with electrical insulation between each channel. Stimulation can be controlled by current and voltage. Each scheme can consist of a sequence of up to 4 stages, in which waves of different shapes can be used. It is also possible to adjust the current intensity of a single channel or all channels simultaneously, suitable for professional medical use. **Figure 2** shows the interface and connector display of the equipment.

Initial treatment parameters are set, with an initial frequency of 50 Hz (Hertz), suitable for the early rehabilitation stage of most muscle injuries. The initial intensity is set at 30mA and can be fine tuned according to the athlete's tolerance level. The initial waveform adopts a square wave, which has a strong stimulating effect on muscles and is suitable for early rehabilitation.

Figure 2. Interface and connectors of modulo plus.

In the bioelectrical stimulation therapy, conductive adhesive is applied, and electrode patches are placed to ensure optimal contact. Equipment parameters are accurately set. Athlete reactions are continuously monitored, and adjustments are made in a timely manner. The equipment and conductive adhesive is checked before treatment, and the equipment is cleaned after treatment. The function is checked weekly, and the electrode pads and conductive adhesive are replaced regularly.

3.3. Personalized regulation and individual differences

Different aerobics athletes have different physical conditions, and personalized adjustments should be made to each athlete during the treatment process. The process designed in this article is shown in **Figure 3**.

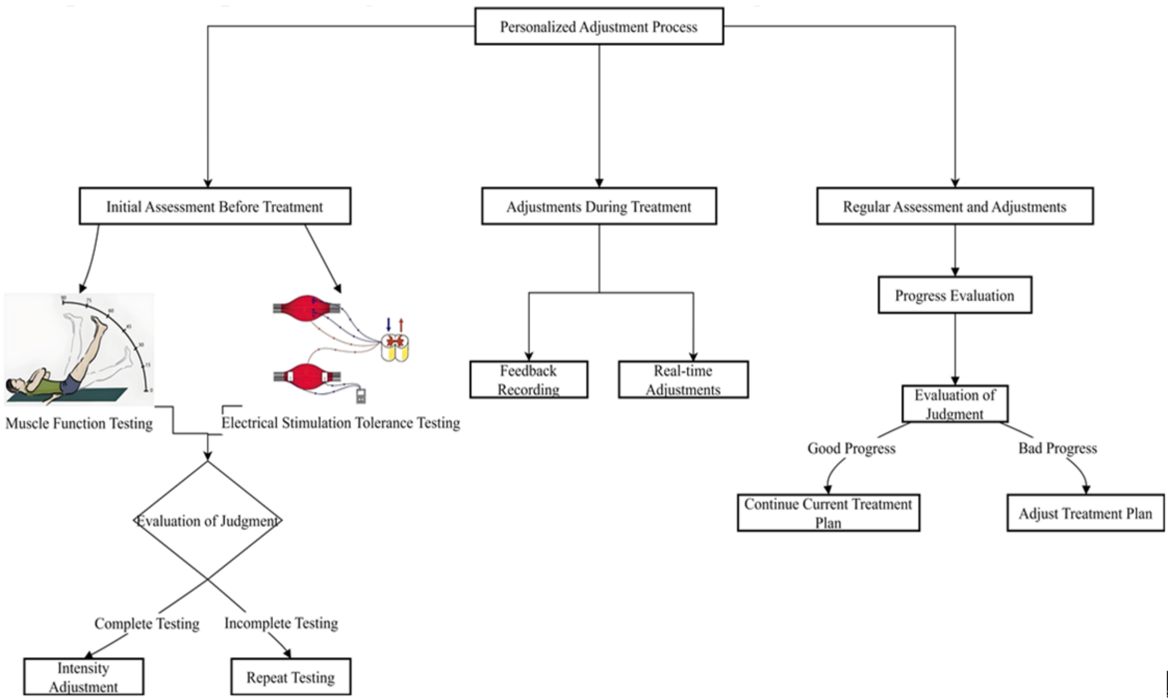

Figure 3. Personalized adjustment process.

The personalized adjustment process includes three main parts: initial treatment assessment, adjustment during the treatment process, and regular evaluation and adjustment. In the initial assessment, muscle injury and rehabilitation needs are evaluated through muscle function testing and electrical stimulation tolerance testing. If the test is passed, the strength is set, and if the test is not passed, retesting is needed.

