

# New perspectives for chest physical therapy in spinal cord injury - a systematic review

Novas perspectivas de fisioterapia respiratória em lesão medular - uma revisão sistemática

Felipe Soares Macedo<sup>1</sup>

Clarissa Cardoso dos Santos Couto Paz<sup>2</sup>

Adson Ferreira da Rocha<sup>3</sup>

Cristiano Jacques Miosso<sup>3</sup>

Hellen Batista de Carvalho<sup>4</sup>

Sergio Ricardo Menezes Mateus<sup>2,3</sup>

## Keywords

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## Descritores

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## Corresponding author

Felipe Soares Macedo  
Campus Universitário Darcy Ribeiro,  
70910-900, Brasília, DF, Brazil.  
macedosfelipe@gmail.com

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## Abstract

**Objective:** To describe and analyze parameters and effects of surface electrical stimulation on the respiratory muscular function among individuals with spinal cord injuries, especially while coughing.

**Methods:** A systematic literature review was developed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. The search was conducted in the PubMed, PEDro, and LILACS databases, using the following descriptors: "functional electrical stimulation," "electrostimulation, electrical stimulation," "coughing," "bronchial hygiene," "quadriplegia," "spinal cord injury", "tetraplegia", and "individual with tetraplegia" – in Spanish, English and Portuguese, with no restrictions on year of publication. Inclusion criteria were: articles describing studies with samples of individuals with spinal cord injuries treated with electrical stimulation and outcomes related to the respiratory system. Articles containing studies with invasive cough stimulation trials were excluded.

**Results:** The 12 selected articles revealed the heterogeneity of electrostimulation protocols for expiratory function, which can include frequencies ranging from 30 to 50 Hz; pulse from 25 to 400  $\mu$ s; applied in up to eight electrodes distributed across the expiratory and accessory muscles. Time of administration also varied, and the current amplitude was usually estimated by the patient's perception, reaching values higher than 100mA.

**Conclusion:** Even though the review did not find rigorous parameters for physical therapy using electrical stimulation, because of the shortage and low-quality of the studies that systematically compare stimulation parameters among subgroups, positive changes were observed in the assessed respiratory muscle function variables, such as peak expiratory and cough flow in individuals with cervical and thoracic spinal cord injury.

## Resumo

**Objetivo:** Descrever e analisar parâmetros e efeitos da estimulação elétrica de superfície na função muscular respiratória de pessoas com lesão medular, sobretudo durante a tosse.

**Métodos:** Foi realizada uma revisão sistemática da literatura, com base no *Preferred Reporting Items for Systematic Reviews and Meta-Analyses*. A busca foi realizada nas bases de dados *PubMed*, *PEDro* e *LILACS*, por meio dos seguintes descritores: "estimulação elétrica funcional", "eletroestimulação, estimulação elétrica", "tosse", "higiene brônquica", "quadriplegia", "lesão medular espinhal", "tetraplegia" e "sujeito com tetraplegia" – em espanhol, inglês e português, sem restrição quanto ao ano de publicação. Foram incluídos artigos com amostra de indivíduos com lesão medular assistidos por estimulação elétrica com desfecho relacionado ao sistema respiratório, e foram excluídos artigos com ensaios invasivos de estímulo a tosse.

**Resultados:** Os 12 artigos incluídos revelam heterogeneidade nos protocolos de eletroestimulação da função expiratória, que podem incluir frequências de 30 a 50 Hz, com pulsos de 25 a 400  $\mu$ s, aplicada por até oito eletrodos distribuídos pelos músculos expiratórios e acessórios. O tempo de aplicação também foi variável e a amplitude de corrente frequentemente estimada pela percepção do paciente, podendo chegar a valores superiores a 100mA.

**Conclusão:** Apesar de não ser possível estabelecer parâmetros rigorosos de fisioterapia por meio da estimulação elétrica, pela escassez e qualidade de estudos que comparem sistematicamente parâmetros de estimulação em subgrupos, foram observadas alterações positivas nas variáveis de função muscular respiratória avaliadas, como o pico de fluxo expiratório e de tosse, em pessoas com lesão medular cervical e torácica.

<sup>1</sup>Faculdade de Medicina, Universidade de Brasília, Brasília, DF, Brazil.

<sup>2</sup>Faculdade de Ceilândia, Universidade de Brasília, Brasília, DF, Brazil.

<sup>3</sup>Faculdade Gama, Universidade de Brasília, Brasília, DF, Brazil.

<sup>4</sup>Instituto de Medicina Integral Professor Fernando Figueira, Recife, PE, Brazil.

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## Introduction

Historically, spinal cord injury (SCI) is associated with high incidence and prevalence rates. In the United States, for example, there are approximately 11,000 new cases per year, and currently, there are up to 288,000 individuals living with SCI in the country. Injuries that result in complete tetraplegia are especially relevant in this scenario because of their frequency, sequela, and burden to patients and the health system.<sup>(1)</sup> In the case of Brazil, on the other hand, data like these are still unknown, due to the absence of an effective notification system, despite high vehicle accident rates, which are the main cause of spinal cord injury.

