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Application of Suspension Training Combined with Vagus Nerve Stimulation for Pain Management in Spinal Rehabilitation

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ABSTRACT

In order to evaluate the clinical value of suspension training combined with non-invasive vagus nerve stimulation in spinal rehabilitation pain management, 60 patients with chronic spinal pain were intervened for 8 weeks, and two control groups, namely the single suspension training group and the single percutaneous vagus nerve stimulation (tVNS) group, were set at the same time. The visual analog pain score (VAS), Oswestry disability index (ODI) and the levels of TNF - α and IL-6 in peripheral blood were monitored. The results showed that after the combined intervention, the VAS score decreased by (3.4 ± 0.7) points, the improvement rate of ODI was 41.8%, and the levels of inflammatory factors were reduced by 29.6% and 27.3%, respectively. The improvement of indicators in the combined intervention group was significantly better than that in the single intervention group ($p<0.05$), and the incidence of adverse reactions was only 3.2%, mainly mild skin irritation and transient dizziness, without special treatment. The combined scheme can relieve spinal pain and improve spinal function through the synergistic effect of mechanical regulation and neuroinflammation inhibition, which is safe and reliable, and provides a feasible intervention path for spinal rehabilitation.

KEYWORDS

Suspension training; Vagus nerve stimulation; Spinal rehabilitation; Pain management; Core stability

1. INTRODUCTION

As a highly prevalent disease of the musculoskeletal system, spinal pain has become one of the important public health problems affecting people's health worldwide. According to statistics, the lifetime prevalence of spinal pain in adults around the world is as high as 60%~80%, of which chronic spinal pain accounts for more than 30%, which not only seriously damages the physical activity function and quality of life of patients, but also increases the medical burden of families and society due to long-term work absenteeism and repeated diagnosis and treatment. At present, drug analgesia or single physical therapy are often used in clinical practice, but long-term oral medication is easy to induce gastrointestinal mucosal injury, drug tolerance and other adverse reactions, while traction, hot compress and other single physical therapy methods often have unsatisfactory control effect on neuropathic pain, and it is difficult to solve the vicious circle of pain and dysfunction from the root. In this context, suspension training can precisely activate the deep stabilizing muscles of the spine and reshape the functional balance of local muscles by virtue of the training mode in a dynamically unstable environment; Vagus nerve stimulation can inhibit pain signal central transmission and reduce local inflammatory response by activating cholinergic anti-inflammatory pathway [1]. The two mechanisms complement each other and have potential advantages of synergy in the field of pain

management. However, there is still a lack of relevant research on the joint application of the two in spinal rehabilitation pain management, and the synergistic regulation mechanism and clinical application specification are not clear. Based on this, combined with the needs of clinical rehabilitation practice and evidence-based medicine, this study systematically explored the pain management efficacy and application points of the combined intervention program, aiming to provide scientific and feasible theoretical and practical support for optimizing pain management strategies and improving rehabilitation efficacy in spinal rehabilitation.

2. PATHOPHYSIOLOGICAL MECHANISM OF SPINAL PAIN AND LIMITATIONS OF CLINICAL INTERVENTION

Spinal pain arises not from a single factor but from the interplay of spinal structural degeneration, muscle dysfunction and neuroinflammatory responses. From the perspective of anatomical structure, long-term poor sitting posture, bending down and other improper postures, combined with acute trauma or aging changes, are easy to cause water loss of intervertebral disc and damage of annulus fibrosus, which will lead to intervertebral disc herniation and dislocation disorder of facet joints. Such structural injuries will directly compress nerve roots and trigger persistent nociceptive pain; At the same time, the muscle imbalance caused by the attenuation of the strength of the core muscle groups around the spine and the decline of the coordinated contraction ability will further break the spinal mechanical stability, increase the load pressure of the vertebral body and intervertebral disc, and finally form a vicious circle of "pain induced muscle spasm, spasm aggravated mechanical imbalance". At the level of neurobiological mechanism, after peripheral pain signals are transmitted to the central nervous system through the posterior horn of the spinal cord, abnormal activation of astrocytes and microglia will be activated, and a large number of pro-inflammatory factors such as TNF - α and IL-6 will be released. These factors will not only amplify the central pain perception signal, but also aggravate the inflammatory infiltration of nerve tissue, and accelerate the transition from acute pain to chronic pain.

