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Research Article

An Experimental Study on the Repair of Spinal Cord Injury after Exercise Based on Multifunctional Material-Like Particles

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Spinal cord injury is a serious neurological injury disease. With the improvement of living standards in China in recent years, we began to develop sports hobbies, so the cases of sports spinal cord injury also increased. The main cause of spinal cord injury is the microenvironment after spinal cord injury, which prevents nerve regeneration. With the support of the state and the efforts of regenerative medical scientists in China, remarkable progress has been made in the reconstruction of microenvironment after spinal cord injury in recent years. The scaffold was combined with multifunctional nanoparticle repair technology to reconstruct the microenvironment of nerve regeneration by transplantation. The purpose of this paper is to carry out an experimental analysis on the repair of spinal cord injury after exercise based on multifunctional nanomaterial particles, and this paper takes badminton as an example to explore. The microenvironment of spinal cord injury was improved by implantation of multifunctional nanomaterial particles and nerve regeneration collagen scaffold. We found 48 patients with spinal cord injury after badminton and divided them into two groups. The pilot group was treated with a multifunctional nanomaterial granular nerve scaffold, whereas the treatment in the control group was with ordinary drugs. The experimental group was followed up for nine months, starting one month after the surgery. After nine months of experimental investigation, we found that the treatment of multifunctional nanoparticle nerve scaffold can not only reduce the injury area and scar formation but also promote the regeneration of nerve microenvironment and the recovery of body function and motor function of patients and reduce the inflammatory reaction caused by injury and pain.

1. Introduction

Spinal cord injury is the most serious complication of the spinal cord, which has the characteristics of high disability rate, high morbidity rate, high mortality rate, and many complications [1]. Spinal cord injury belongs to the central nervous system injury, and its repair after injury has always been a major problem in the international medical community [2]. At present, with the rapid development of high-altitude work, modern transportation industry, and the endless variety of difficult sports injuries, the incidence of this disease is increasing year by year. What follows is the highly degraded physical health and quality of life of the patients, as well as the heavy mental and economic burden to the patient's family and even the whole society, which greatly hinders the development of society [3].

Following spinal cord injury, some conduction tracts in the medulla spinalis, such as the corticospinal tract [4], can regenerate and grow into the medulla spinalis distal to the injury, but this does not significantly improve motor function after playing badminton in spinal cord injury patients. This is mainly due to the fact that after spinal cord injury, although some nerve fibers in the corticospinal tract can sprout and grow, they cannot form the correct neural

circuit with the motor center of the nerve loop originally dominated by the lower part of the injury. It affects the recovery of original nerve function.

With the continuous development of modern biomedical diagnosis and treatment technology, the original traditional disease diagnosis mode and treatment mode can no longer meet the needs of precision medicine and personalized medicine [5]. Multifunctional diagnosis and treatment mode, with its own accuracy, reliability, and the function of multiple examinations at the same time, has been highly praised by patients and medical workers. Multifunctional nanoparticle [6] technology, that is to integrate multiple components with different properties into one nanoparticle, can conduct real-time tracking and adjuvant treatment of disease diagnosis and treatment through its own physical and chemical properties at the same time of diagnosis and treatment. Therefore, in this paper, we applied the multifunctional nanoparticle technology to the treatment of spinal cord injury, combined the multifunctional nanoparticles with collagen nerve scaffold [7], and improved the wound site of patients with spinal cord injury due to badminton sports, as far as possible to reduce the pain of patients, shorten the recovery cycle, and reduce the burden of patients.

Multifunctional composite nanostructures are usually composed of two parts: the core and the outer shell [8]. Compared with the common simple nanostructures, core-shell nanostructures play a good role in protecting the core components, especially the easily oxidized or unstable components, and significantly improve the physical and chemical stability of multifunctional particles. In addition, the biocompatible shell outside the core can effectively reduce the biological toxicity of nanoparticles, improving the biological dispersion ability and phagocytosis efficiency of nanoparticles [9]. Core shell structure [10] can also effectively improve the connectivity of multifunctional nanoparticles with other biomolecules by changing the shell composition, so that the nanoparticles have better targeting and drug-loading capacity. In addition, the composition of the core and the shell can be selectively changed according to the specific application requirements, so that the multifunctional nanoparticles have the characteristics of both at the same time, so as to achieve a variety of biomedical diagnosis and treatment purposes. At present, core-shell nanomaterials with different functions have been widely used in electronic instruments, biomedicine, optics, and catalysis.