During the treatment process, feedback after each treatment is recorded, and treatment parameters are adjusted in real time based on feedback and muscle response to ensure optimal results. During the regular evaluation phase, a comprehensive assessment is conducted once a week, including muscle strength, flexibility tests, and pain scores, to evaluate rehabilitation progress. If everything goes smoothly, the current treatment plan is continued, and if the progress is not satisfactory, the treatment plan is adjusted to optimize the effect.

All 100 athletes who participate in the treatment are classified, pain scores before and after treatment, muscle strength data before and after treatment, and the time from the start of treatment to the athletes' return to normal training are recorded. The *t*-test [25,26] is used to compare the differences in pain scores and recovery time among athletes. Simultaneously, multiple regression analysis [27,28] is used to evaluate the independent effects of multiple variables.

The classification of age variables is as follows: youth group (18–25 years old), adult group (26–35 years old), and middle-aged group (36 years old and above). The injured parts are classified as follows: waist, shoulders, legs, abdomen, and back. The degree of injury is divided into the following groups: mild injury group, moderate injury group, and severe injury group.

A feedback mechanism is established to collect athletes' feelings and suggestions through questionnaires and face-to-face interviews. The data is analyzed to identify common problems and individual needs, and targeted adjustments are made. By conducting stratified analysis and personalized adjustments, it is ensured that the bioelectrical stimulation therapy fully considers individual differences and improves treatment effectiveness.

In order to further optimize the parameter setting of bioelectrical stimulation therapy, a model can be calculated in the future to simulate the effect of bioelectrical stimulation on muscle tissue. These models analyze the effects of parameters such as frequency, intensity, pulse width, and treatment duration on the muscle healing process, providing accurate predictions for optimizing treatment parameters. In addition, a comprehensive safety assessment was conducted to monitor possible side effects and long-term effects of bioelectrical stimulation therapy to ensure the safety of the treatment.

3.4. Physiological mechanism

The application of the bioelectrical stimulation therapy in muscle injury repair relies on its physiological effects on muscle tissue. Through physiological mechanism research, the specific effects of electrical stimulation on muscle cells, nervous system, and blood circulation can be revealed, providing scientific basis for optimizing treatment parameters such as frequency, intensity, and waveform, and further improving the effectiveness of therapy. This study can also promote technological development, such as improving electrode materials and signal processing algorithms and enhancing equipment performance. Constructing a scientific theoretical system and elucidating the role of electrical stimulation in muscle repair can contribute to the standardization and normalization of therapies. The research results are widely disseminated through academic exchanges, promoting cooperation, and can be directly applied in clinical practice to guide the optimization of treatment processes and enhance the skills of medical staff.

For aerobics athletes, studying the physiological mechanisms of the bioelectrical stimulation therapy can help quickly restore muscle function, improve athletic performance, prolong their careers, and provide guidance for long-term health management. Studying physiological mechanisms can not only improve treatment efficacy and safety, but also promote technological progress, academic exchanges, and clinical practice guidance, providing guarantees for athletes' health and performance and bringing social and economic benefits.

This article uses electromyography (EMG) [29,30] and ultrasound technology to monitor the effects of the bioelectrical stimulation therapy on muscle tissue and explore its physiological mechanism of promoting muscle repair.

Before treating athletes, surface electrodes are accurately attached according to the anatomical position of the muscles to avoid data errors caused by electrode displacement. The electromyographic activity data at rest is collected as a baseline control. During the process of bioelectrical stimulation therapy, the real-time collection of electromyographic activity data is carried out to record the response of muscles under different stimulation parameters. After each treatment, data should be saved and backed up.

To remove interference and noise, this article uses high-pass filtering to process electromyographic signals [31,32]. The basic formula of a high-pass filter can be expressed by the following difference equation:

$$y[n] = x[n] - \alpha x[n-1] + \beta y[n-1] \tag{1}$$

Among them, $x[n]$ represents the collected electromyographic signals, which record the muscle activity of aerobics dancers during exercise. α and β are cutoff frequencies. This article sets the cutoff frequency to 20Hz, and signals below 20Hz are removed. $y[n]$ is the signals processed by the high-pass filter, which can more clearly reflect the muscle activity of athletes and is not affected by low-frequency noise interference. The electromyographic activity parameters at each time point are calculated. The data during the treatment process is compared, and the impact of the bioelectrical stimulation on muscle activity is evaluated, so as to explore its effect on promoting muscle repair. **Figure 4** shows the effect of high-pass filtering on electromyographic signals.