In addition to their challenging psychological, social, and economic impacts, spinal cord injuries are also considered complex clinical and functional dysfunctions, triggered by damage to the spinal cord nerve tissue, usually through traumatic mechanisms, such as fractures or dislocation of vertebral bodies. These mechanisms invariably lead to wide-reaching and heterogeneous physiological changes, which include damage to neuromotor function – such as loss of motion due to complete limb paralysis, in addition to ineffective respiratory muscle strength for voluntary ventilation.<sup>(1,2)</sup> According to data from the National Spinal Cord Injury Statistical Center, changes in the last 40 years in rehabilitation and care paradigms have favored survival rates and life expectancy of individuals with SCI. However, respiratory complications still account for the main cause of hospitalization, re-hospitalization, and death of individuals with spinal cord injuries, representing more than 20% of the cause of deaths that occur especially within the first six months following the injury.<sup>(2,3)</sup>

This reality can be related to mechanic respiratory alterations, triggered by increased bronchial tonus, which associated with weakness and/or respiratory muscle paralysis culminate in non-parenchymal restrictive diseases.<sup>(3)</sup> Paralysis of respiratory muscles causes damage to the pulmonary function, which due to impaired muscle contractions, affects inspiratory volume, peak cough flow,

and maximum expiratory pressure. This renders coughing inefficient to perform bronchial hygiene, constituting a risk factor for atelectasis, respiratory infection, and respiratory failure, and installing the ideal conditions for vulnerability to hospitalization and death.<sup>(4-8)</sup>

In this context, therapeutic interventions are essential to assist respiratory muscle mechanics and reestablish functions directly related to cough efficiency, in addition to keeping airway permeability and promoting bronchial hygiene.<sup>(9-11)</sup> Physical therapy practices and resources have stood out among existing therapies for their capacity to promote artificial muscle contractions through the use of surface electrical stimulation on respiratory muscles. The modulation of electrical stimulation parameters can cause intermittent pressure on the paralyzed respiratory muscles, which contributes to increasing intra-abdominal pressure and influences peak cough flow, similar to the physiological bronchial hygiene mechanism.<sup>(12-13)</sup>

Based on the aforementioned issue, the objective of this systematic literature review was to identify and describe parameters and effects of surface electrical stimulation on respiratory muscle function among individuals with SCI, especially while coughing.

## Methods

A systematic literature review was developed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), organized and conducted by two independent researchers specialized in respiratory muscle dysfunction (voluntary cough), surface electrical stimulation, and spinal cord injury.<sup>(14)</sup>

### Article search and identification

Computerized searches were carried out by two independent researchers with experience on the studied topic, with a third reviewer available in case of divergence in the results. Searches were conducted using the library of the Latin-Amer-

ican and Caribbean Center on Health Sciences Information (LILACS), and the databases Medical Literature Analysis and Retrieval System Online (MedLine/PubMed) and Physiotherapy Evidence Database (PEDRO). First, the search strategy included descriptors in Spanish, English, and Portuguese, according to the list of Health Science Descriptors (DeCS), followed by other common keywords that emerged in the resulting articles.

Portuguese descriptors included “*estimulação elétrica funcional*”, “*eletroestimulação*”, “*estimulação elétrica*”, “*tosse*”, “*higiene brônquica*”, “*quadriplegia*”, “*lesão medular espinhal*”, “*tetraplegia*”, and “*tetraplégico*”. Descriptors in English were “functional electric stimulation”, “electrostimulation”, “electrical stimulation”, “cough”, “mucociliary clearance”, “quadriplegia”, “spinal cord injury”, “tetraplegia”, and “tetraplegic”. For studies published in Spanish, the keywords were “*estimulación eléctrica funcional*”, “*electroestimulación*”, “*estimulación eléctrica*”, “*tos*”, “*higiene bronquial*”, “*cuadriplejía*”, “*traumatismos de la médula espinal*”, “*tetraplejía*”, and “*tetraplégico*”.

The search equation was created based on the combination of OR and AND operators, according to the characteristics of each database. In the Pubmed database and LILACS library, the search was conducted in the “advanced search” field. Searches in the PEDro database used the “simple search” field, and “basic form.” The search was conducted between May and December 2016 and updated in August 2017. In addition to the computerized search, a manual search was carried out based on the references of the articles found in the electronic databases. Additionally, an expansive search was conducted in the Central Library of the University of Brasília (BCE/UnB), based on printed journals, end-of-course papers, dissertations, and theses.

### Selection of evidence

To reach the proposed objective, the following question was formulated based on the PICO (Patient Intervention Comparison Outcome) strategy: Which parameters of surface electrical stimulation

are used in physical therapy for individuals with SCI and what are its effects?