In this paper, we will analyze the pathological mechanisms of marrow injury from all aspects, starting from the physiological structure of the marrow, from chronic spinal cord injury to acute spinal cord injury. From the theme of this paper, the application of multifunctional nanomaterial particles in the treatment of spinal cord injury is described. The objectives are to analyze the research status and prospect of multifunctional nanomaterial particles in the treatment of spinal cord injury and combine the multifunctional nanomaterial particles with collagen nerve scaffold to maximize the efficacy of both in spinal cord injury.

2. Mechanism of Spinal Cord Injury

2.1. Physiology of the Spinal Cord. The medulla spinalis not only connects the brain to the peripheral nerves but also produces spinal reflexes [11]. The spinal cord begins in the medulla oblongata at the base of the brain, passing across the greater foramen and through the vertebral canal. In humans, the spinal cord ends at the level of the first lumbar spine, while in rats the spinal cord ends at the level of the third lumbar spine. In the process of growth, the growth rate of the lumbar spine is faster than that of the spinal cord, so the spinal nerve under the cervical spine passes through the intervertebral foramen under the corresponding vertebral body. From the inside to the outside, the spinal cord is covered by the leptomeningeal, arachnoid, and dural H-layer fibrous tissue. There is a subarachnoid space filled with cerebrospinal fluid [12] between the pia mater and arachnoid. There are fibrous connective tissue and adipose tissue between the dura mater and spinal plate. These structures, along with the spine, protect the spinal cord. The gray matter of the spinal cord is located in the center and surrounded by white matter. The gray matter is composed of interneurons, neuronal cell [13], dendrites, afferent nerve fibers, and glial cells. The peripheral white matter is mainly composed of multiple groups of myelinated axons. These axons with different functions are called fiber bundles or fiber pathways, which run longitudinally along the spinal cord. Some axons send information down from the brain to the peripheral nerves, while others transmit information from the peripheral nerves to the brain.

At present, spinal cord injury can be divided into three stages.

(1) Acute stage: in the first few days after injury, the main necrosis cells and then hematoma appear in the gray matter of the spinal cord, compressing the surrounding tissues, causing edema and microcirculation disorders, and aggravating the spinal cord injury

(2) Secondary reaction stage: injury after several minutes to a few weeks, including continuous ischemia and necrosis of cells, inducing or promoting apoptosis and necrosis of nerve cells, injured sites and surrounding areas

(3) Chronic stage: it can last for several days or even years, the range of apoptosis continues to grow, and scar formation, cystic regional expansion, and changes in nerve impulse transmission pathway were observed; some patients even have chronic central pain such as hyperalgesia and allergy

2.2. Primary Injury and Secondary Injury. When the spinal cord is severely injured, or the most common sudden impact, compression or vascular blockage, nerve injury has begun. We call it "primary injury." The primary injury is the mechanical injury of spinal cord caused by the injury itself, which results in necrosis of intramedullary cells and interruption of axons. It can be divided into spinal cord

concussion, spinal cord contusion and hemorrhage, spinal cord compression, cauda equina injury, etc. It can lead to permanent irreversible dysfunction of the spinal cord. The prognosis and rehabilitation were in direct proportion to the degree of injury at that time. At present, the local treatment of primary spinal cord injury is not effective. This is mainly because the local treatment of primary spinal cord injury is not suitable for primary spinal cord injury.

A series of harmful biological reactions caused by mechanical spinal cord injury are called "secondary injury." Secondary injury occurs after primary injury, sometimes more severe than primary spinal cord injury, leading to central hemorrhage and necrosis to edema and apoptosis area 2-3 cm long near the spinal cord, which is often replaced by glial scar tissue in the late stage. The mechanisms include microcirculation, free radical and lipid peroxidation, excitatory amino acid theory, calcium overload, electrolyte disturbance, and inflammatory reaction. It is one-sided to discuss one or more pathological injury mechanisms. Secondary injury is the result of multiple mechanisms. The interaction of various mechanisms affects the development of spinal cord injury. Secondary injury can occur within minutes to weeks after primary injury and last for several years. It can develop to both ends of the spinal cord, leading to more severe nerve damage, and eventually into a chronic phase.