In **Figure 4**, the effect before and after processing a certain segment of electromyogram using high-pass filtering is shown. The upper figure in **Figure 4** shows the raw electromyogram signals that contain low-frequency components due to baseline drift and interference in athlete muscle activity. Low-frequency noise may affect the accurate analysis of muscle activity. The lower figure in **Figure 4** shows the electromyographic signal after high-pass filtering processing. By filtering out low-frequency components, the baseline drift of the signal is effectively suppressed, thereby preserving high-frequency information of muscle activity. High-pass filtering can more accurately capture and analyze the real electrical activity of muscles, which plays a key role in developing personalized bioelectrical stimulation therapies and promoting muscle injury recovery.

In ultrasound monitoring, professional ultrasound doctors perform ultrasound scans at different time points before, during, and after athlete treatment to obtain real-time images of muscle tissue. Ultrasound images of injured muscles are collected as baseline control before the bioelectrical stimulation therapy. During the treatment process, regular ultrasound images of muscles are collected to observe changes in muscle tissue under different stimulation parameters. The ultrasound images before, during, and after treatment are compared, and they are combined with electromyography data to comprehensively evaluate the effect of the bioelectrical stimulation therapy on muscle repair. **Figure 5** shows some ultrasound images of calf muscles.

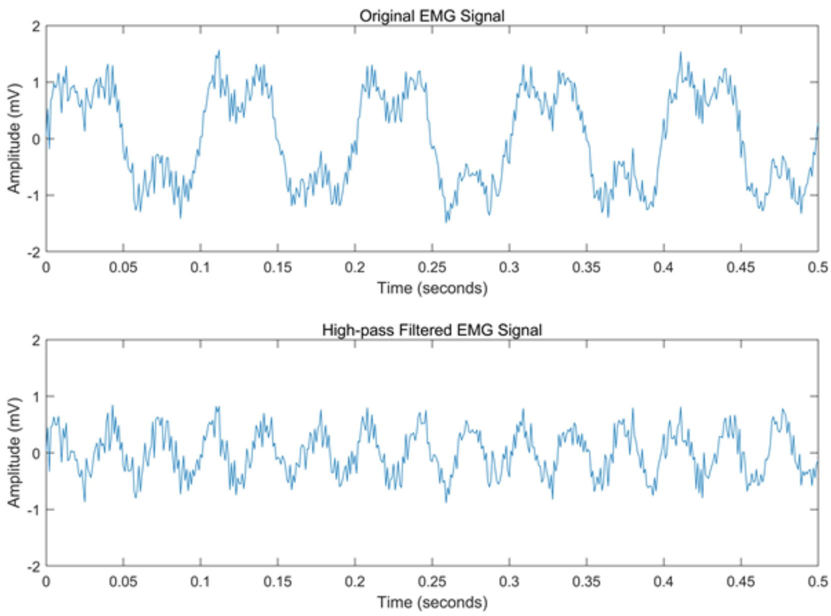

Figure 4. Effect of high-pass filtering.

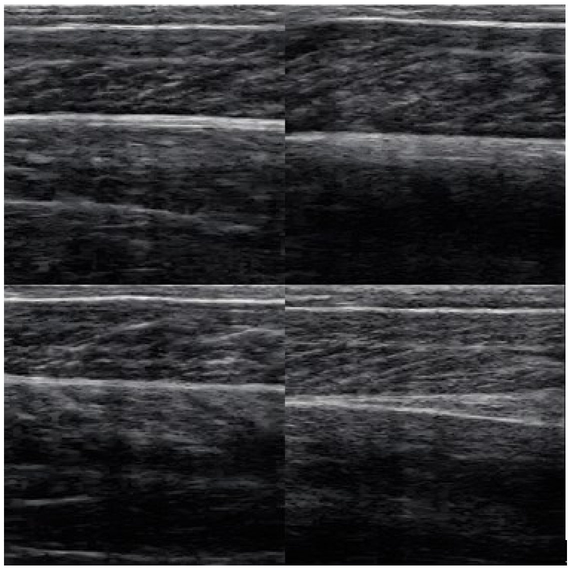

Figure 5. Ultrasound images of calf muscles.

