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Development of a Rehabilitation Instrument of Neurological Training for Cervical Spine

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ABSTRACT

Objective: To develop a kind self active resistance movement training equipment for cervical spine, so as to restore the dynamic balance of the front and back muscle strength of the cervical spine in order to correct the abnormal physiological radian of the cervical spine, thereby relieving the clinical symptoms. Methods: The air spring with adjustable strength was used to provide the power of resistance active movement, and the neurological training cervical audio-visual synthesis training software was used to automatically guide patients to perform resistance active movement training of the cervical spine. Thirty two patients with cervical spondylosis were enrolled for treatment, and SPSS26 was used to statistically analyze the VAS, Lovett muscle strength, head and neck range of motion and C2-3 vertebral body curvature before and after the treatment. Result: There were significant differences in posterior cervical muscle strength (Lovett), dizziness, shoulder and neck pain (VAS) and C2-3 vertebral curvature before and after training in 32 patients ($p < 0.001$). Conclusion: The application of neurological training cervical vertebra self rehabilitation training instrument can effectively relieve clinical symptoms, restore head and neck range of motion, improve nape muscle strength, restore the dynamic balance of front and rear cervical muscle strength, and also can correct the abnormal physiological radian of the cervical vertebra.

1. INTRODUCTION

Cervical vertebra is the most flexible part of human spine, which is most likely to cause injury. Re-

search shows that the incidence of cervical spondylosis among college students is as high as 79% [1], and that among white-collar workers is 34%. Among these people, 54% were accompanied by neck and shoulder pain or limb numbness [2]. It is reported by the media that [3] primary and secondary school students are also more common to suffer from cervical spondylosis. In an investigation involving the incidence of cervical spondylosis in 500 adolescents, only 92 cases (18.40%) have normal physiological radians, while 408 cases (81.60%) have abnormal physiological radians. Among them, 233 cases (46.60%) had straight physiological radians and 175 cases (35.0%) had reverse curvature [4]. Therefore, cervical spondylosis is one of the urgent medical problems to be solved.

At present, the international treatment for cervical spondylosis is divided into surgery and conservative two treatment methods. In conservative treatment, cervical traction is often one of the preferred methods [5], among which traction Angle, traction force, traction duration and traction position are the main four factors [6]. However, this method still has many shortcomings, such as: 1) In terms of traction angle, there is still a debate about which position should be used, such as forward bending, neutral or backward stretching [7]?; 2) The size of traction force is not clear [8]; 3) There is no consensus on the optimal traction duration [9]. Although medicine and physical therapy have better immediate therapeutic effect, they are very easy to recur. Although surgical treatment of cervical vertebra is considered to have a good effect, it often seriously affects the mobility of cervical vertebra and easily causes other secondary diseases due to problems such as vertebral fixation and tissue adhesion after surgery. In addition, the above methods are passive therapy, lacking the function of enhancing the muscle strength of the posterior cervical group, so they cannot restore the dynamic balance of the anterior and posterior cervical muscle strength and correct the abnormal physiological radian of the cervical spine, which is the basic reason for the recurrence after treatment.

Zhao Wenru *et al.* [10] have innovated the treatment method of induced resistance active movement of cervical vertebra in response to the above needs, which has a better effect of enhancing the muscle strength of the posterior cervical muscles [11] and restoring the dynamic balance of the muscle strength of the anterior and posterior cervical vertebrae. This method can not only effectively alleviate the clinical symptoms of such patients, but also prevent and correct the physiological curvature of cervical spine. However, in order to consolidate the curative effect and prevent recurrence, besides requiring patients to get rid of the bad habits that lead to the decline of the strength of the cervical dorsal muscles, they also need to adhere to lifelong self exercise to maintain the dynamic balance of the strength of the cervical spine before and after, which may be difficult for many patients to do. In addition, the incidence of cervical spondylosis is very high, and the number of people to be treated is large, which will definitely cause a shortage of treatment personnel. Therefore, it is very necessary to develop a self training device for cervical vertebra that can replace artificial therapy.