It is very necessary to understand the biochemical and cytological mechanisms of primary and secondary spinal cord injury [14]. Therefore, we can study the treatment methods of these two periods to reduce the area of secondary injury and promote nerve regeneration. In 1911, Allen removed the inflammatory fluid from the spinal cord injury area in dogs and found that the motor function of dogs was significantly improved. Therefore, he proposed the concept of secondary spinal cord injury. With the development of research, Dr. Allen proposed that local hemorrhage at the injury site could lead to more severe spinal cord injury.

2.3. Apoptosis. Apoptosis [15] is a kind of programmed cell death that occurs under physiological or pathological conditions. Trauma can also lead to apoptosis. There is clear morphological and histological evidence that spinal cord injury can induce apoptosis. Apoptosis occurs in neurons, oligodendrocytes, microglia, and astrocytes. After spinal cord injury, oligodendrocytes in white matter die within weeks due to demyelination. Apoptotic cells were found in dentate and monkey and human spinal cord injury, which indicated that the active cell death aggravated the injury degree of central nervous system. The mechanism of apoptosis after spinal cord injury has not been fully studied, but the apoptosis of microglia and oligodendrocytes is closely related, suggesting that the activity of microglia may be related to apoptosis.

2.4. Inflammatory Response Theory. Inflammatory response theory: immune inflammatory response is the mechanism of self-defense and repair when the body is injured. Studies have shown that in spinal cord injury, the main inflammatory cells involved are neutrophils, monocytes, lymphocytes, and microglia in nerve cells. After spinal cord injury, resident microglia are activated, leukocytes rapidly infiltrate into the injured area and release unfavorable cytokines and reactive oxygen species, which leads to more leukocyte aggregation and more serious tissue damage. Secondary inflammatory reaction often plays a negative role in injuring spinal cord tissue, destroying and repairing, and promoting apoptosis and excessive hyperplasia of scar. A scholar believes that human intervention can control the development of secondary inflammatory response in favor of spinal cord repair; otherwise, inflammatory reaction will promote cell apoptosis and expand the scope of injury. Some studies suggest that inflammatory reaction is not completely harmful, it may play a beneficial role in the process of nerve tissue repair.

2.5. Chronic Stage of Spinal Cord Injury. The chronic stage of spinal cord injury includes slight demyelination of white matter, dissolution of gray matter, deposition of connective tissue [16], proliferation of reactive glial cells, and eventually formation of therapeutic scars. Glial scar [17] is mainly composed of reactive astrocytes, microglia (macrosatellite cells), extracellular matrix, and chondroitin sulfate polysaccharide. It acts as a barrier to prevent axons from passing through. About 25% of patients with spinal cord injury will form cystic cavity around glial scar [18]. Syringomyelia is usually caused by syringomyelia, which usually causes neuropathic pain. As a result, many patients develop pain syndrome, which eventually leads to depression. The mechanisms of pain and depression following spinal cord damage have not been clearly studied, but animal experiments have found that neurons from the back corners of the spinal cord are hyperexcitable for several weeks after injury, which could be associated with pain. In addition, studies have shown that chronic pain is related to the activation of the hypothalamic pituitary adrenal axis, and chronic pain is an inevitable stressor. The activation of HPA axis can also cause the release of glucocorticoid, which is closely related to depression.

3. Research on the Repair of Spinal Cord Injury with Nanomaterials

3.1. Research Background of Spinal Cord Injury. Spinal cord injury leads to partial or total loss of function below the wound. It not only brings great changes to patients and their families but also brings economic losses far beyond our expectation. The quality of life of patients with spinal cord injury is the lowest compared with other healthy people or disabled people. The average quality of life of patients with spinal cord injury is low, and their ability of self-care is low. They are eager to recover and to be able to take care of themselves. In this paper, we studied the changes of physical function of patients with spinal cord injury for nine months under two different treatment methods: multifunctional nanoparticle nerve scaffold and drug treatment, hoping to change the life status of patients with spinal cord injury.

3.2. Research Status. In view of the current high incidence rate and high disability rate of spinal cord injury, treatment

after onset has been a hot and difficult point in clinical research. At present, medical researchers divide the mechanism of spinal cord injury into two kinds: mechanical primary mechanism and biochemical secondary injury mechanism. We should choose appropriate treatment methods to block the two different injury mechanisms. At present, animal experiments and some clinical studies have confirmed the neuroprotective effects of surgery, drug therapy, and genetic engineering therapy on spinal cord injury. However, the specific surgical treatment and drug protection mechanism are not mature and controversial. It is expected that more research results will be translated into clinical practice to benefit patients with spinal cord injury.