The ultrasound images of the calf muscles in **Figure 5** are obtained from the FASCICLE calf muscle ultrasound dataset. In **Figure 5**, features such as muscle fiber arrangement and muscle thickness can be observed. Ultrasound images can visually demonstrate the repairing effect of the bioelectrical stimulation therapy on injured muscle tissue, providing a basis for evaluating treatment efficacy.

The bioelectrical stimulation therapy utilizes EMG and ultrasound imaging techniques to conduct in-depth research on muscle injuries in aerobics athletes, in order to explore their physiological repair mechanisms. By applying high-pass filtering technology to process electromyographic data, experiments can capture the impact of electrical stimulation on muscle activity. Meanwhile, ultrasound imaging technology provides an intuitive perspective to observe changes in muscle repair during the treatment process. These images not only reveal the positive role of electrical stimulation in promoting muscle fiber rearrangement and muscle layer thickening, but also confirm its importance in muscle injury repair.

In addition, this study adopted an interdisciplinary research approach, combined with in-depth knowledge in the fields of biophysics, biochemistry and bioinformatics, to comprehensively explore the mechanism of action of bioelectrical stimulation therapy. Biophysical analysis allows us to accurately measure the response of muscle tissue to electrical currents; Biochemical studies reveal how electrical stimulation promotes molecular changes during muscle repair at the cellular level; At the same time, the application of bioinformatics tools helped us process and analyze a large amount of data, which led to the identification of key biomarkers that affect muscle recovery.

4. Efficacy evaluation indicators

4.1. Single-blind experiment

To exclude the placebo effect of aerobics athletes [33,34] and verify the true effectiveness of the bioelectrical stimulation therapy on muscle injury, the 100 selected aerobics athletes in this article are randomly divided into an experimental group and a placebo group, with 50 participants in each group. The experimental group receives the bioelectrical stimulation therapy, while the placebo group receives the simulated electrical stimulation therapy. Athletes are unaware of the specific treatment they receive. The treatment lasts for 4 weeks, with 3 treatments per week. Pain score, functional recovery score, and flexibility are recorded and measured once a week. The pain score is calculated using visual analogue scale method (a total of 10 points); the functional recovery score is obtained through a 36-item health survey questionnaire (a total of 100 points); the flexibility is measured by sit and reach test. The statistical measurement results are shown in **Table 2**.

Table 2 shows the pain scores, functional recovery scores, and flexibility measurements of the experimental group and placebo group at different time points in the single-blind experiment. Before treatment, the mean values of each indicator are similar between the two groups. The mean pain score of the experimental group is 7.8 points with a standard deviation of 1.2 points, and the mean pain score of the placebo group is 7.6 points with a standard deviation of 1.4 points. These data indicate that the grouping in this experiment is random. During the treatment process, the pain score of the experimental group gradually decreases, while the functional recovery score and flexibility gradually improves. Especially in the fourth week, in the experimental group, the mean pain score decreases to 2.4 points; the mean score for functional recovery is 75.2 points; the sit and reach data reaches 19.2 cm. However, the changes in indicators in the placebo group are relatively small, and the improvement in indicator performance is related to the body's self-healing. These results indicate that the bioelectrical stimulation therapy has significant effects in reducing pain, promoting functional recovery, and improving flexibility, ruling out the possibility of placebo effects.

Table 2. Results of the single-blind experiment.

Time point of measurement	Group	Pain score	Functional recovery score	Sit and reach (cm)
Before treatment	Experimental group	7.8 ± 1.2	45.3 ± 10.2	12.4 ± 3.5
	Placebo group	7.6 ± 1.4	46.1 ± 9.8	12.7 ± 3.4
The first week	Experimental group	6.5 ± 1.3	52.3 ± 9.5	14.1 ± 3.6
	Placebo group	7.0 ± 1.5	48.5 ± 10.1	13.0 ± 3.5
The second week	Experimental group	5.2 ± 1.3	60.7 ± 8.9	15.8 ± 3.6
	Placebo group	6.5 ± 1.5	52.4 ± 9.5	13.4 ± 3.5
The third week	Experimental group	3.8 ± 1.1	67.8 ± 8.4	17.5 ± 3.6
	Placebo group	6.0 ± 1.6	54.2 ± 9.4	13.6 ± 3.6
The fourth week	Experimental group	2.4 ± 1.0	75.2 ± 8.1	19.2 ± 3.7
	Placebo group	5.8 ± 1.6	55.3 ± 9.3	14.0 ± 3.6

To verify the significance of the statistical results, a *t*-test is performed on the pain score data in the fourth week after treatment. Firstly, the assumptions are set:

Null hypothesis (H0): There is no significant difference in the mean pain scores between the experimental group and the placebo group in the fourth week after treatment.

