RESEARCH ARTICLE

Clinical application of respiratory muscle training combined with respiratory electrical stimulation therapy on trunk function in stroke patients

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Stroke is the main disease leading to death and disability in the middle-aged and elderly population in China. Its incidence remains high, and the risk of death is severe. The existing stroke rehabilitation interventions focus on improving the patients' limb dysfunction, speech disorder, and other significant symptoms, but often ignore the attention of respiratory dysfunction. This study explored the effect of combining respiratory muscle training and respiratory electrical stimulation therapy on the recovery of diaphragm function in patients with diaphragm dysfunction after stroke. Forty (40) patients with diaphragm dysfunction after stroke and being treated in the hospital from September 2019 to September 2020 were randomly divided into control group (n = 20) and experimental group (n = 20). The control group carried out respiratory muscle training, while the experimental group carried out respiratory muscle training plus respiratory electrical stimulation training for a total of 3 weeks of treatment. Lung function, respiratory muscle strength, diaphragm function, recovery, and the occurrence of stroke-associated pneumonia (SAP) were recorded for all patients before and after treatment. After the treatment, the forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), maximum ventilation volume (MVV), and peak expiratory flow rate (PEF) of the two groups were significantly increased. The pulmonary function indexes were significantly improved ($P < 0.05$). The maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), and peak inspiratory flow rate (PIF) of the two groups were improved after treatment. The recovery of respiratory muscles in the experimental group was better than that in the control group ($P < 0.05$). The end-inspiratory diaphragm thickness (IDT), end-diaphragm thickness (EDT), diaphragm thickening fraction (DTF), and diaphragm mobility (DE) of the two groups were significantly increased after treatment, and the recovery of diaphragm function was significantly different between the two groups ($P < 0.05$). The scores of trunk impairment scale (TIS), modified Barthel index (MBI), and fatigue severity scale (FSS) were also significantly increased in the two groups after treatment ($P < 0.05$). SAP was developed in 2 patients of the experimental group and 7 patients in the control group during the treatment with a significant difference ($P < 0.05$). In clinical treatment, the combination of respiratory muscle training and respiratory electrical stimulation therapy could restore the patient's lung function, respiratory muscle force, and diaphragm function faster, quickly relieve the patient's fatigue symptoms, and reduce the incidence of pneumonia.

Keywords: stroke; respiratory muscle training; respiratory electrical stimulation therapy; trunk dysfunction.

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Introduction

Stroke is the primary cause of death and disability in middle-aged and elderly people in China. Its prevalence is high, and the mortality rate cannot be underestimated. According to the results of statistics, the prevalence rate of stroke in China is 1,596 per 100,000 population, and the mortality

rate is 147 per 100,000 population [1]. Research showed that the maximum expiratory pressure and maximum inspiratory pressure of stroke patients were significantly reduced, which was because stroke patients had decreased strength of some respiratory muscles due to central nerve system damage or blocked nerve conduction pathways that affected breathing and cough, and even leads to pulmonary infection and non-vascular death [2, 3]. The spontaneous co-contraction of respiratory muscles is an important factor to maintain the stability of human trunk [4]. In stroke patients, trunk dysfunction seriously affects their daily life. Even some patients' limb, swallowing, speech, and other functions have been improved, their sitting, standing, and walking posture are still unstable. The weight of the trunk shifts to the healthy side, and the affected leg seems to become shorter than the other side. Some patients may also have difficulty defecating. Therefore, it is very important to find an effective treatment for stroke patients.