3.3. Research Prospects. As one of the world's medical problems, the research on the treatment of spinal cord injury has attracted the attention of researchers and clinical scholars. The number of clinical studies on spinal cord injury is increasing. However, there are still some key problems to be solved.

(1) Analysis of microenvironment of nerve regeneration: after spinal cord injury, injury will lead to local ischemia, hypoxia, edema, stem cell activation and other reactions, and then axon demyelination, glial cell proliferation, nerve cell necrosis, and other problems, and finally form a cavity or scar injury is not conducive to nerve regeneration microenvironment. The process of continuous dynamic change is accompanied by the dynamic changes of various signal molecules and cells in the microenvironment

(2) Regeneration and repair mechanism of complete spinal cord injury: spinal cord injury can be divided into complete injury and incomplete injury. After incomplete spinal cord injury, some axons with intact nerves can regenerate and recover their functions by means of springing. However, complete spinal cord injury can completely cut off the nerve, and its regeneration and repair mechanism were a key issue to be studied

(3) Clinical research path of spinal cord injury: although relevant clinical studies have been carried out, there are still some problems to be solved in the clinical research of spinal cord injury. For example, due to the existence of spinal cord shock, the current commonly used Asian classification is not suitable for judging the severity of acute spinal cord injury. How to judge a patient as a complete injury? The scars of old spinal cord injury in patients will inhibit nerve regeneration. It is difficult to distinguish the scar tissue of old spinal cord injury from normal nerve tissue in operation and to remove the scar

The repair of spinal cord injury is a complex process, which involves not only spinal cord injury but also peripheral nerve and muscle degeneration, as well as different psychological changes of patients. Therefore, it is necessary to establish a complete psychological rehabilitation plan for spinal cord injury, which is combined with the continuous development of regenerative medicine technology, and repair the spinal cord tissue and reconstruct the injured spinal cord through the combination of multifunctional nanoparticles and nerve regeneration scaffold. In the near future, nerve regeneration and motor function recovery of patients with spinal cord injury will be realized.

3.4. Research Methods. First of all, we need to determine the purpose of the study and the content of the study and select the research object reasonably for the experiment. We selected 48 eligible patients with spinal cord injury after badminton. Under the condition of ensuring the patients' knowledge, we randomly divided the patients into two groups, 24 people in each group. From the patients' choice of treatment, the influence of nanoparticle nerve scaffold on body weight recovery, the promotion of motor function recovery by nanoparticle nerve scaffold, and the alleviation effect of nanoparticle nerve scaffold on inflammatory reaction were explored. Finally, the data were collected and sorted out to study the effect of multifunctional nanomaterials on the repair of spinal cord injury after badminton.

3.5. Experimental Process. The microenvironment is not conducive to nerve regeneration after spinal cord injury, which mainly includes the following: (1) primary injury and secondary injury lead to nerve cell death; (2) lack of nutritional factors to promote nerve regeneration; and (3) cell proliferation forms scar tissue and some chemical molecules in scar, such as chondroitin sulfate proteoglycans (CSPGs), which act as physical and chemical barriers to nerve regeneration. On the one hand, they inhibit the growth of axons; on the other hand, they inhibit the differentiation of neural stem cells into neurons. With the deepening of research, scientists gradually realize that due to the complex microenvironment formed after spinal cord injury, single strategy is difficult to effectively promote the repair of spinal cord injury, and the combination of multiple strategies is the focus of spinal cord injury repair. It is the most suitable and effective method to reconstruct the microenvironment of spinal cord regeneration by using multifunctional nanoparticles.

At present, multifunctional nanomaterial particle collagen scaffold for nerve regeneration is used. It is a kind of polymer material. We prepared the nerve regeneration scaffold by coating the multifunctional nanoparticles on the collagen nerve scaffold and then implanted the scaffold into the spinal cord injury site of the experimental group. Due to the characteristics of the growth of spinal cord nerve cells, the ideal spinal cord injury repair material structure should be cell oriented, that is, it can guide the orderly growth of cell axons. According to the characteristics of longitudinal and orderly growth of spinal cord neurons, nerve fibers were guided to extend orderly. The results showed that compared with the control group, the function of the patients was significantly improved, and the basic movement of the patients showed coordination and mobility. Histological and immunocytochemical analysis showed that the recovery may be due to the decrease of tissue loss and glial scar. After 9

Table 1: General information of patients.