The articles found in the computerized and manual searches were previously analyzed by title and abstract. As in the search phase, this analysis was conducted by two experienced independent researchers, with a third reviewer available in case of divergences in search reports. The articles found in the computerized and manual searches were compared to identify any possible intra- and inter-duplicates among databases and search strategies.

### Inclusion and exclusion criteria

Eligible papers for data summarization had to contain samples composed of human individuals with SCI, published in English, Portuguese, or Spanish, whose intervention variables were surface electrical stimulation and clinical outcome variables were related to the respiratory function such as peak expiratory and cough flow, vital capacity, and tidal volume. These articles were then fully read and analyzed according to a previously structured chart (Chart 1). Articles that did not meet these criteria were eliminated, such as literature reviews, systematic reviews and the like, in addition to articles that were not indexed or were not available in full in the studied libraries, databases, and data platforms. Studies with samples of individuals under mechanical ventilation, submitted to noninvasive mechanical ventilation, invasive cough stimulation interventions, and whose outcomes were not relative to respiratory or pulmonary muscle function were also excluded.

### Summary of the data

Summarization was conducted with the extraction of data as follows: authors and year of publication, sample characteristics, instruments and/or equipment used to assess the effects of surface electrical stimulation on respiratory muscle function, and finally, outcomes associated with the electrical stimulation intervention on the respiratory function of individuals with assessed SCI.

**Chart 1.** Evidence selected with the description of the parameters and effects of surface electrical stimulation to stimulate voluntary cough in people with spinal cord injury

Study	Sample	Assessed respiratory variables	Electrostimulation parameters	Respiratory function outcomes
Linder S H., (1993) <sup>17</sup>	8 male subjects Classification: traumatic and complete Level: C4 - 5	Variables of pulmonary function and maximum expiratory pressure (MEP) at baseline and electrical stimulation in supine position.	Modality: Functional electrical stimulation (FES) Frequency: 50 Hz Pulse width: 300 $\mu$ s Pulse duration: 2-3 s Amplitude: 100% Time on/off: - Rise: 0s Wave: asymmetrical biphasic Time: Up to 30 min Electrodes: 4 - 8 electrodes on abdominal wall	MEP increased an average of 33 cm H <sub>2</sub> O when electrostimulation was applied in relation to baseline values. No differences were observed regarding the use of belts and patient position.
Jaeger R J. et al., (1993) <sup>18</sup>	14 male and 5 female subjects Classification: complete and incomplete Level: C4 - 7	Baseline, manual, and electrostimulation peak expiratory flow (PEF).	Modality: Electrical stimulation Frequency: 50 Hz Pulse width: 300 $\mu$ s Pulse duration: 0.75s Amplitude: Up to 110 V Time on/off: - Rise: - Wave: - Time: Up to 30 min. Electrodes: Self-adhesive, round and 7.62 cm in diameter, placed on the abdomen	Electrostimulation significantly increased PEF, reaching a peak of 230 L/min $\pm$ 64 L/min; however, values were lower than those for manually assisted coughing.
Sorfi J. et al., (1996) <sup>19</sup>	1 female subject with SCI Classification: traumatic and complete Level: C6 - 7	Trunk volume (chest and thorax) by optical tracking system, measured in supine position before and during electrostimulation.	Modality: Electrical stimulation Frequency: 50 Hz Pulse width: 25 -300 $\mu$ s Pulse duration: 1s Current amplitude: 20-100 mA Time on/off: - Wave: - Rise: - Time: 2 x 1 min Electrodes: a pair or rectangular electrodes (3 x 8 cm) on the abdomen, along the midline (6 cm above and the second 5 cm below the umbilicus)	Thoracic volume varied with electrostimulation, suggesting increased tidal volume.
Zupan A. et al., (1997) <sup>20</sup>	11 male and 3 female subjects Classification: complete and incomplete Level: C4 - 7	Forced vital capacity (FVC) and forced expiratory volume in the first second (FEV <sub>1</sub> ) assessed before and after protocol in sitting and supine position. Electrostimulation associated with muscle training was applied by a physical therapist and by the patient.	Modality: Electrical stimulation Frequency: 50 Hz Pulse width: 300 $\mu$ s Pulse duration: 0.75 s Voltage amplitude: up to 110 V Time on/off: - Wave: - Rise: - Time: 20 - 30 min. Electrodes: 4 electrodes on the abdomen	Average increase of 19% in VC in sitting position and 17.5% in supine position. Average increase of 20.5% in FEV <sub>1</sub> in sitting position and 16% in supine position. One month post-intervention, the average increase was 9.5% in FCV and 7% in FEV <sub>1</sub> .
Cheng et al., (2006) <sup>21</sup>	Trial group: 11 male and 2 female subjects Levels: C4 - 7 Classification: complete. Control group: 10 male and 3 female Level: C4 - 7 Classification: complete	Pulmonary function variables measured in supine position before and after (3 weeks, 3 months and 6 months) each protocol (physical therapy protocol vs. physical therapy protocol associated with stimulation).	Modality: Neuromuscular electrical stimulation Frequency: 30 Hz Pulse width: 300 $\mu$ s Pulse duration: - Current amplitude: 0 - 100 mA Time on/off: 4s/4s Wave: symmetric biphasic wave Rise: 0.5 s Time: 30 min Electrodes: placed on motor points of the clavicular part of the bilateral pectoral and abdominal muscles (3 cm above umbilicus)	Pulmonary function variables, such as vital capacity, forced vital capacity, forced expiratory volume in 1 second and peak flow improved after physical therapy intervention, however, these data were more favorable when physical therapy was associated with electrostimulation. Six months post-intervention, 6 of the 13 individuals in the control group presented pulmonary complications, whereas only one person presented complications in the experimental group. Still in the control group, one subject was submitted to a tracheostomy and invasive ventilation.
Golle et al., (2006) <sup>22</sup>	3 male and 1 female subjects Level: C4 - 6 Classification: complete	Peak cough flow (PCF) and tidal volume (TV) measured in sitting or supine position, during calm breathing and stimulated cough through electrostimulator controlled by an algorithm that identifies respiratory flow.	Modality: Electrical stimulation Frequency: 50 Hz Pulse width: 100 - 400 $\mu$ s Pulse duration: - Current amplitude: 30-100 mA Time on/off: - Wave: Balanced monophasic Rise: - Time: - Electrodes: 4 on the rectus abdominis, 2 on the transverse abdominal (33 mm x 53 mm rectangular), 2 on the external and 2 on the internal oblique muscles (50 mm round)	Automated electrical stimulation increased CV in 71% and PCF in 54%. The greatest variation of tidal volume was 0.35 L to 0.6 L, and the lowest difference, 0.32 L to 0.35 L, respectively. The highest variation rate of cough was from 2.2 L/s to 3.4 L/s with stimulation.