Respiratory muscle training combined with electrical stimulation therapy aims to improve the trunk function of stroke patients by improving the strength of respiratory muscle and enhancing the stability and control ability of trunk [5]. Research showed that stroke patients' respiratory muscle strength was less than half of healthy adults, of which 89.0% had inspiratory muscle damage and 82.6% had expiratory muscle damage. Stroke patients with long-term bed rest and mechanical ventilation were more prone to respiratory muscle disuse atrophy [6, 7]. Electrical stimulation therapy uses the external pulse current to stimulate the neuromuscular junction point, so that the muscle contracts, and then improves the muscle strength. In stroke patients, electrical stimulation can preferentially mobilize type II muscle fibers and cause the increase of muscle strength [8]. Simultaneously, electrical stimulation can also enhance muscle endurance, which may be related to the activity of heat shock protein protective enzymes [9]. A previous study on 40-minute low-frequency electrical stimulation in rats found that the swimming time of rats was prolonged, the cross-sectional area of gastrocnemius muscle fibers and the number of capillaries were increased, the expression of heat shock protein 70 was observed, and the activity of superoxide dismutase was increased [10]. Therefore, respiratory muscle training combined with electrical stimulation therapy may play a synergistic effect and further improve the trunk function of stroke patients [11]. The respiratory muscle training can enhance respiratory muscle strength, improve respiratory function, and provide sufficient oxygen supply for the body, while the electrical stimulation therapy can directly stimulate trunk muscles, improve muscle strength and endurance, and enhance trunk stability and control ability. In addition, the combined treatment may also promote the reorganization of brain function and improve the balance ability and walking stability of patients.

This study explored the effect of combining respiratory muscle training and respiratory electrical stimulation therapy on the recovery of diaphragm function in patients with diaphragm dysfunction after stroke. Respiratory muscle training combined with respiratory electrical stimulation would provide a new way to improve the trunk function of stroke patients. This combination therapy is expected to enhance the strength of respiratory muscle, improve the control and coordination ability of trunk, and promote the reorganization of brain function and the recovery of balance ability.

Materials and methods

Selection of patients

A total of 40 post-stroke-induced diaphragmatic dysfunction patients who were admitted into Hengshui People's Hospital (Hengshui, Hebei, China) between September 2019 and September 2020 were included in this study and were divided into experimental group and control group according to random distribution with 20 patients in each group. There were 11 males and 9 females in the experimental group with an

average age of 57.23 ± 8.86 years old and an average stroke duration of 42.76 ± 10.84 days. Among them, 20 cases were cerebral infarction including 10 patients with hypertension and 5 patients with diabetes. In the control group, there were 13 males and 7 females with an average age of 58.49 ± 9.52 years old, average stroke duration of 40.24 ± 11.70 days, 20 cases of cerebral infarction. Among them, 9 cases were hypertension, and 4 cases had diabetes. The inclusion criteria were patients with acute cerebral infarction diagnosed by CT or MRI [12, 13], age greater than 18 years old with clear consciousness and spontaneous respiration, no cerebral infarction, meningitis, and other intracranial organic lesions, and so on before and 1 month after treatment. The exclusion criteria included patient with fuzzy consciousness, serious heart, lung, liver, and kidney diseases, having recently undergone systematic respiratory function training, having difficulty in swallowing, choking, coughing, and unable to cooperate. All procedures of this study were approved by the Ethics Committee of Hengshui People's Hospital, Hebei Medical University (Hengshui, Hebei, China). All patients were aware of the study and signed the informed consent form.

