Physiotherapy rehabilitation of respiratory system and the factors which facilitate its plasticity after Spinal Cord Injury

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ABSTRACT

Spinal cord injury (SCI) is quite common and can occur either as an acute injury after an accident or a fall, or as the result of other pathological conditions. SCI results in important loss of functionality, which apart from the kinetic affects multiple physiological systems, such as the respiratory system. The aim of this study was to review the methods of respiratory physiotherapy rehabilitation in patients with SCI. For this reason, a review of the current literature was performed by using the online PUBMED database and the following keywords: spinal cord injury; respiratory physiotherapy; respiratory muscle training. Inclusion criteria in the review were: primary studies in humans with SCI, published after 2000 in English language. Twenty-one studies were finally included in the review. Currently, many respiratory physiotherapy protocols are available aiming at the strengthening of respiratory and abdominal muscles, respiration training and phrenic nerve stimulation. The respiratory and abdominal muscles strengthening interventions improve respiratory function and cough production capacity and decrease the frequency of respiratory infections. Phrenic nerve stimulation constitutes a promising technique, as it promotes cough production, decreases respiratory infections and is more cost- effective compared with other respiratory physiotherapy interventions.

Key Words: spinal cord injury, respiratory physiotherapy, respiratory muscle training

Introduction

Spinal Cord Injury (SCI) is a severe type of trauma of the central nervous system, which continues to be a global concern. It significantly affects patients' quality of life and increases the burden at the social care systems. In addition, it prevents social accession, causes physical impairment and malfunction of several body organs, but more importantly increases mortality [1], [4]. The prevalence rate of SCI is 20.7-83 per million in the USA and approximately 8.0-130.6 per million in Europe. Many studies have shown similar frequency in China [1].

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The pathophysiology of SCI can be divided in two stages: primary and secondary injury. The primary injury is caused by immediate damage to the nerve tissue from the main mechanical attack. The secondary injury is caused by a series of events, such as bleeding, edema, demyelination and inflammatory reactions [15].

In case of SCI due to an accident or a fall, a significant percentage of patients die instantaneously or within a few days after the injury. More than half of the SCI patients will have to be treated for associated injuries during their initial hospitalization, such as traumatic brain and cerebrovascular injury. In their future life, patients who survive the primary injury will face several risks related to post-injury medical complications. The overwhelming consequences of SCI were considered, until very recently, non reversible. Before the appearance of improvements in the acute clinical management in the middle of 20th century, the expectation of life of SCI patients was low. Nowadays, patients with SCI are successfully reintegrated in the society, and to a great extent, people with incomplete damage can live independently, having almost a normal life. However, the absence of functional improvement can increase the rate of serious complications, such as respiratory failure. [24] Respiratory muscle weakness after SCI has negative consequences for the patient, by affecting ventilation and pulmonary volumes. Furthermore, the inefficiency of the expiratory muscles, leads to incomplete achievement of cough and secretion explement. Therefore, there is a high possibility of respiratory morbidity with continuous respiratory infections (2/year/person) often leading to pneumonia. [6] [22]. Indeed, respiratory dysfunction complications as atelectasis and pneumonia keep on being among the main death causes in patients with complete SCI [27], [2]. Respiratory failure can partly be treated with mechanical respiratory support, however, making the patient more prone to pneumonia and atelectasis. Because of these complications, the research of therapies and strategies for functional improvement of respiratory function after SCI is of major importance [34]. Respiratory muscle training includes special training of the inspiratory and expiratory muscles to improve strength and resistance. Respiratory muscles can be trained in a similar way as the extremity muscles with devices that increase the muscle load. A respiratory physiotherapy session contains a specific number of repetitive exercises or a specific time-period for each exercise. The intensity is defined individually as a percentage of the maximum measured respiratory strength and the respiratory pressure or capacity [13].

Although the advantages of physiotherapy in patients with SCI are well known, there is currently no literature review providing collective information about the several used techniques and their efficacy. The aim of this study was to review the methods of respiratory physiotherapy rehabilitation in patients with SCI.