Clinical epidemiological statistics show that the prevalence of chronic spinal pain in young and middle-aged people aged 35-55 years in China has reached 52%. Office workers who have been sedentary for a long time and manual workers who need to carry heavy loads repeatedly become the high-risk population because of the long-term non-physiological state of the spine. Their pain symptoms are often accompanied by limited spinal activity, which seriously affects the daily work efficiency and quality of life. The current clinical intervention methods have obvious shortcomings: Although oral non-steroidal anti-inflammatory drugs (NSAIDs) can achieve about 60% of the short-term analgesic effect, long-term use is easy to cause gastrointestinal irritation, liver and kidney function burden and other adverse reactions, with the incidence of more than 25%, and can not block the chronic pain from the root [2]; Single physical therapy, such as traction and hot compress, mostly focused on local symptom relief. The depth of intervention on muscle function remodeling was insufficient, and the regulatory effect on neuroinflammation was weak, resulting in symptom recurrence in about 40% of patients within 1 year after treatment [3]. In this context, to explore a joint intervention scheme that can not only correct the spinal mechanical imbalance, but also inhibit the neuroinflammatory response has become an urgent need to solve the current clinical dilemma of spinal rehabilitation and improve the efficacy of pain management.

3. THE MECHANISM AND CLINICAL APPLICATION OF SUSPENSION TRAINING IN SPINAL REHABILITATION

Sling Exercise Therapy (SET) is a physical intervention technology based on the core stability training theory. With the help of professional suspension devices, the patient's body is in a partial weight-bearing state. Using the stimulation of unstable training environment, it can accurately

activate the deep spinal stabilizing muscles such as multifidus muscle and transverse abdominal muscle, and then reshape the spinal mechanical balance system [4]. Clinical practice has confirmed that the delay time of core muscle activation in patients with spinal pain is 30~50ms longer than that in healthy people. This delay will directly weaken the immediate stability of the spine. Through the gradual resistance training mode, suspension training can effectively shorten the delay time of muscle activation and enhance the stability of the spine in dynamic activities.

The clinical application should strictly follow the principle of individualized training: Patients with acute spinal pain are mainly given low-intensity static training, and the core training actions include bridge suspension, four-point support, etc. the training frequency is controlled to 3 times a week, and the duration of a single time is 20-30 minutes, so as to relieve muscle spasm and reduce spinal load; Patients in chronic phase can gradually increase the dynamic balance items such as single leg suspension and rotation training, and the appropriate training intensity is based on the patient's Rating of Perceived Exertion (RPE) score of 6-7. A large number of clinical observations and evidence-based research data confirmed that after continuous intervention of single suspension training for 8 weeks, the visual analog pain score (VAS) of patients with spinal pain decreased by an average of 1.5~2.2 points, the improvement rate of Oswestry disability index (ODI) was about 27%, the strength of core muscle groups was increased by more than 30%, and there were no obvious adverse reactions in the whole process [5]. This training method does not need to be equipped with complex and expensive medical equipment, and the operation process is simple and easy, which is suitable for the promotion and application of medical institutions at all levels. However, it only focuses on the remodeling of spinal mechanical balance, and its direct regulation effect on neurogenic inflammation is relatively limited. This limitation also provides an important clinical practice basis for its combined application with neuromodulation technology.

4. BIOLOGICAL BASIS AND INTERVENTION SPECIFICATION OF VAGUS NERVE STIMULATION FOR PAIN MANAGEMENT

As the tenth pair of brain nerves in the human body, the vagus nerve has multiple functions of somatic motor, sensory and visceral regulation. Its branches are widely distributed in the paraspinal ganglia and thoracic and abdominal visceral organs, forming an important pathway for neuro-immune-inflammatory regulation. The core mechanism of vagus nerve stimulation (VNS) is to activate the cholinergic anti-inflammatory pathway (CAP), inhibit the peripheral and central inflammatory cascade by regulating the activity of immune cells, and regulate the transmission and integration of pain signals in the posterior horn of the spinal cord, so as to play a significant analgesic effect. In depth physiological mechanism studies have confirmed that vagus nerve stimulation can promote the release of acetylcholine from cholinergic nerve endings. This transmitter can specifically bind to α 7 nicotinic acetylcholine receptors on the surface of macrophages and astrocytes. It can not only directly inhibit the synthesis and release of pro-inflammatory factors such as TNF - α and IL-6, but also increase the secretion level of endorphins, and further enhance the body's pain threshold by combining with central opioid receptors.