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Study	Sample	Assessed respiratory variables	Electrostimulation parameters	Respiratory function outcomes
Spivak et al., (2007) <sup>(23)</sup>	10 male subjects Level: C4 - 7 Classification: complete.	Assessed pulmonary function variables: unassisted, with manual physical therapy, with electrostimulation administered by caregiver, with electrostimulation administered by patient, and stimulation activated by EMG signals measured in supine position.	Modality: Functional electrical stimulation Frequency: 50 Hz Pulse width: 300 µs Pulse duration: - Current amplitude: 0 - 100 mA Time on/off: - Wave: - Rise: - Time: - Electrodes: 4 electrodes on the left and 4 on the right of the abdomen	Peak expiratory flow, forced vital capacity, and maximum voluntary ventilation increased in all interventions, except in self-administered electrostimulation. Manual physical therapy presented the best results when compared to other forms of cough assistance.
Golle et al., (2008) <sup>(24)</sup>	3 male and 1 female subjects Level: C4 - 6 Classification: complete	Peak cough flow (PCF), tidal volume (TV), expiratory reserve volume (VER), minute ventilation (MV), respiratory frequency and partial CO2 pressure of exhaled air measured in sitting position during calm respiration and automatically electrostimulated cough through a respiratory flow controller.	Modality: Functional electrical stimulation Frequency: 50 Hz Pulse width: 400 µs Pulse duration: - Current amplitude: 30 - 100 mA Time on/off: - Wave: - Rise: - Time: - Electrodes: 8 self-adhesive electrodes distributed in 2 pairs on the rectus abdominis muscle, 1 pair on the transversal abdominal muscle, 1 on the external oblique muscle, and 1 on the internal oblique muscle	An increase of up to 50% was observed in the number of coughs during electrostimulation, with an increase in PCF in all subjects. Maximum increase was 0.49 L/s (p < 0.05). CV varied up to + 0.23L. Forced vital capacity improved up to + 0.49 L/s and PCF improved in all subjects, as well as CV. The other assessed variables presented heterogenous data.
Butler et al., (2010) <sup>(25)</sup>	8 male and 3 female subjects Level: C3 - T6 Classification: complete and incomplete	Inspiratory capacity (IC), vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1) measured in sitting position during cough with occlusion of the glottis with and without electrostimulation. Stimulation was controlled and automatically triggered in 6 subjects and self-controlled by 5.	Modality: Functional electrical stimulation Frequency: 50 Hz Pulse width: - Pulse duration: 1 s Current amplitude: 50-350 mA Time on/off: - Wave: - Rise: - Time: 3 applications Electrodes: 2 pairs of electrodes (4 x 18 cm) bilaterally placed on the lateral-posterior part of the trunk	Pulmonary function variables increased in individuals submitted to electrical stimulation while coughing. Peak cough flow increased 36%, whereas mean expiratory flow increased 80%, and expiratory pulmonary volume, 41%. Occlusion of the glottis during maneuvers also contributed to improving pulmonary function variables; however, the best results were presented when electrostimulation was administered automatically by the system.
McLachlan et al., (2013) <sup>(12)</sup>	11 male and 1 female subjects Level: C3 - 6 Classification: complete and incomplete	Forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), peak expiratory flow (PEF), maximum expiratory pressure (MEP), forced expiratory volume in 1 second (FEV1), measured during voluntary cough before, during and after a respiratory muscle rehabilitation program using functional electrical stimulation.	Modality: Functional electrical stimulation Frequency: 30 Hz Pulse width: 50 µs Pulse duration: - Current amplitude: 0-120 mA Time on/off: - Wave: Biphasic Rise: - Time: 6 weeks, 5 days per week, 11 - 230 min Electrodes: 8 self-adhesive electrodes distributed in 2 pairs of oblique abdominal muscles (bilateral) and 2 pairs on rectus abdominis muscle	Stimulation did not produce vigorous contractions in all subjects; neither was it tolerated by the entire group. The repercussions of the protocol on pulmonary function were heterogeneous, with slight positive changes in peak cough flow, maximum expiratory pressure, and tidal volume during training. However, after training, no statistically significant differences were found in FEV1 in the relation FEV1/FVC and PEF.
McBain et al., (2013) <sup>(26)</sup>	Group A: 7 male subjects Level: C4 - T5 Classification: complete and incomplete Group B: 8 male subjects Level: C4 - 7 Classification: complete	Inspiratory capacity (IC), vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), peak expiratory flow (PEF) measured in sitting position during baseline state, voluntary cough, and expulsion phase of cough, both submitted to electrical stimulation.	Modality: Functional electrical stimulation Frequency: 50 Hz Pulse width: - Pulse duration: 3 s Current amplitude: Up to 250 mA Time on/off: - Wave: - Rise: - Time: 6 weeks, 5 days per week (5 series of 10 coughs per day) Electrodes: 2 electrodes (5 x 18 cm) placed bilaterally on the lateral-posterior part of the abdomen	Stimulation improved acute cough in patients with high SCI. During voluntary coughs, cough stimulation increased PEF in 50%. After 6 weeks of cough training, there was a significant increase in PEF (3.1 ± 0.1 to 3.6 ± 0.1 L/s) and in expiratory cough flow during non-stimulated voluntary cough among the assessed subjects. Pulmonary function measures improved after training. FEV1 increased from 1.3 ± 0.1 to 1.4 ± 0.1 L (P = 0.002), FVC increased from 1.7 ± 0.2 to 1.9 ± 0.2 L (P = 0.03), PEF increased from 2.1 ± 0.1 to 2.4 ± 0.2 L / s (P = 0.03), VC increased from 1.5 ± 0.1 to 1.8 ± 0.1 L (P = 0.009) and IC increased from 1.4 ± 0.1 to 1.6 ± 0.1 L (P = 0.04).