Treatment plan

All patients received conventional drug therapy including antiplatelet aggregation, brain protection, and other drugs, and were given appropriate doses of hormones for anti-inflammatory and immunosuppressive therapy according to the changes in individual condition and clinical observation [14]. In the control group, only respiratory muscle resistance training was applied, while, in the experimental group, respiratory muscle resistance training plus respiratory electrical stimulation training were performed for a total of 3 weeks. Respiratory muscle resistance training included the use of a LUD-V1 portable lung function tester (Xuzhou Pinyuan Electronic Technology Co., Ltd., Xuzhou, Jiangsu, China) to guide patients taking a sitting or semi lying position, holding the instrument tightly with their lips, biting their mouth, setting the resistance value to 30% mean effective pressure (MEP), and allowing the patient to breathe to the maximum extent as possible. The patient was also guided to gradually increase gas resistance during exhalation until they were unable to continue exhaling. In addition, the patient was instructed to gradually reduce gas resistance during inhalation until normal breathing was achieved [15, 16]. The above treatment procedures were repeated 5 groups at a time with a 1-minute break between groups, twice a day, 6 days per week, for 3 weeks. Respiratory electrical stimulation training involved using a KT-2 neuromuscular electrical stimulator (Zhengzhou Dajing Medical Technology Co., Ltd., Zhengzhou, Henan, China), guiding the patient to lie flat, connecting a bioelectrical impedance sensor, placing the phrenic nerve stimulation electrodes on both sides of chest walls and the rectus abdominis stimulation electrodes on each side of the rectus abdominis muscle, and setting the stimulation parameters. During the breathing process, the patient sensed changes in impedance and adjusted the breathing rhythm and depth according to the prompts. Meanwhile, the instrument sent current out to stimulate the phrenic nerve [17]. The patient was instructed to breathe in a nasal inhalation and oral exhalation manner, and to ensure that the neck and chest were in a relaxed state during the breathing process. The patient needed to adjust their breathing rhythm according to the device's prompt sound. Specifically, when the device sent out the "inhalation" signal, the patient should start inhaling and expand their abdomen, while the device released current to stimulate the phrenic nerve. When the device sent out the "exhale" signal, the patient should quickly exhale and relax the abdomen, while the device released current to stimulate the abdominal muscles. The frequency of electrical stimulation was set at 40 Hz. The initial stimulation intensity was set at 10 - 20 mA, and then gradually increased according to the patient's tolerance level with the upper limit of 100 mA. The patient's respiratory rate gradually slowed down from 12 to 10 breaths per minute, and the ratio of inhalation to exhalation

was maintained at 1:1.5 to 1:2. The treatment lasted for 15 minutes each time, twice a day, for 3 weeks.

Observation of indicators

(1) Pulmonary function testing

The patient's pulmonary function indexes including maximum expiratory volume in the first second (FEV1), forceful lung capacity (FVC), maximum ventilation volume (MVV), and peak expiratory flow rate (PEF) were tested before and after 3 weeks of treatment. The test was repeated 3 times, and the average value was recorded.

(2) Respiratory muscle strength (RMS) testing

All patients received RMS tests before and after treatment. The patients' maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), and peak inspiratory flow rate (PIF) were measured. The test was repeated 3 times to take the average value.

(3) Diaphragm function test

A DW-T8 Echocardiography instrument (Dawei Medical (Jiangsu) Co., Ltd., Xuzhou, Jiangsu, China) was employed to detect the diaphragm function of the patients including diaphragm contraction speed, diaphragm thickness, and other indicators. The patients in both groups were examined for diaphragm function before and after treatment. The diaphragm thickness was measured under the calm breathing state. The maximum diaphragm thickness was recorded as the end-inspiratory diaphragm thickness (IDT) at the end of inspiration, while the minimum diaphragm thickness was recorded as the end-diaphragm thickness (EDT) at the end of expiration with the average value being taken from three measurements. The abnormal diaphragm function was determined using the diaphragm thickening fraction (DTF) that was calculated as follows.

$$DTF = (IDT - EDT)/EDT \times 100\%$$

Normally, the value of DTF should be greater than 20%, otherwise, it indicated diaphragmatic dysfunction [18]. The diaphragm mobility (DE) was determined under calm breathing. The diaphragm movement velocity was calculated by capturing the velocity changes during diaphragm contraction and relaxation through the sensor. Three sets of data were repeated and averaged.

(4) Assessment of recovery status

The assessment of trunk impairment scale (TIS) was performed by measuring sitting balance and coordination in dynamic and static situations with a total score of 23. Patients in both groups underwent TIS assessment before and after treatment. Higher scores indicated better trunk control. The modified Barthel index (MBI) assessment included ten aspects of function assessment such as eating, bathing, dressing, toileting, walking, going up and down stairs, *etc*. with a total score of 100 points. The two groups of patients were assessed for MBI before and after treatment, respectively. Higher scores indicated that the patients' ability to perform daily activities was better. The fatigue severity scale (FSS) assessment included nine aspects of fatigue symptom assessment, each with a range of scores. Patients in both groups underwent FSS rating before and after training. Higher scores indicated more severe fatigue in patients.

(5) Incidence of pneumonia

Throughout the course of treatment, the occurrence of stroke-associated pneumonia (SAP) was recorded in both groups and the incidence of pneumonia was compared.