Project		Experimental group ($N = 24$)	Control group ($N = 24$)
Age	15-25	5	7
	26-35	12	11
	35-45	7	6
Place of residence	Countryside	9	12
	Town	15	12
Marital status	Married/cohabitation	19	15
	Divorced/unmarried	5	9
Fitness	Frequently	4	5
	Occasionally	8	8
	Rarely	6	4
	Never	6	7

months of follow-up, the patient had no obvious adverse reactions, which initially proved that nerve regeneration collagen scaffold transplantation was safe.

For the control group, we were on medication. Only two drugs, methylprednisolone and sialic acid tetrasaccharide ganglioside, were found to have significant effects on recovery from spinal cord injuries and have obvious effects on the rehabilitation of spinal cord injury. The dose and course of treatment determined by NASCIS should be strictly followed. There are many similarities between GM-1 and MP in pharmacological mechanism, such as reducing tissue edema, reducing lipid peroxidation, reducing the production of free radicals, and stabilizing membrane structure. GM-1 can also promote axon growth, stimulate synaptic formation, and improve nerve conduction function. GM-1 was given 48 hours after injury and lasted for several months. At the same time, they received medical observation together with the experimental group.

4. Results and Discussion

4.1. General Information Survey. As shown in Table 1, in order to improve the biological experimental study on the repair of spinal cord injury after badminton with multifunctional nanomaterial particles, we collated the general data of patients in the experimental group and the control group. From the above data, we can see that the age of patients with spinal cord injury due to badminton is mainly between 26 and 35 years old. However, no matter when the experimental group is still in the control group, the patients who often exercise are relatively few. From this, we know that as long as the 26-35 age groups are office workers, it is precisely because they usually lack exercise, so they are more likely to be injured in sports.

4.2. Selection of Treatment Methods for Spinal Cord Injury. At present, the common spinal cord treatment methods in China include multifunctional nanoparticle nerve scaffold, drug therapy, and stem cell therapy. We investigated the patients with spinal cord injury after badminton in a certain place from 2017 to 2019 and calculated the treatment method when treating spinal cord injury.

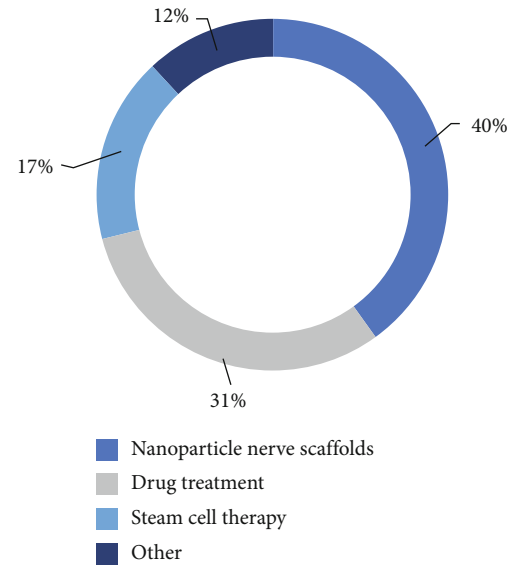

Figure 1: Selection of current methods of spinal cord injury quality.

As shown in Figure 1, the current common clinical treatment of spinal cord injury is focused on nanoparticle nerve scaffold treatment, which accounts for 40% of the clinical treatment of spinal cord injury. The second is drug therapy. Compared with the surgical treatment of nanoparticle nerve scaffold, the clinical selection rate of drug treatment is less, but still accounts for 31%. And stem cell therapy accounts for 12%. In addition, other methods also accounted for 17%, which shows that some of these methods still have certain development prospects.

4.3. Weight Recovery of Patients after the Operation of Nanomaterial Nerve Scaffold. After some medical research, we know that the recovery of patients' body weight is closely related to the recovery of patients' body function.