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Study	Sample	Assessed respiratory variables	Electrostimulation parameters	Respiratory function outcomes
McBain et al., (2015) <sup>27</sup>	7 male subjects Level: C4 - 7 Classification: complete and incomplete	Pulmonary function variables measured in sitting position during baseline state, voluntary cough, and expulsion phase of cough, both submitted to electrical stimulation.	Modality: Functional electrical stimulation Frequency: 50 Hz Pulse width: - Pulse duration: 1 s Current amplitude: 50 - 360 mA Time on/off: - Wave: - Rise: - Time: - Electrodes: 2 pairs of electrodes (4 x 18 cm) placed bilaterally on the lateral-posterior part of the abdomen	The greatest percentage of patients submitted to electrical stimulation while coughing had an increase in cough flow simultaneously with the increase of the current amplitude applied. Peak cough flow reached $4.0 \pm 0.4$ L/s with parameters of 80 to 240 mA and was significantly higher than in voluntary cough without electrostimulation, which was $2.2 \pm 0.1$ L/s, $p < 0.05$ . Total expiratory volume was also higher during stimulating, reaching 2.1 L whereas no stimulation had 1.3 L with the same parameters.

SCI - Spinal cord injury; C - cervical level injury; Maximum expiratory pressure - MEP; Not informed (-); PEF - Peak expiratory flow; FES - Functional electrical stimulation; Hz - abbreviation of hertz, unit of measurement equal to one cycle per second;  $\mu$  - symbol for micron, unit of length equal to 1/1000000 of a meter; s - abbreviation for seconds, unit of measurement of time; mA - abbreviation for milliampere, unit of measurement of one-thousandth of an ampere; Min - abbreviation for minutes, unit of measurement of time, corresponding to 60 seconds. V - abbreviation for Volts, unit of measurement of potential difference

## Methodological quality evaluation

Considering the methodologies found in the selected articles, methodological rigor was assessed using two different instruments. For randomized clinical trials, the PEDro assessment scale was used.<sup>(15)</sup> Observational studies were assessed using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist.<sup>(16)</sup> Data summary and methodological evaluation also followed independent assessment criteria and were conducted by two expert researchers, with a third reviewer available in case of divergence. However, the third reviewer's participation was not needed in any of the steps described above.