Statistical analysis

SPSS 21.0 (IBM, Armonk, NY, USA) was employed for statistical analysis of this study. All data were represented as $x \pm s$. The independent sample t-test and chi square (χ^2) test were performed to check the difference between groups. The recovery of patients' respiratory function before and after treatment was taken as the dependent variable, and the improvement of diaphragmatic motor function was taken as the independent variable. *P* value less than 0.05 was defined as significant difference.

Table 1. Lung function indexes of the two groups before and after treatment (x ± s).

Testing index	Experimental group		Control group	
	Before	After	Before	After
FEV1 (L)	1.90 ± 0.42	2.57 ± 0.64	1.94 ± 0.45	2.13 ± 0.56
FVC (L)	2.12 ± 0.39	2.85 ± 0.57	2.15 ± 0.41	2.53 ± 0.49
PEF (L/s)	4.52 ± 0.49	5.76 ± 0.72	4.60 ± 0.54	5.29 ± 0.68
MVV (L/min)	80.33 ± 8.46	95.90 ± 13.36	81.85 ± 9.03	87.24 ± 11.43

Table 2. Comparison of respiratory muscle strength indexes between the two groups (x ± s).

Testing index	Experimental group		Control group	
	Before	After	Before	After
MIP (cmH_2O)	45.30 ± 7.29	61.26 ± 10.85	46.57 ± 8.04	53.47 ± 9.13
MEP (cmH_2O)	86.47 ± 16.15	105.96 ± 21.28	89.04 ± 18.36	96.79 ± 19.64
PIF (cmH_2O)	2.42 ± 0.11	5.27 ± 0.13	2.40 ± 0.09	4.82 ± 0.11

Results and discussion

Comparison of lung function indicators between two groups of patients before and after treatment

The weakness of respiratory muscles in stroke patients makes the thorax unable to fully expand, while the atrophy and thinning of the diaphragm and the reduction of the movement of the diaphragm cause the narrowing of the thorax, resulting in restrictive ventilation dysfunction and cough weakness [19]. The indexes of lung function before and after treatment in the two groups were shown in Table 1. Before the treatment, FEV1, FVC, PEF, and MVV in the experimental group were 1.90 ± 0.42 L, 2.12 ± 0.39 L, 4.52 ± 0.49 L/s, and 80.33 ± 8.46 L/min, respectively, while FEV1, FVC, PEF, and MVV of the control group were 1.94 ± 0.45 L, 2.15 ± 0.41 L, 4.60 ± 0.54 L/s, and 81.85 ± 9.03 L/min, respectively. There was no significant difference in lung function between the two groups before the treatment. After treatment, FEV1, FVC, PEF and MVV of the experimental group were 2.57 ± 0.64 L, 2.85 ± 0.57 L, 5.76 ± 0.72 L/s, and 95.90 ± 13.36 L/min, respectively, while FEV1, FVC, PEF and MVV of the control group were 2.13 ± 0.56 L, 2.53 ± 0.49 L, 5.29 ± 0.68 L/s, and 87.24 ± 11.43 L/min, respectively. The results showed that the FVC, FEV1, MVV and PEF of the two groups after treatment were significantly improved, and the treatment effect of the experimental group was significantly better than that of the control group ($P < 0.05$).

Comparison of respiratory muscle strength indicators between two groups of patients before and after treatment

Stroke can lead to respiratory dysfunction through direct involvement of respiratory centers, nerve conduction pathways between respiratory centers and effectors, and nerve fibers between each respiratory center [20]. The results showed that MEP, MIP, and PIF values of the experimental group before treatment were 45.30 ± 7.29, 86.47 ± 16.15, and 2.42 ± 0.11 cmH_2O, respectively, compared to the control group's 46.57 ± 8.04, 89.04 ± 18.36, and 2.40 ± 0.09 cmH_2O, respectively (Table 2). There was no significant difference in MEP, MIP, and PIF values between the two groups before treatment. The MEP, MIP, and PIF values of the experimental group after treatment were 61.26 ± 10.85, 105.96 ± 21.28, and 5.27 ± 0.13 cmH_2O, respectively, while the MEP, MIP, and PIF values of the control group were 53.47 ± 9.13, 96.79 ± 19.64, and 4.82 ± 0.11 cmH_2O, respectively. The MEP, MIP, and PIF values after treatment were significantly improved compared with those before treatment ($P < 0.05$).