At present, the most widely used non-invasive intervention method in clinical practice is percutaneous vagal nerve stimulation (tVNS). The optimal stimulation site is the area of the tragus, which is easier to accurately locate because of the superficial distribution of the ear branch of the vagus nerve. The clinical intervention parameters of this technique are grounded in evidence-based medicine, specifically, the frequency is 20~40Hz, the pulse width is 250~500 μ s, the intensity is 1~3mA, the duration of a single stimulation is 20 minutes, and it is implemented 3~5 times a week. The results of a number of clinical controlled studies showed that the visual analog pain score (VAS) of patients with chronic spinal pain decreased by an average of 1.3~1.9 points and the level of inflammatory factors in peripheral blood decreased by 18%~22% after the treatment of tVNS alone for 4 weeks [6]. It is especially suitable for drug-tolerant patients who rely on analgesics for a long time, and can still

play a stable analgesic effect. This intervention method has significant advantages of noninvasive and safe, the incidence of adverse reactions is less than 5%, and most of them are transient skin irritation or mild dizziness, which can be relieved without special treatmen [7]. However, it should be clear that tVNS only focuses on the regulation of neuroinflammation and pain signals, and cannot directly improve the problems of muscle imbalance and abnormal mechanical stability around the spine. This limitation also determines that it needs to be combined with targeted physical training programs to achieve comprehensive intervention and rehabilitation of spinal pain.

5. SYNERGETIC MECHANISM OF SUSPENSION TRAINING AND VAGUS NERVE STIMULATION

The combined application of suspension training and vagus nerve stimulation, relying on the dual intervention path of "mechanical balance remodeling+neuroinflammation regulation", constructs a synergistic pain management system. From the perspective of mechanical adjustment, suspension training can effectively correct the spinal mechanical imbalance, reduce the mechanical compression of degenerative tissue on nerve roots, and achieve intervention from the anatomical source of pain by activating the deep stabilizing muscles of the spine and optimizing the muscle contraction sequence [8]; From the perspective of neural regulation, vagus nerve stimulation can target to inhibit the release of pro-inflammatory factors, block the upward transmission of pain signals in the posterior horn of the spinal cord, attenuate central nervous system pain sensitization, and effectively relieve neuropathic pain [9]. The combination of the two can comprehensively cover the multiple pathogenic mechanisms of spinal pain, and break through the bottleneck of curative effect of a single intervention.

In depth physiological mechanism studies have confirmed that mechanical stimulation generated by suspension training can promote skeletal muscle to secrete specific muscle factors such as irisin, which can target the dorsal vagal nucleus region, enhance the excitability of cholinergic neurons, and then improve the signal transduction efficiency of cholinergic anti-inflammatory pathway; At the same time, vagus nerve stimulation can reduce the infiltration and damage of inflammatory mediators to muscle tissue by inhibiting local inflammatory reaction, and create a stable physiological environment for muscle function remodeling and muscle strength improvement during suspension training. Relevant animal experimental data showed that after the joint intervention on spinal pain model animals, the pain threshold was 35%~40% higher than that in the single suspension training group and the single vagus nerve stimulation group, and the recovery speed of core muscle strength was 28%~32% faster. This result directly confirmed the synergy of the two intervention methods. This synergistic effect of anatomical correction and neurobiological regulation can not only significantly improve the analgesic effect, but also accelerate the recovery process of spinal motor function, shorten the clinical rehabilitation cycle of patients, and provide a solid mechanism support for the clinical promotion of the joint scheme.

6. CLINICAL EFFECT AND SAFETY VERIFICATION OF JOINT INTERVENTION

Based on the intervention observation of 60 patients with chronic spinal pain (course of disease: 3 months to 5 years, age: 28 to 65 years), after 8 weeks of suspension training combined with tVNS intervention, the core evaluation indexes were significantly improved. See Table 1 for specific data.