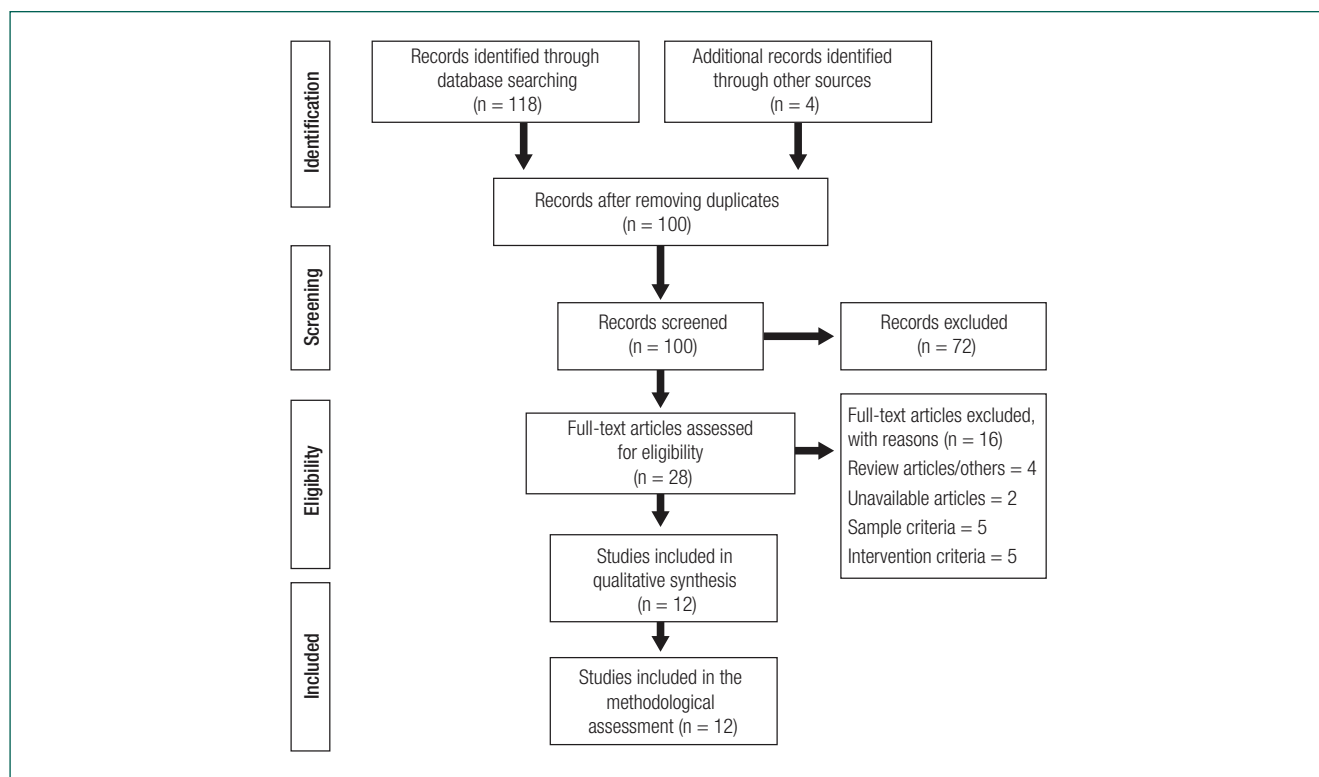
## Results

The trajectory regarding the search, selection, eligibility, and inclusion of scientific evidence related to the effects and parameters of surface electrical stimulation on respiratory function of individuals with SCI can be seen in Figure 1.

Using these strategies, 74 papers were found in the PEDro database, 44 in PubMed, and none in the other databases, totaling 118 papers. The manual search resulted in 4 pertinent documents, with two articles published before 1993. Next, 22 duplicate studies were identified. In the end, 100 articles were initially related to the research question; however, 72 did not meet the eligibility criteria and were excluded. The reason for this exclusion was the fact that even though the search strategy used attempted to find poten-

tially eligible documents, much of the evidence did not meet the inclusion criteria. For example, articles with randomized clinical trials with animals were eliminated, as the inclusion criteria for this systematic review required samples made up of human subjects. Of the 28 papers included for full assessment, 16 were excluded for not meeting the eligibility criteria shown in the flowchart below (Figure 1). Detailed reasons for exclusion were: studies conducted in individuals submitted to invasive mechanical ventilation or non-invasive ventilation. Studies based on invasive cough stimulation interventions, such as epidural electrical stimulation, and review articles were also excluded, in addition to two articles published prior to 1993. In the case of these two articles, the Central Library of the University of Brasília requested the complete version via email, but no response was obtained. Furthermore, one of these papers was a letter to the author, so it was excluded nonetheless because of the previous criterion.

Concluding the eligibility process, 12 articles were included for data summary and assessment of methodological quality. Thus, the evidence extracted originated from articles in English, published between 1993 and 2015, and that were mostly observational. These articles presented heterogeneous samples in terms of injury level (cervical and thoracic) and classification, time of injury, gender, and age. Variations were also observed in terms of physical therapy intervention and assessment protocols using surface electrical stimulation.