Table 3. Diaphragm function before and after treatment (x ± s).

Testing index	Experimental group		Control group	
	Before	After	Before	After
IDT (mm)	2.31 ± 0.19	3.78 ± 0.17	2.34 ± 0.13	3.37 ± 0.19
EDT (mm)	1.82 ± 0.17	2.49 ± 0.28	1.84 ± 0.14	2.24 ± 0.31
DTF (mm)	27.92 ± 12.77	58.35 ± 17.23	26.48 ± 11.13	51.81 ± 18.12
DE (mm)	11.29 ± 2.08	15.97 ± 2.32	11.38 ± 2.17	14.52 ± 2.48

Table 4. TIS, MBI, and FSS scores before and after treatment (x ± s).

Testing index	Experimental group		Control group	
	Before	After	Before	After
TIS	9.43 ± 4.73	14.38 ± 3.98	9.58 ± 4.58	12.27 ± 4.21
MBI	37.43 ± 15.92	51.07 ± 18.78	37.86 ± 17.18	47.52 ± 18.72
FSS	4.12 ± 0.69	2.73 ± 0.72	4.17 ± 0.71	3.51 ± 0.81

Diaphragm function test

Diaphragm training, as a means of respiratory rehabilitation, aims to enhance the function of the patient's diaphragm through respiratory exercise, thereby increasing pulmonary ventilation and improving the body's metabolic level to improve the patient's quality of life [21]. Before the treatment, the values of IDT, EDT, DIF, and DE in the experimental group were 2.31 ± 0.19, 1.82 ± 0.17, 27.92 ± 12.77, and 11.29 ± 2.08 mm, respectively, while the values of IDT, EDT, DIF, and DE in the control group were 2.34 ± 0.13, 1.84 ± 0.14, 26.48 ± 11.13, and 11.38 ± 2.17 mm, respectively, with no significant difference between the two groups. After treatment, the values of IDT, EDT, DIF, and DE in the experimental group were 3.78 ± 0.17, 2.49 ± 0.28, 58.35 ± 17.23, and 15.97 ± 2.32 mm, respectively, while those in the control group were 3.37 ± 0.19, 2.24 ± 0.31, 51.81 ± 18.12, and 14.52 ± 2.48 mm, respectively (Table 3). The values of IDT, EDT, DIF, and DE after treatment were significantly improved compared with those before treatment, and the treatment effect of the experimental group was significantly better than that of the control group ($P < 0.05$).

Assessment of recovery status

The scores of TIS, MBI, and FSS in the experimental group before treatment were 9.43 ± 4.73, 37.43 ± 15.92, and 4.12 ± 0.69, respectively, while the scores of TIS, MBI, and FSS in the control group were 9.58 ± 4.58, 37.86 ± 17.18, and 4.17 ± 0.71, respectively. There was no significant difference between the two groups before treatment. The scores of TIS, MBI, and FSS in the experimental group after treatment were 14.38 ± 3.98, 51.07 ± 18.78, and 2.73 ± 0.72, respectively, compared to the control group's 12.27 ± 4.21, 47.52 ± 18.72, and 3.51 ± 0.81, respectively (Table 4). After treatment, the scores of TIS and MBI were significantly improved ($P < 0.05$). However, the score of FSS was significantly reduced ($P < 0.05$).

Comparison of pneumonia incidence rates

During the treatment period, two patients in the experimental group had pneumonia, and the incidence of pneumonia was 10%. Seven patients in the control group had pneumonia, and the incidence of pneumonia was 30%. The chi square (χ^2) test value was 5.562, indicating that there was a significant difference in the occurrence of SAP between the two groups ($P < 0.05$).

Conclusion

The combination of respiratory muscle training and respiratory electrical stimulation could

significantly improve the patients' pulmonary function, respiratory muscle force, and diaphragm function. in addition, it could also promote the recovery of the patients' trunk muscle force, improve the ability of daily life activities, reduce the fatigue symptom, and reduce the incidence of pneumonia.

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