Alternative hypothesis (H1): There is a significant difference in the mean pain scores between the experimental group and the placebo group in the fourth week after treatment.

The significance level is set to 0.05.

According to the data in **Table 2**, the mean pain score of the experimental group in the fourth week after treatment is 2.4 with a standard deviation of 1, and the mean pain score of the placebo group in the fourth week after treatment is 5.8 with a standard deviation of 1.6. The sample size for both groups is 50. The formula for the T-statistic is:

$$\mathrm{T} = \frac{\overline{\mathrm{X}} - \overline{\mathrm{Y}}}{\sqrt{\frac{\mathrm{S_1}^2}{\mathrm{N_1}} + \frac{\mathrm{S_2}^2}{\mathrm{N_2}}}} \tag{2}$$

Among them, $\overline{\mathrm{X}}$ and $\overline{\mathrm{Y}}$ are the mean values of the experimental group and the placebo group; $\mathrm{S_1}$ and $\mathrm{S_2}$ are the standard deviations of two groups; $\mathrm{N_1}$ and $\mathrm{N_2}$ are sample sizes for two groups. The calculated T is approximately −12.7420. The calculation method for degrees of freedom is:

$$\mathrm{DF} = \mathrm{N_1} + \mathrm{N_2} - 2 \tag{3}$$

After calculation, DF = 98 can be obtained. According to the T-distribution critical value table, in the two-sided test, with a significance level of 0.05 and a degree of freedom of 98, the T-critical value is approximately 1.9845. In this article's statistics, the absolute value of T is 12.7420, which is greater than the critical value. Therefore, the null hypothesis is rejected, and it is believed that there is a significant difference in the mean pain scores between the two groups in the fourth week after treatment. The T-statistic is calculated for each time point of the indicators in **Table 2**, and the results are shown in **Table 3**.

Table 3. Results of T-statistic for multi-time point indicators

Time point of measurement	Pain score T-statistic	Functional recovery score T-statistic	Sit and reach T-statistic
Before treatment	0.7670	−0.3999	−0.4347
The first week	−1.7812	1.9379	1.5491
The second week	−4.6311	4.5085	3.3799
The third week	−8.0119	7.6284	5.4167
The fourth week	−12.7420	11.4097	7.1226

Table 3 shows the T-statistics of pain scores, functional recovery scores, and flexibility measurements at different time points. Before treatment and in the first week of treatment, the T-statistic of each group is less than the T-critical value (1.9845), indicating that there is no significant difference in the data at this time. Since the second week, all indicators show significant improvements. In the second week, the T-statistic of pain score is −4.6311; the functional recovery score is 4.5085; the flexibility is 3.3799. In the fourth week, the T-statistic of pain score is −12.7420; the functional recovery score is 11.4097; the flexibility score is 7.1226. The T-statistic values of the experimental group and the placebo group gradually increase, indicating that the gap between the two groups' data is becoming larger and larger. The experimental results indicate that the bioelectrical stimulation therapy has a significant therapeutic effect on muscle injuries in aerobics athletes, and the possibility of placebo effect is ruled out.

Although the single-blind design of this study reduced the placebo effect, participants' expectations may have had some influence on the results. During the experiment, participants' expectations about the effects of the treatment were collected through questionnaires, and the analysis showed that those who were positive about the treatment reported more significant pain reduction and functional recovery. This suggests that participants' expectations may have contributed to the treatment effect to some extent, a finding that underscores the importance of psychological factors in muscle injury recovery.