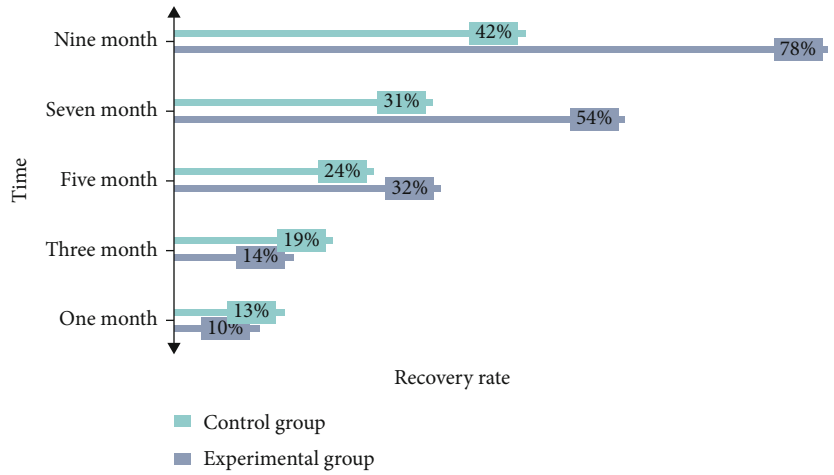

Figure 2: Weight gain of patients after nerve stenting with nanomaterials.

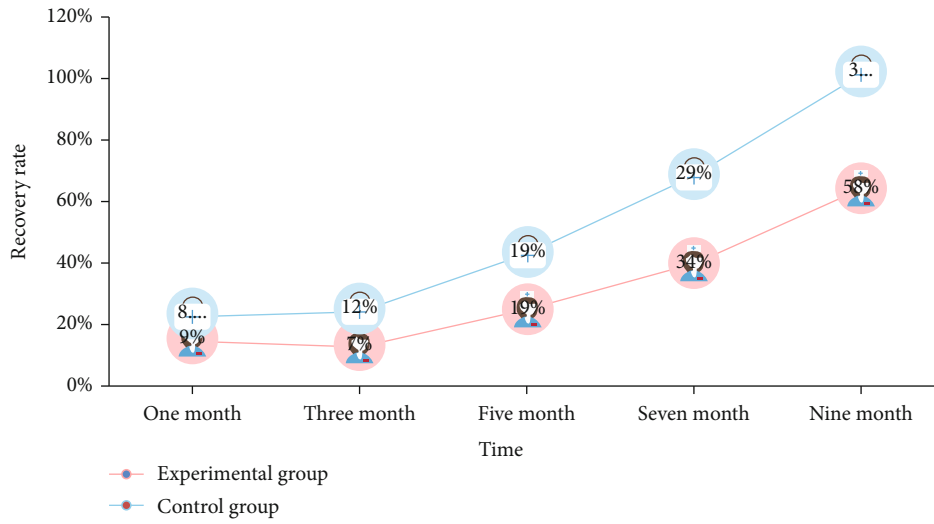

Figure 3: Recovery rate of motor function promoted by nanoparticle nerve scaffolds.

Postoperative weight recovery of patients is conducive to speeding up the recovery of bodily functions.

As shown in Figure 2, we recorded and compared the weight of patients in the experimental group and the control group one month after operation. According to the research, the weight recovery of patients after surgery represents the recovery of patients' body function to a certain extent. From the comparison of our data, we can see that the weight of the experimental group and the control group in the observation period is rising, but relatively speaking, from the first to the third month, the body weight of the experimental group and the control group was almost the same, but from the fifth month, the body weight of the experimental group rapidly recovered, and the recovery speed was much faster than that of the control group.

4.4. Nanomaterial Nerve Scaffold Promotes the Recovery of Motor Function. During the 9-month follow-up treatment, we recorded not only the weight data of the two groups but also the recovery level of motor function. Motor function is very important for everyone, especially for patients with spinal cord injury due to badminton.

As shown in Figure 3, we started recording from the first month after surgery. In the first month, the motor functions of the experimental group and the control group were at the same level. In the third month, the motor function of patients in the experimental group decreased slightly due to some reasons after operation, but in the follow-up treatment, the motor function quickly caught up with the control group, and in the fifth month, the motor function of the experimental group recovered rapidly, while the recovery of the control group was relatively slow. It can be seen that nanoparticle nerve scaffold can promote the recovery rate of motor function.