2. DESIGN OF NEUROLOGICAL TRAINING CERVICAL VERTEBRA SELF-TRAINING REHABILITATION INSTRUMENT

2.1. Basis of Equipment Development

The cervical spondylosis is caused by the long-term imbalance of the anterior and posterior muscle strength of the cervical spine, which leads to the change of its physiological radian, and then compression of the vertebral artery, spinal cord and nerve roots, causing headache, dizziness, limb numbness and paralysis and a series of clinical symptoms. It is usually accompanied by neck stiffness, mobility limitation and intertissue adhesions caused by nacroligamentous calcification [12], and a vicious cycle of further limitation of joint motion and gradual aggravation of adhesions is easy to follow. As the flexibility of the posterior cervical tissue decreases and gradually becomes hard, it is easy to be torn and painful during exercise. Therefore, the key point of treatment of cervical spondylosis should first solve the dynamic imbalance of the anterior and posterior cervical muscle strength. The treatment method should be able to effectively improve the strength of the cervical muscle, truly restore the dynamic balance of the anterior and posterior cervical muscle strength, and correct the abnormal physiological curvature of the cervical spine. At the

same time, patients must be told to overcome the bad habits that lead to muscle strength decline, and adhere to lifelong self exercise after treatment to prevent recurrence.

Based on the above mechanism, a power device that can automatically provide resistance active motion is developed by imitating the treatment method of induced resistance active motion. By compiling a cervical audio-visual training software, patients can be automatically guided to carry out training. The patient can carry out the training of self resistance active movement of cervical vertebra, so as to improve the effect of rehabilitation training and easily carry out lifelong self training to prevent recurrence.

2.2. Design Principle

Five corresponding training modes are designed according to the five methods of induced active resistance movement therapy, namely, "neck backward extension, neck left bending, neck right bending, neck left rotation and neck right rotation" (see **Figure 1** to **Figure 5**). The following explains the whole process of training with the example of neck extension self resistance training: The patient takes a sitting position and adjusts the automatic lifting part to fit the head ring to the occipital tuberosity, two temporal parts and two sides of the forehead. Let the patient try out the resistance in all directions to understand the strength of their muscle, and then adjust the resistance of the air spring in all directions to match the strength of the muscles around the neck of the patient. Open the neural training audio-visual synthesis training software, and the patient will walk along the meridians as well as the acupuncture points displayed

Figure 1. Cervical extension.

Figure 2. Left flexion of neck.

Figure 3. Right flexion of neck.

Figure 4. Neck left rotation.

Figure 5. Neck right rotation.

with flashing animated light points displayed on the screen and adjust their mind and breath with the guidance of training voice, When the displayed meridians run to the occipital tuberosity, the training voice will prompt the patient: "Are you ready? Ready, go!", The patient immediately started the neck extension activity and forced the air spring behind the occipital tuberosity to compress as much as possible. When the top support of the air spring is pressed backward, the greater and greater resistance will act on the patient's occipital tuberosity, prompting the patient to further increase the backward force, and resist for 6 seconds at the highest point of the force, so as to better induce the patient's cervical dorsal muscle to generate force. With the increase of training times and the continuous improvement of neck muscle strength, adjust the initial strength of the air spring to adapt to the patient's enhanced neck muscle training. This is repeated until the dynamic balance of the front and rear muscle forces of the cervical spine is restored and maintained, the adhesion of the cervical tissue is fully released, the range of motion of the cervical joint is improved, the abnormal physiological radian is corrected, and the normal physiological radian is maintained.