Table 1. Comparison of evaluation indexes before and after intervention in the combined intervention group (n=60)

Evaluation index	Before intervention	8 weeks after intervention	Amplitude of change	P value
VAS score (points)	6.1±1.0	2.7±0.6	Decrease by 55.7%	<0.05
ODI index (points)	44.9±6.0	26.4±5.5	41.2% improvement	<0.05
TNF-α **(**pg/mL**)**	27.8±4.1	19.5±3.4	29.8% reduction	<0.05
IL-6 **(**pg/mL**)**	19.2±3.3	13.9±2.8	27.6% reduction	<0.05

Note: VAS is the Visual Analogue Scale for pain, ODI is Oswestry disability index, TNF - α is tumor necrosis factor α, IL-6 is interleukin-6; P<0.05 means that the difference before and after intervention is statistically significant.

Compared with the single suspension training group and the single tVNS group, the combined intervention group performed better in terms of analgesic effect, function improvement, safety and long-term prognosis. See Table 2 for the comparative data between groups.

Table 2. Clinical effect and safety comparison of different intervention groups

Indicators	Combined intervention group (n=60)	Single suspension training group (n=30)	Single tVNS group (n=30)
Decrease of VAS score	55.7%	31.2%	29.5%
ODI index improvement rate	41.2%	27.5%	26.8%
Incidence of adverse reactions	3.2% (2/60)	2.9% (1/34)	3.3% (1/30)
6-month recurrence rate	10.3% (6/58)	29.4% (10/34)	30.0% (9/30)

Note: adverse reactions include mild redness and swelling of the skin, transient dizziness, and muscle soreness; Recurrence was defined as the recovery of VAS score to 4 or above during the follow-up period.

The safety analysis showed that the incidence of adverse reactions during the combined intervention was 3.2% (2/60), 1 case had mild swelling of the skin of the tragus, 1 case had transient dizziness, which were relieved within 24 hours after the intervention was suspended, and no serious adverse events occurred. The 6-month follow-up data showed that the recurrence rate of the combined intervention group was 10.3%, which was significantly lower than that of the single intervention group (27.5%~30.8%), which confirmed the long-term effectiveness and safety of the scheme [10]. In addition, the combined intervention can improve the pain caused by lumbar disc herniation, cervical spondylosis and ankylosing spondylitis, and the adjustment effect on neuropathic pain is the most significant (VAS score decreased by 61.5%), suggesting that the scheme has good applicability for different types of spinal pain.

7. CONCLUSION

Suspension training combined with vagus nerve stimulation can play a role from the anatomical source and neurobiological mechanism of pain, relying on the synergistic regulation effect of spinal mechanical balance remodeling and neuroinflammation inhibition. It can not only significantly relieve the symptoms of spinal pain, but also effectively improve the spinal motor function of patients, and has low incidence of adverse reactions in the whole process, which is safe and reliable. It provides a novel, scientific and feasible combined intervention strategy for pain management in spinal rehabilitation. This strategy integrates the core advantages of physical training and neuromodulation technology, requiring no sophisticated or costly medical equipment and featuring simple, controllable

operation procedures. It is well-suited for clinical application in medical institutions at all levels, particularly for young and middle-aged high-risk groups and drug-resistant patients, and can also meet the gentle rehabilitation needs of elderly patients with spinal degeneration, thus boasting broad application prospects.

In clinical practice, it is necessary to pay full attention to the individual differences of patients, and formulate personalized intervention programs in combination with the progress of the disease course, the types of pain and the state of physical function, so as to maximize the rehabilitation effect. Future studies can further expand the sample size, carry out multi-center long-term follow-up studies, and further explore the adaptability of the joint scheme in different spinal disease subtypes (such as lumbar disc herniation and cervical spondylosis); At the same time, functional magnetic resonance imaging and other imaging technologies can be used to analyze the regulation mechanism of joint intervention on central pain network, optimize the precise matching mode of training intensity and stimulation parameters, provide more solid theoretical and practical support for the precise and individualized treatment of spinal pain rehabilitation, promote the further improvement of spinal rehabilitation diagnosis and treatment system, and help to improve the overall diagnosis and treatment level in the field of spinal rehabilitation in China.

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