4.2. Case-control study

To analyze the effectiveness of the bioelectrical stimulation therapy in the rehabilitation of muscle injuries in aerobics athletes, a 9-week rehabilitation cycle is used to record the current number of rehabilitation patients in the experimental group and the control group, as well as the number of individual relapses per week. The 50 aerobics athletes of the control group receive conventional muscle injury treatment, while the 50 aerobics athletes of the experimental group receive the bioelectrical stimulation therapy. The statistical results are shown in **Figure 6**.

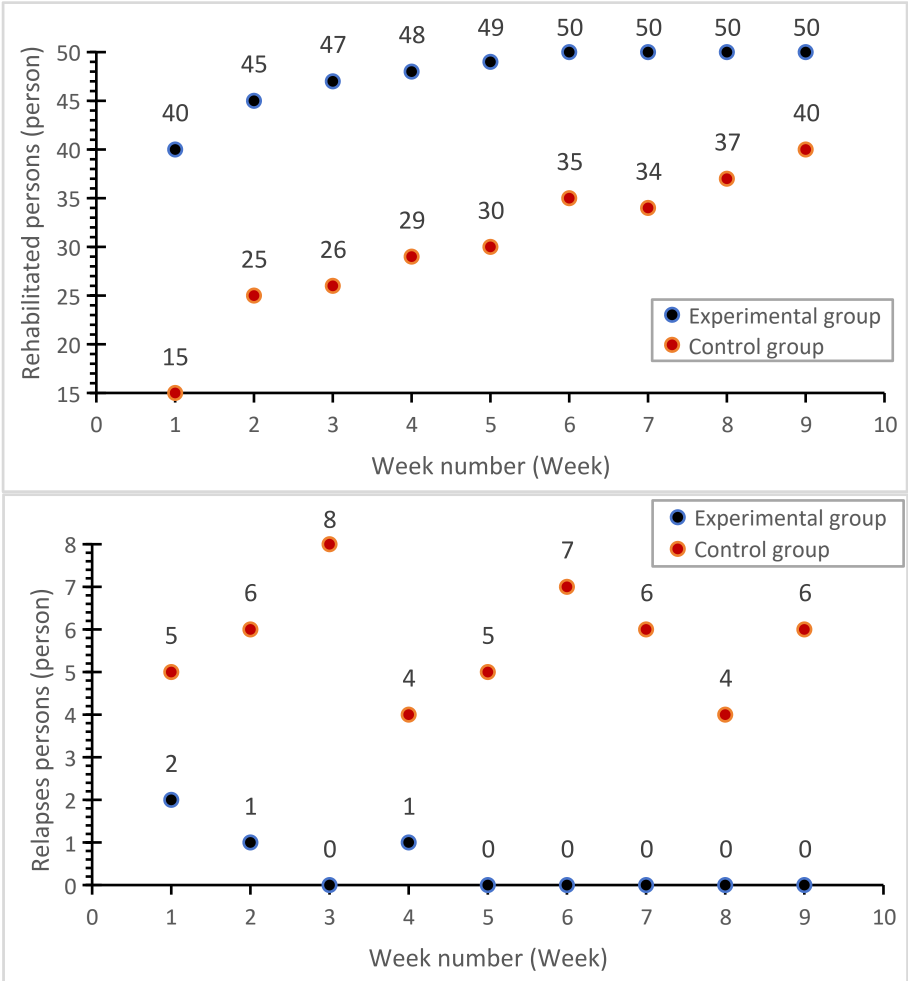

Figure 6. Results of the case-control study.

In **Figure 6**, the current number of rehabilitated individuals and the weekly number of individual relapses under two different muscle injury therapies are recorded. In the first week, the bioelectrical stimulation therapy helps 40 athletes recover, while the conventional therapy only helps 15. By the sixth week, all 50 athletes in the experimental group recover, while 35 are cured and recovered with the conventional therapy. From the perspective of recurrent cases, the experimental group has a lower recurrence rate, with no athletes experiencing recurrence from the fifth week onwards, while the conventional therapy results in 4 or more recurrent athletes per week. The experimental results demonstrate that the bioelectrical stimulation therapy has significant effects in promoting the recovery of muscle injuries in aerobics athletes, not only accelerating the recovery speed but also significantly reducing the recurrence rate.