3. BASIC STRUCTURE OF EQUIPMENT

3.1. Hardware

To ensure the comfort of patients during training, we use air spring as the power source to provide resistance strength. The gas spring has the advantages of smooth movement speed, stable dynamic force and easy control. The resistance plate at the end of the air spring ejector rod is a semi arc, which is suitable for the shape of the skull. The distance and height between the resistance plate and the head, as well as the resistance degree of the air spring can be flexibly adjusted, so as to be suitable for training with patients who have different muscle strength. The surface of the semi arc plate is made of elastic medical rubber to prevent the scalp from being damaged by local pressure when the head is under pressure. When the patient finishes the exercise or feels unwell, he only needs to slowly remove his head from the resistance plate, which can effectively protect the patient's safety. The physical diagram of the equipment is shown in Figure 6, the physical diagram of the head resistance module is shown in Figure 7, and the cervical vertebra self training instrument touch control all-in-one machine and support arm is shown in Figure 8, the head ring automatic lifting module shown in Figure 9.

Figure 6. Outline drawing of cervical vertebra self training instrument.

Figure 7. Anti resistance head ring of cervical vertebra self training instrument.

Figure 8. Cervical vertebra self training instrument Touch control all-in-one machine and support arm.

Figure 9. Head ring automatic regulating system.

3.2. Training module

The cervical audio-visual comprehensive training system guided by nerves along the meridians consists of five parts: "neck extension, neck bending to the left, neck bending to the right, neck rotation to the left, and neck rotation to the right". After entering the training mode, the dynamic movement of the meridians and key points will be displayed on the screen, through which the mind and breath can be adjusted. After the voice automatically tracks and guides the patient to gather qi to the target muscle, the voice automatically encourages the patient to perform standard induced resistance active training according to the action video displayed on the screen (see **Figure 8**). The touch control all-in-one machine equipped with the training software for cervical spine audio-video synthesis with nerve training along the meridians and collaterals is fixed on the mechanical arm with four degrees of freedom, which can be flexibly adjusted so that the patient can operate comfortably, and self training is conducted under the guidance of training voice and action video.

4. CLINICAL TRIALS

4.1. Patients and Methods

According to the order of hospitalization, 32 patients with old cervical spondylosis, half male and half female, were randomly selected from the rehabilitation center of Hunsen Hospital, Harbin Medical University, Sanya, Hainan Province from September 2021 to April 2022. The age range is 13 - 76 years old, with an average of 59 years old. The medical history was 1.1 - 32.2 years, with an average of 7.6 years. All the above patients were diagnosed by MRI, and their cervical physiological radians were straightened or reversed to varying degrees. The therapist assisted the patient to sit on the seat of the cervical resistance active exercise self training instrument, and put his head into the head ring of the instrument. Open the touch control all-in-one machine to enter the training interface, start the training software, under the automatic voice guidance of the image synthesis software, and imitate the action video to successively carry out the training of resistance active movement of self neck backward extension, neck left and right bending, and neck left and right rotation, and repeat the training for 6 times for each movement, once a day, a total of 10 days. After completing the training every day, the patient is required to follow the training action and insist on lifelong self exercise.

4.2. Statistical Analysis

After treatment, cervical MRI was rechecked. SPSS 26 statistical software was used to process the data of patients before and after treatment, such as C2-3 inflection angle, head and neck range of motion, VAS, Lovett muscle strength, etc. The data were expressed in $\overline{\chi} \pm s$, and paired sample t-test was conducted. The counting data were expressed in frequency, and $p < 0.05$ was statistically significant.

4.3. Results

Among the 32 patients in this group, 24 (75%) had C2-3 recurvatures. After treatment, the degree of recurvatures recovered from 154˚ ± 11.75˚ before treatment to 171.71˚ ± 13.31˚, with a significant difference ($p < 0.01$). There were significant differences in the activity of cervical extension, left and right flexion, and left and right rotation before and after treatment, as well as the results of VAS and Lovett muscle strength assessment ($p < 0.001$). After treatment, it was significantly better than before treatment. See **Figure 10** for the comparison results of C2-3 flexion degree before and after treatment, **Figure 11** for the comparison results of cervical spine range of motion before and after treatment, and **Figure 12** for the comparison results of posterior cervical muscle strength (Lovett) and pain degree (VAS) before and after treatment .