A review of the current literature was performed by using the online PUBMED database and the following keywords: spinal cord injury; respiratory physiotherapy; respiratory muscle training. Inclusion criteria in the review were: primary studies in humans with SCI, published after 2000 in English language. Initial search resulted in 56 articles. After checking titles and abstracts, 23 articles were rejected for not meeting the inclusion criteria. More specifically, the studies were rejected because of their irrelevant title and because the examined population was animals or people without SCI. Of the 33 remaining publications, 6 were rejected because respiratory physiotherapy was not the main intervention. Finally, there were 27 studies included in the present review (Table 1).

Discussion

Respiratory muscles strengthening

Respiratory muscles are skeletal muscles. Training can increase the strength of the muscles involved in inspiration and expiration, improving the pulmonary function. In case of complete muscle paralysis, training cannot improve muscle function. However, in patients with incomplete SCI, training could reinforce the activation and the coordination of the respiratory muscles. Nowadays, there are several respiratory muscle training (RMT) techniques for patients with quadriplegia to enhance and improve their endurance. These techniques include resistance breathing, endurance loading devices, flow spirometry, positive expiratory flow devices, lingual-pharyngeal respiration and singing. RMT in patients with quadriplegia has proven to be beneficial for the respiratory function and resistance and patients' perceived difficulty to breathe. In a recent study, one year after RMT, 84% of patients who were

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included in the study improved in terms of strength and breathing and reported to have more air in their lungs [3]. Furthermore, in another study, patients who did not receive RMT had three times higher incidence of mortality compared to the intervention group [18]. Similar results have been reported with respiratory physiotherapy application in patients with incomplete quadriplegia or complete hemiplegia. [25] Moreover, RMT leads to significant improvement of the spirometric values, the VO_2max, the time until fatigue and the maximum output [29]. It has been reported, that 1000 repetitions of Inspiratory Muscle Strenght Training (IMST) can lead to 1% increase of maximum inspiratory pressure ($PI_{max),}$ during a high intensity training (above 80-85% of peak oxygen uptake). Also, an increase of 10 units in training intensity can lead to a 7% increase of the maximum expiratory pressure ($PE_{max)}$ in patients with complete motor lesions [27].

The improvement of cough strength is also a factor that minimizes the risk of respiratory complications. To achieve an adequate cough a person needs not only an increased forced expiratory activity, but also an increased pre-cough inspiration. Muscle strength is highly related with cough capacity [26]. It has been found that the Respiratory Resistance Training (RRT) flow devices can enhance the lung function and performance in patients with SCI. A concurrent flow resistance device can increase the maximum inspiratory pressure (MIP) which is highly related to diaphragm strength. After training, there is an activation of phrenic motor neurons in patients with weak diaphragm. In a recent study, the MIP in the group of patients that received therapy was 33cm H_2O higher compared to the control group [19]. The singing intervention is also beneficial for patients with SCI who have vocal restriction. It has been observed, that singing intervention activates laryngeal muscle [30].

Abdominal muscle training

In addition to the respiratory muscles, the abdominal muscles play an equally important role in the respiratory function. Consequently, patients with SCI that have weak diaphragm, abdominal and intercostal lateral muscles, have a poor pulmonary function. Therefore, stimulation and strengthening of the abdominal muscles is a basic goal of respiratory physiotherapy. A combination of exercises for the abdominal and the respiratory muscles could have major effects in pulmonary function. Patients that performed the abdominal drawing-in maneuver using a stabilizer and RMT using a spirometer showed 19,98% higher Forced Vital Capacity (FVC) and 16,71% higher Forced Expiratory Volume in one second (FEV_1) [16]. In fact, abdominal muscles training can lead to a faster weaning from the mechanical ventilation. In a recent study, patients submitted to abdominal muscles training were able to wean from mechanical ventilation 11 days earlier, compared to patients who didn't perform abdominal muscles training [21]. Studies have shown that the application of an abdominal binder in patients with acute complete quadriplegia can improve their respiratory and vocal function and their blood pressure. The binding of the paralyzed abdomen can significantly improve the FVC, the FEV_1, the maximum expiratory flow, the maximum inspiratory pressure, and the maximum phonation time [33].