4.3. Cohort study

The recovery effect of long-term use of the bioelectrical stimulation therapy on muscle injuries in aerobics athletes is evaluated. 100 aerobics athletes are randomly divided into two groups: a group of 50 people who use the bioelectrical stimulation therapy for a long time and a group of 50 people who don't used this therapy. During the 1-year follow-up period, the recovery time (days), recurrence rate (whether the athlete is injured again during the follow-up period), and pain score (0–10 points) are recorded for each athlete's injury. In addition, information such as the age, gender, and training intensity of athletes is recorded. The data obtained from the cohort study are shown in **Table 4**.

Table 4. Results of the cohort study.

	Indicator	**Value**		**Indicator**	**Value**
Group **with** the bioelectrical stimulation therapy	Sample size	50	Group **without** the bioelectrical stimulation therapy	Sample size	50
	Average recovery time (days)	15.3		Average recovery time (days)	22.7
	Recurrence rate (%)	16		Recurrence rate (%)	35
	Mean pain score	2.8		Mean pain score	4.6
	Average age (years)	25.4		Average age (years)	24.9
	Proportion of males (%)	46		Proportion of males (%)	50
	Average training intensity (hours/week)	12.5		Average training intensity (hours/week)	12.3

Table 4 shows the evaluation results of the long-term use of the bioelectrical stimulation therapy on the recovery effect of muscle injuries in aerobics athletes. The average recovery time of the athlete group using the bioelectrical stimulation therapy is 15.3 days, while the group not using the therapy is 22.7 days, indicating that the former has a faster recovery speed. The recurrence rate of the group using the bioelectrical stimulation therapy is 16%, significantly lower than the 35% of the group not using the therapy, indicating that the bioelectrical stimulation therapy can effectively reduce the injury recurrence. The average ages of the two groups are 25.4 years and 24.9 years, respectively; the proportion of males is 46% and 50% respectively; the average training intensity is 12.5 h and 12.3 h per week, respectively. These data show that the situations of the two groups of athletes are similar, indicating that the influence of other factors in this process is relatively small. The one-year follow-up period of this study provided valuable insights into the long-term effects of bioelectrical stimulation therapy. Detailed analysis showed that athletes who used the therapy not only recovered faster in the short term, but also maintained lower recurrence rates and pain scores in the long term. These findings highlight the potential value of bioelectrical stimulation therapy in promoting long-term recovery from muscle injuries.

4.4. Muscle recovery experiment

This article aims to explore the effect of the bioelectrical stimulation therapy on the recovery process after muscle injury. 50 aerobics athletes are selected from the 100 cases and randomly assigned to an experimental group and a control group, with 25 athletes in each group. The experimental group receives the bioelectrical stimulation therapy, while the control group receives traditional treatment methods, with a total treatment period of 8 weeks. Before the treatment and in the second, fourth, sixth, and eighth weeks after treatment, EMG technology is used to measure the electromyographic activity levels and fatigue characteristics of the injured muscles in two groups of athletes. At the same time, ultrasound imaging technology is used to monitor the morphological changes and healing process of muscles, including muscle thickness and echo intensity. The EMG and ultrasound results of two groups at different time points are compared and analyzed. The results obtained are shown in **Table 5**.

Table 5. Results of muscle recovery experiment.

Time point of measurement	Group	Electromyographic activity level (μV)	Muscle thickness (mm)	Echo intensity (dB)	Fatigue characteristics (point)
Before treatment	Experimental group	45.3 ± 5.2	3.1 ± 0.4	52.8 ± 3.2	6.7 ± 0.8
	Control group	44.8 ± 5.6	3.2 ± 0.5	52.5 ± 3.5	6.8 ± 0.7
The second week	Experimental group	48.7 ± 4.8	3.4 ± 0.3	55.2 ± 2.9	5.5 ± 0.9
	Control group	45.1 ± 5.3	3.3 ± 0.4	52.9 ± 3.1	6.4 ± 0.8
The fourth week	Experimental group	52.3 ± 5.1	3.8 ± 0.3	58.4 ± 2.6	4.3 ± 0.7
	Control group	46.5 ± 5.0	3.5 ± 0.4	53.6 ± 2.8	5.8 ± 0.6
The sixth week	Experimental group	55.9 ± 4.7	4.1 ± 0.2	60.7 ± 2.4	3.2 ± 0.5
	Control group	48.3 ± 4.8	3.7 ± 0.3	54.8 ± 2.7	5.2 ± 0.6
The eighth week	Experimental group	58.6 ± 4.4	4.3 ± 0.2	63.1 ± 2.2	2.1 ± 0.4
	Control group	50.1 ± 4.5	3.9 ± 0.3	56.3 ± 2.6	4.6 ± 0.5