4.5. Nanoparticle Nerve Scaffold Reduces Inflammatory Response. In the recovery process of the disease, no matter whether it is surgical treatment or delayed treatment, as long as there is a wound, there is the possibility of inflammation, so we also recorded the experimental group of patients in the

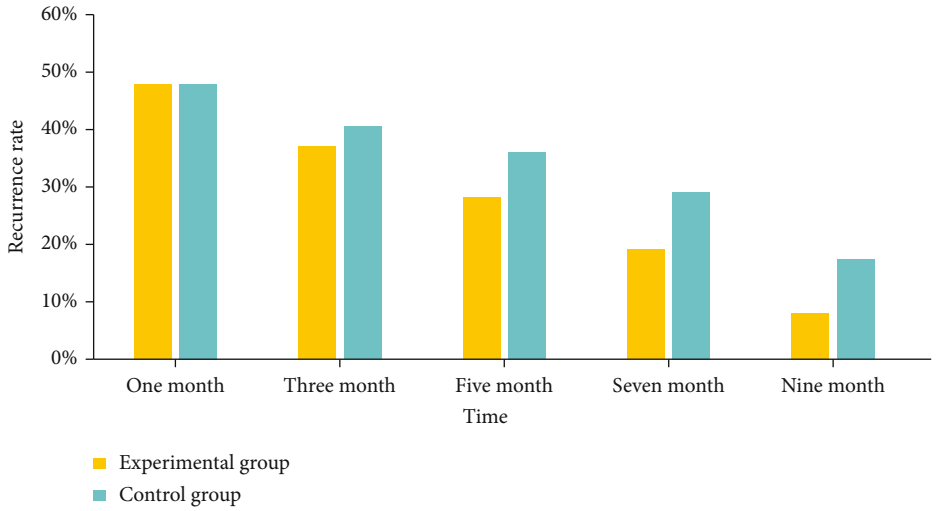

Figure 4: Inflammatory changes after nerve stenting of nanoparticles.

control group during the experimental period of inflammatory reaction.

As shown in Figure 4, we monitored the inflammatory response of the pilot and controlled patients from the first month after surgery. In the first month, the inflammatory response rates in the test and control arms were very similar. In the following eight months, the rate of inflammatory response in both groups decreased. But with the passage of time, the inflammatory response rate of the experimental group decreased much faster than that of the control group. After nine months, the inflammatory response rate of the experimental group decreased from 45% at the beginning to 8% at the ninth month. The control group was treated with drugs, from 47.85% at the beginning to 17% at the ninth month.

5. Conclusions

This paper mainly explores the repair of spinal cord injury after badminton sports with multifunctional nanomaterial particles. After spinal cord injury, patients will have a certain degree of movement disorders, and at the same time, various functions of the body will also have different degrees of problems, for example, urinary system infection, hydronephrosis, and dysuria. The follow-up treatment of spinal cord injury is not only a challenge to the patient's bearing capacity but also a heavy burden for the patient's family. Based on this point, we began to explore the use of multifunctional nanomaterial particle nerve scaffold for the treatment of patients. We found 48 patients with spinal cord injury after badminton exercise and divided them into two groups. The experimental group was treated with multifunctional nanoparticle nerve scaffold surgery, and the control group was treated with drug therapy. After nine months of treatment data recording, we compared the data and found the following three points: first, although the weight of the control group and the experimental group increased after operation, the overall recovery rate and recovery rate of the experimental group were much higher than those of the control group. The weight recovery after the operation represents the recovery of body function to a certain extent. It can be seen that the surgical treatment of multifunctional nanoparticle nerve scaffold has great help for the recovery of body function of patients with spinal cord injury after badminton exercise. Second, we focus on the recovery of motor function of patients with nanoparticle nerve scaffold. From one month after the operation, we recorded nine months. Although motor function was recovering in both control and laboratory patients, it recovered quite quickly and increased in magnitude over time in the laboratory group versus the control group. Third, we observed the inflammatory response after the nanoparticle nerve scaffold surgery. In the first month, because of the surgical wound, the inflammatory reaction of the experimental group was slightly stronger than that of the control group. But in the follow-up treatment, the inflammatory reaction of the experimental group of patients quickly went down. Through the above three points, we found that the multifunctional nanoparticle nerve scaffold treatment can make the body function and motor function of patients recover quickly, shorten the treatment cycle, and greatly reduce the pain of patients and the burden of patients' families. At the same time, it can greatly and rapidly reduce the postoperative inflammatory reaction of patients. In addition, we also investigated the treatment options of spinal cord injury patients with badminton sports in a hospital from 2017 to 2019. Among them, 40% of the patients chose nanoparticle nerve stent surgery. To sum up, it is meaningful and promising to study the experiment of repairing spinal cord injury after badminton with multifunctional nanomaterial particles.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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