As mentioned before, cough is a significant parameter of the normal respiratory function. Functional electrical stimulation (FES) with electrodes placed in a posterolateral position over the abdominal wall is a very promising technique that improves cough. Thus, cough training in addition with FES can increase the voluntary cough pressures in patients with SCI (especially those with high level injuries). In a recent study, patients submitted to this treatment showed a 50% increase in the PEF rates [20]. In addition, a device called sniff controller can be used to self- trigger the abdominal FES to enhance cough. Patients using this device showed a higher peak flow which is the first event of the cough process. Moreover, the Peak Expiratory Flow (PEF) of automatic Sniff Controller-FES assisted cough increased about 23-27%. Furthermore, 30% of the patients maintained the abdominal muscle strength after the cough effort. All assistive methods improved cough efficacy compared to unassisted cough by about 25% and reached 76% of the mean expected values of PEF [13].

Breath training

Breath training exercises include specific techniques of breathing such as hyperpnoea, intermittent positive pressure breathing and intermittent hypoxia.

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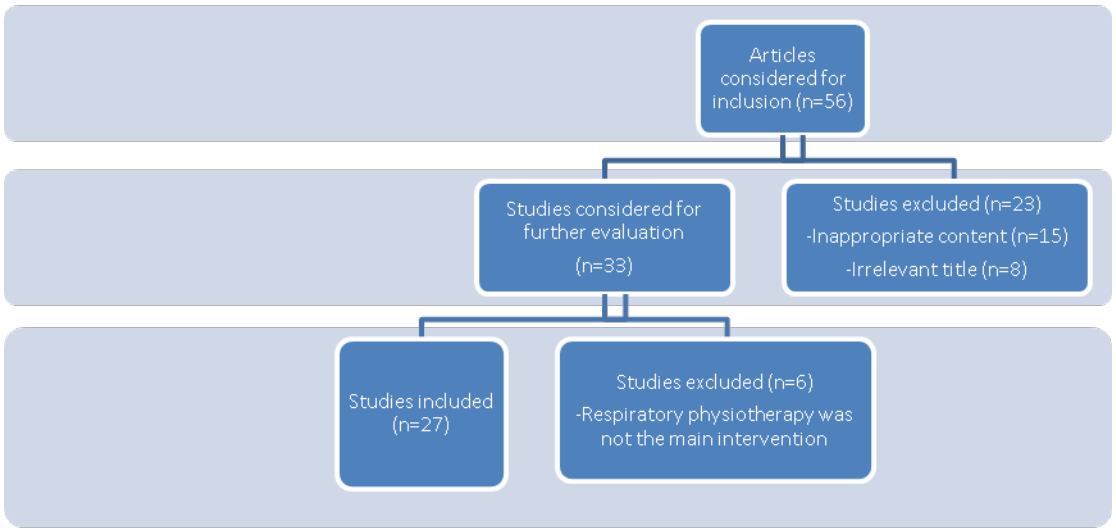

Table 1: *Current review flowchart.*

Normocapnic hyperpnoea using a laboratory-developed device can improve the endurance of respiratory muscles. In a recent study, after a muscle endurance training program with normocapnic hyperpnoea, patients showed a difference about -20% in Borg Scale [32]. It has been proven that forced hyperpnoea is beneficial for RMT, as these muscles usually work at law resistance [35]. There are also similar devices that contribute to the expiratory muscle resistive training with maximal expiratory force. A small handheld device is used to make repeated expiratory resistance breathing exercises to improve the measures of ventilator function in patients with SCI [28].

Electrical nerve stimulation

Electrical nerve stimulation techniques are widely used for skeletal muscle function rehabilitation in several kinetic systems, in patients with SCI. For more than five decades, this technique is also used for the rehabilitation of the respiratory muscles [5], [11]. In phrenic nerve stimulation the electrodes are placed in the thoracic wall of the patient. In a recent study, the authors reported that by using this technique patients avoided the need of mechanical ventilation [14]. The intramuscular placement of phrenic nerve electrodes instead of the conventional phrenic nerve pacing reduces the risk of phrenic nerve injury [7]. The use of a Spinal Cord Stimulation (SCS) system implanted in the lower thoracic spine of patients with SCI can successfully enhance cough, while it increases the airway pressures and high peak airflow rates. It is more beneficial when the patients try the glossopharyngeal breathing and then perform cough. Another type of functional electrical stimulation is the intramuscular diaphragm pacing system which also enhances the respiratory muscle function [8], [9].

In conclusion, respiratory physiotherapy in patients with SCI can be especially helpful in improving breathing and cough, preventing infections, and improving patients' overall quality of life. Respiratory physiotherapy has a wide scientific field and several interventions that should be applied individually according to patient needs.

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