**Figure 1.** Flowchart of the screening of evidence based on the PRISMA guidelines

**Table 1.** Assessment of methodological rigor using STROBE: observational studies of electrical stimulation for assisted coughing in individuals with spinal cord injury

Article	STROBE items																						Total items
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Linder S H., (1993) <sup>(17)</sup>	0	1	1	1	0	1	0	1	0	0	1	0	1	0	1	0	0	1	0	1	1	0	11/22
Jaeger R J. et al., (1993) <sup>(18)</sup>	0	1	0	1	0	0	0	1	1	0	1	1	1	1	1	1	0	1	0	1	1	0	13/22
Sorli J. et al., (1996) <sup>(19)</sup>	0	1	1	1	0	1	0	1	0	0	1	0	1	1	1	1	0	1	0	1	1	0	13/22
Golle et al., (2006) <sup>(22)</sup>	0	1	1	1	0	0	0	1	0	0	1	0	1	1	1	0	0	1	0	1	1	0	11/22
Spivak et al., (2007) <sup>(23)</sup>	1	1	1	1	0	0	0	1	0	0	1	1	1	1	1	1	0	1	1	1	0	0	13/22
Golle et al., (2008) <sup>(24)</sup>	0	1	1	1	1	1	0	1	0	0	1	1	1	1	1	0	0	1	1	1	0	0	14/22
Butler et al., (2010) <sup>(25)</sup>	0	1	1	1	0	1	0	1	0	0	1	1	1	1	1	1	0	1	0	1	0	1	14/22
McLachlan et al., (2013) <sup>(12)</sup>	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	0	1	1	1	0	0	16/22
McBain et al., (2015) <sup>(27)</sup>	0	1	1	1	0	1	0	1	0	0	1	1	1	1	1	1	0	1	0	1	0	1	14/22

0 - Does not meet the recommended criterion; 1 - Meets the recommended criterion; the percentage refers to the total value obtained in the items assessed, with 100% corresponding to 22 items

**Table 2.** Assessment of methodological rigor using the PEDro scale: clinical trials using electrical stimulation for assisted coughing in individuals with spinal cord injury

Article	PEDro scale items											Total score
	1*	2	3	4	5	6	7	8	9	10	11	
Zupan A. et al., (1997) <sup>(20)</sup>	*	1	0	1	0	0	0	1	0	0	0	2/10
Cheng et al., (2006) <sup>(21)</sup>	*	1	0	1	0	0	0	1	0	1	1	5/10
McBain et al., (2013) <sup>(26)</sup>	*	1	0	1	0	0	0	0	0	0	0	2/10

0 - Does not meet the recommended criterion. 1 - Meets the recommended criterion; \* - Criterion not scored according to the PEDro scale recommendation

Respiratory muscle function was evaluated using pulmonary function measures, such as peak cough or expiratory flow, and maximum expiratory pressure. These measures showed that the baseline performance of the assessed individuals was lower than expected. The electrostimulation parameters,

shown in detail in Chart 1, indicate that this resource, used in different modalities and modulations, with current amplitude up to 360 milliamperes (mA), positively impacted the assessed respiratory muscle function variables, such as peak cough flow (Tables 1 and 2).

## Discussion

The evidence found in this review shows that physical therapy intervention using surface electrical stimulation can improve respiratory muscle function in individuals with different levels and complexities of spinal cord injury, with short-, mid- and long-term impacts, including in the prevention of severe respiratory complications, such as pneumonia.<sup>(9,12,17, 21,27)</sup>

Regarding the samples included in the trials, papers that mentioned patient age demonstrated results similar to the statistics of specialized SCI treatment centers. Most individuals with SCI are usually part of the economically active population; in this review, individuals were between 16 and 60 years old, with a predominance of men, and mainly trauma-related etiology.<sup>(17-27)</sup> These characteristics corroborate studies conducted in the United States, in some European countries, and in Brazil.<sup>(2,28,29,30)</sup>

The evidence showed that the values for pulmonary and respiratory function and cough variables, such as vital capacity (VC), forced expiratory volume (FEV<sub>1</sub>), maximum expiratory pressure (MEP), peak expiratory flow (PEF), and peak cough flow (PCF), used to classify the sample and assess intervention protocols, were lower than expected; however, none of the patients presented parenchymal lung disease.<sup>(17-27)</sup> In cases of individuals with complex clinical profiles, which include, in addition to care to global musculoskeletal function, care to respiratory and pulmonary muscle function, interventions by means of electrical stimulation in patients with SCI are a classic technique in the repertoire of physical therapists. However, the use of electrical stimulation, like rehabilitation physical therapy practices, have undergone changes, as shown in evidence about physical therapy gathered in the last 30 years.<sup>(31-33)</sup>

Surface electrostimulation protocols for pulmonary function and cough include different current modalities. The most common modalities used in the primary studies were functional electrical stimulation (FES), and functional neuromuscular electrical stimulation.<sup>(17-27)</sup> Regarding the effects of

the analyzed protocols, different modulations of electrostimulation were able to produce artificial muscle contractions and, consequently, increase intra-abdominal pressure and lead to increased peak expiratory flow, improved muscle and pulmonary function in individuals with chronic and acute spine injuries, with different levels of injury - from the third cervical level (C3) to the twelfth thoracic level (T12) - and classifications (complete and incomplete).