5. DISCUSSION

At present, the main methods to treat cervical spondylosis are surgery and conservative treatment. In

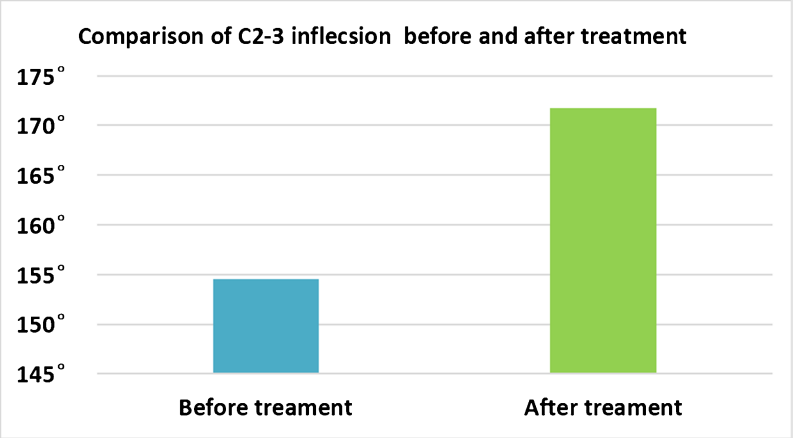

Figure 10. Comparison of C2-3 inflection before and after treatment.

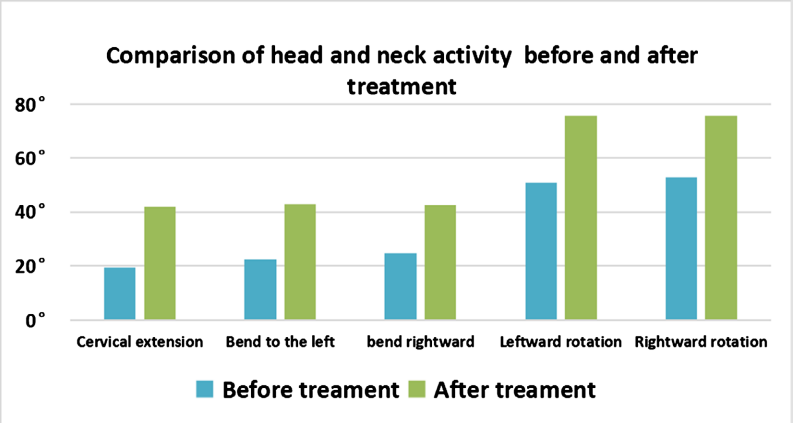

Figure 11. Comparison of head and neck activity before and after treatment.

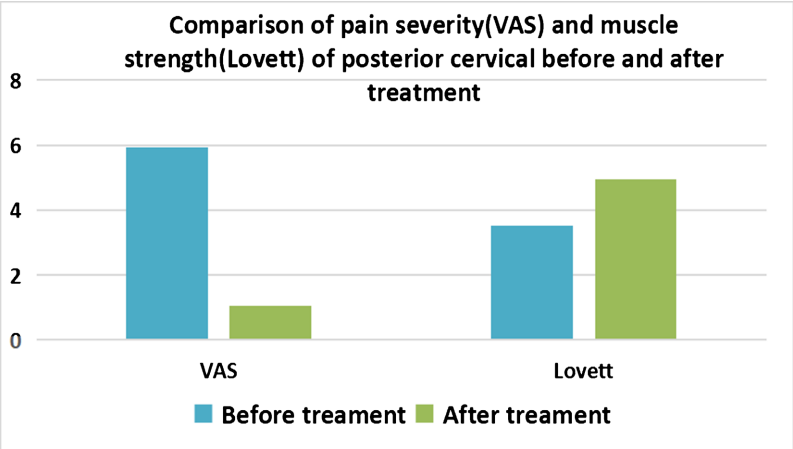

Figure 12. Comparison of pain (VAS) and muscle strength (Lovett) of posterior cervical before and after treatment.

addition to the high risk of surgical treatment, because the operation itself is invasive treatment, it often leads to a series of sequelae such as postoperative tissue adhesion. Therefore, most patients choose conservative therapy. In conservative therapy, cervical traction is often one of the preferred methods [5].