Table 5 shows that the experimental group shows significant improvements in electromyographic activity level, muscle thickness, and echo intensity compared to the control group. In the eighth week after treatment, the electromyographic activity level of the experimental group increases to 58.6 μV; the muscle thickness increases to 4.3 mm; the echo intensity increases to 63.1 dB; the fatigue characteristic score drops to 2.1 points. These data indicate that the bioelectrical stimulation therapy significantly promotes muscle recovery, enhances muscle electrical activity and thickness, improves tissue structure, and reduces muscle fatigue.

To explore the differences in response to bioelectrical stimulation therapy for different types and severity of muscle injury in order to determine the applicability and effectiveness of this therapy in the broader spectrum of muscle injury. 100 athletes were selected and grouped according to the type and severity of muscle injury. Ensure that the number of participants within each subgroup is balanced to ensure the validity of the statistical results. Tailor treatment courses to the type and severity of the injury. Depending on patient feedback and progress, the frequency and intensity are adjusted during treatment. The changes of these indexes in different injury types and severity were compared. The results obtained are shown in **Table 6**.

Table 6. Recovery experiment results of different injury types and severity.

Injury Type	Severity	Pain Reduction (%)	Muscle Strength Improvement (%)	Flexibility Increase (cm)	Recovery Time (days)
Leg	Mild	44.3 ± 4.8	29.7 ± 4.1	5.3 ± 0.4	11.8 ± 2.1
Leg	Severe	32.2 ± 5.7	20.4 ± 3.2	3.7 ± 0.3	20.5 ± 2.9
Shoulder	Moderate	50.3 ± 4.9	34.8 ± 4.6	4.7 ± 0.5	14.6 ± 2.3
Back	Mild	59.7 ± 4.2	39.6 ± 4.8	6.1 ± 0.4	10.2 ± 1.4
Abdomen	Severe	25.4 ± 4.7	15.3 ± 2.8	2.6 ± 0.3	24.8 ± 3.5

Table 6 shows the recovery effects of bioelectrical stimulation for different types and severity of muscle injury. Overall, the recovery effect of mild and moderate injuries was significantly better than that of severe injuries, the recovery effect of back and shoulder was relatively better, and the recovery effect of severe abdominal injuries was the worst. These differences may be related to the structural characteristics of muscle tissue in different parts and the effect of injury severity on tissue repair ability.

5. Conclusion

This article provides clinical efficacy and scientific evidence of the bioelectrical stimulation therapy in the recovery of muscle injuries in aerobics athletes through systematic research. The research results show that compared with traditional treatment, the bioelectrical stimulation therapy can significantly reduce pain, promote functional recovery, improve flexibility, shorten recovery time, and reduce recurrence rate. The study of the therapeutic mechanism reveals the positive physiological effects of electrical stimulation on muscle tissue, verifying its role in promoting muscle fiber rearrangement and muscle layer thickening. The contribution of this article lies in establishing the effectiveness and safety of the bioelectrical stimulation therapy, providing a new treatment option for aerobics athletes, and promoting research and development in the field of the bioelectrical medicine. Future research directions should focus on optimizing treatment plans, exploring the treatment effects of different types and stages of injuries, and examining the long-term impact on athletes' athletic performance and health management. Further expansion of the sample size is needed to achieve personalized treatment and provide more accurate guidance for clinical applications. Given the remarkable effect of bioelectrical stimulation therapy in muscle injury recovery, future research should be extended to the molecular and cellular levels to fully understand its mechanisms of action. It is recommended to carry out long-term follow-up studies to monitor the biomarker changes and long-term adaptability of muscle tissue structure of athletes after treatment, so as to provide more in-depth scientific basis for personalized treatment. To ensure the safety and efficacy of bioelectrical stimulation therapy, future studies should focus on safety assessment at different doses and intensities, as well as long-term follow-up to monitor delayed adverse reactions. In addition, the establishment of a detailed patient monitoring plan and adverse event reporting system will help timely detection and management of possible risks during treatment, thereby further optimizing treatment plans and improving the overall safety of therapy.

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