Some studies have focused on surface electrostimulation in patients with SCI submitted to invasive mechanical ventilation, but these were not within the scope of this review. However, the immediate application of surface electrical stimulation on expiratory abdominal muscles is recommended for hemodynamically stable patients with SCI between the cervical and thoracic levels, even when free of invasive or non-invasive ventilation. This practice is based on the presence of early symptomatology of expiratory muscle dysfunction to the detriment of respiratory muscle paralysis.<sup>(17-27)</sup>

Time of intervention can vary according to the respiratory muscle performance of individuals with SCI, requiring longitudinal assessments of respiratory muscle function and clinical symptoms relative to respiratory infection. In this direction, the investigated interventions and follow-up proposals went up to six months. In this time, not only did patients submitted to electrical stimulation of expiratory muscles show greater values for respiratory and pulmonary muscle function variables, such as peak expiratory flow, but also lower frequency of respiratory infections.<sup>(21,26)</sup>

To treat respiratory muscle function non-invasively, the literature recommends placing surface electrodes on expiratory and accessory muscles, such as the rectus and oblique abdominis muscles, as shown in Chart 1. Different shapes (round, rectangular and square), size and number of electrodes were reported, and location was determined with greater precision by using electrodiagnostic testing of motor points. Water-based gel was used between the electrodes and the skin to conduct the electrical current from the equipment to the neuromotor fibers. Even though the current should



flow through the path of least possible resistance, the investigated studies did not cite any previous preparation for electrode placement, such as trichotomy and local asepsis.<sup>(17-27)</sup>

The most common position of patients during electrostimulation assessment and intervention was supine and/or sitting, which can be related to several factors, such as classification of SCI, pulmonary function, and patients' level of functional independence and autonomy. Furthermore, other parameters presented greater relevance and visibility when it came to electrotherapeutic modalities, such as in the case of dosimetry applied to assist respiratory muscles.<sup>(17-27)</sup>

Regarding dosimetry parameters to promote functional contractions for respiratory function, there was a predominance of 30 to 50 Hz frequencies, generally associated with 300  $\mu$ s pulse width and current amplitude of up to 350 mA. Currents with these characteristics are capable of stimulating deep and higher-threshold fibers. Current amplitude was estimated by the visible contraction of sensibility of each patient.<sup>(17-27)</sup> Frequency modulation was related to the recruitment of the muscle fiber, and consequently, to the conditioning of the contraction, being that bands higher than 30 Hz were able to stimulate slow- and fast-twitch muscle fibers.<sup>(34,35)</sup>

Other relevant variables were frequently omitted in the investigated studies. Some examples include the current waveform and rise time, which is defined as the interval needed to obtain the final amplitude of current pulses. Only one study informed rise time (0.5 second), together with on (contraction) and off (rest) times (4 seconds each).<sup>(21)</sup>

Using frequency ranges between 30 Hz and 50 Hz associated with average pulse width of 300  $\mu$ s resulted in increased peak expiratory flow and lower occurrence of pulmonary infections when compared with groups that were treated without electrostimulation.<sup>(17-27)</sup> These parameters may be associated with the conditioning of respiratory muscles through intermittent contractions, which increases intra-abdominal pressure that mimics the physiological breathing and coughing mechanisms.

The studies included in this review presented methodological flaws, and the assessment of their performance is displayed in Tables 1 and 2, which correspond to observational studies and randomized clinical trials, respectively. It is worth noting that none of the studies carried out sample calculations, criteria recommended for well-conducted research. Additionally, none of the studies cited their sources of funding and measures adopted to avoid potential biases. These points weaken precise conclusions about physical therapy interventions using surface electrostimulation for respiratory assistance in individuals with SCI. Thus, new randomized clinical trials that follow appropriate design recommendations should be conducted to provide a better scenario of the effects of surface electrostimulation on pulmonary function and the respiratory complications of patients with SCI.

## Conclusion

The analyzed evidence revealed that surface electrical stimulation is a physical therapy intervention that can change and improve the performance of respiratory, pulmonary and cough muscle function in individuals with SCI. However, despite the mostly positive results, it cannot be stated that surface electrostimulation of respiratory function of the studied samples presented better results than traditional physical therapy practices, such as manual physical therapy to condition intra-abdominal pressure. Considering these findings, the authors recommend further research on the theme.

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## Collaborations

Macedo FS, Paz CCSC, Rocha AF, Miosso CJ, Carvalho HB and Mateus SRM contributed to the study's conception and design, data analysis and in-

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