However, traction is mainly through the passive pulling force to release the adhesive tissue. It is reported that this method lacks the function of correcting the physiological radian of cervical vertebra, and may even cause the opposite result [13]. Murphy [14] found that traction cannot quickly relax muscles and increase the range of motion of the cervical spine. Although the intermittent traction method has a better effect of relieving pain, like all forms of traction, physical therapy, acupuncture and massage and other passive treatment methods, it cannot increase the muscle strength of the posterior cervical muscles, but lacks the role of restoring the dynamic balance of the muscle strength of the front and rear cervical vertebrae, thus it cannot correct the physiological radian of the straightened and reversed cervical vertebrae [15].

In this group, 32 patients with cervical spondylosis received self resistance active exercise training with neurological training self training instrument, which not only effectively restored the muscle strength of the posterior cervical muscle and the full range of motion of the neck, relieved the adhesion of soft tissue painlessly, but also effectively improved the straightening of the cervical physiological radian and the reverse bending of the C2-3 physiological radian.

The neurological training cervical vertebra self rehabilitation training instrument is suitable for patients with a series of clinical symptoms such as headache, dizziness, limb numbness and paralysis caused by cervical spondylosis to carry out self training. If properly trained, the symptoms can be significantly alleviated after several minutes of the first training. After 2 weeks of training, the symptoms can be alleviated. After 8 weeks of training, the C2-3 reflex can be corrected. Since the self training instrument is equipped with an audio and video synthesis training system that explains the use method and is like the personal guidance of a therapist, the patient can self train in the hospital or at home without the help of a therapist. For patients with serious disease, the therapist needs to conduct manual treatment of cervical vertebra first, and then start self training after the symptoms are relieved and the condition is stable. For patients with severely deformed physiological curvature of the cervical spine, it is difficult to be corrected and restored to normal by using this equipment for training. However, through long-term self training, the adhesion of pericervical tissues can be relieved, the muscle strength of the cervical muscles, especially the posterior cervical muscles, can be enhanced, and the dynamic balance of the front and rear muscle strength can be achieved on the basis of the physiological curvature of cervical deformation, which can also play a better role in preventing the recurrence of symptoms. Therefore, it is very necessary to use the equipment for self training for life.

6. CONCLUSION

The application of nerve training cervical vertebra self rehabilitation training instrument and self training under the automatic guidance of audio and video synthesis speech can effectively enhance the muscle strength of posterior cervical muscles, correct the inflection of cervical C2-3, increase the range of motion of cervical vertebra, alleviate clinical symptoms, prevent recurrence and save human resources, laying a foundation for the next step of developing intelligent cervical vertebra rehabilitation training equipment.

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AUTHORS CONTRIBUTION

Corresponding author Wenru Zhao conceived the research, innovated the treatment method and completed the clinical trial. The basic design idea of the equipment is put forward, and the development of the equipment is guided. He personally recorded the audio-visual synthesis system for neurological training along meridians and collaterals, and directed the master student Chenyu Wang to write and revise the

paper. Chenyu Wang, a graduate student, used his professional knowledge to refine the design of the equipment, collect the data of patients treated and conduct statistical analysis, draft a paper and make a chart. Professor Zhigang Hu guided the writing of the paper, read it and put forward suggestions for revising it. Xiaohua Wang and Hongquan Su completed the manufacturing of the whole equipment. Engineer Luyang Jia compiled the software of the cervical spine audio-visual synthesis training system. The head nurse Sun Lei drew all the treatment methods by hand.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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