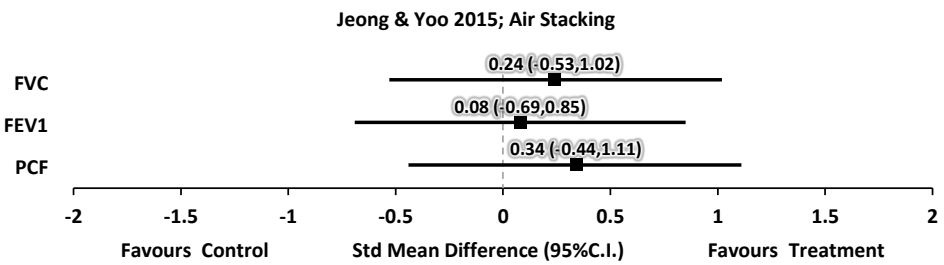
Author Year Country Research Design Score Sample Size	Methods	Outcome
DiMarco et al. 2019 USA Pre – post Level 4 N = 3	**Population:** 3 male patients with SCI who were being ventilated with a DPS to support ventilation, mean age 35 years, ASIA A (n = 2) and ASIA B (n = 1). **Treatment:** Patients received spinal cord stimulation (SCS) to restore expiratory muscle function and cough. SCS had to be applied every 30 s for 5–10 min, 2 or 3 times/ day, and during evacuation of secretions or airway clearance, as needed. Stimulus parameters were set at values resulting in maximal PAP generation. **Outcome Measures:** PE_{max}; PEF and airway pressure generation during SCS after pacing volume (maneuver #1), SCS after pacing volume and participant maximal spontaneous inspiratory effort (maneuver #2), and SCS after pacing volume and participant maximal spontaneous inspiratory with maximal spontaneous expiratory effort (maneuver #3); and a short questionnaire (an assessment of the degree of difficulty in raising secretions) were assessed every 4-5 weeks for an approximately 6-month period post implantation.	1. At baseline, when participants assisted the pacing system by making a maximal inspiratory effort synchronized with the paced breath, inspired volumes increased to 1.5 ± 0.1 L when participants made maximum inspiratory and expiratory efforts synchronized with DP, mean PEF and PE_{max} were 2.2 ± 0.2 L/s and 39 ± 6 cmH_2O, respectively. 2. After a mean of 16.0 ± 5.9 weeks after initiation of SCS: With maneuver #1, PEF and PE_{max} were 3.7 ± 0.4 L/s and 56 ± 3 cmH_2O respectively ($P < 0.05$ for both when compared with unassisted efforts). With maneuver #2, PEF and PE_{max} were 7.5 ± 1.5 L/s and 75 ± 4 cmH_2O respectively ($P < 0.05$ for both when compared with maneuver #1). With maneuver #3, PEF and PE_{max} were 9.0 ± 1.9 L/s and 90 ± 6 cmH_2O respectively ($P < 0.05$ when compared with maneuvers #1 and #2). 3. At the 20-, 24-, and 28-week after implantation, participants reported substantial improvement reporting none to only mild difficulty. With regard to ease in raising secretions with use of the cough system compared with other

		methods, there was also marked improvement in each person at each of the three time points. 4. 2/3 participant developed asymptomatic signs of autonomic dysfunction. No other side effects were noted.
DiMarco et al. 2020 USA Pre – post Level 4 N = 10	**Population:** 10 male patients with cervical SCI and marked paresis of their expiratory muscles, mean age 40 years, and 7 years post injury. **Treatment:** SCS (this device involves the minimally invasive placement of wire electrodes on the dorsal epidural surface of the spinal cord at the T9 and T11 levels). Participants were instructed to use SCS every ~30s for 5– 10 min, 2–3 times/day and as needed to clear airway secretions. Stimulus parameters were set at values (30–40 V, 50 Hz, pulse width 0.2ms) which resulted in near maximal PAP generation. **Outcome Measures:** Spontaneous IC, PI_{max}, PE_{max} and maximum airway pressure generation during SCS at TLC with individual maximal expiratory effort, were measured at baseline and over a 20-week period.	1. Each study participant used SCS on a regular, daily basis. 2. Lung function increased gradually from over the course of the study. By week #20, mean IC and PI_{max} had increased by 127 ± 8% ($P < 0.05$) and 127 ± 6% ($P < 0.05$), respectively. By the other hand, spontaneous PE_{max} increased 127 ± 14% of baseline values but without reaching significance ($P > 0.05$). 3. At week #20, the magnitude of airway pressure generation during SCS with patient effort at TLC was linearly related to IC and PI_{max} with correlation coefficients of 0.72 ($P < 0.05$) and 0.82 ($P < 0.05$), respectively.
DiMarco et al. 2021 USA Pre – post Level 4 N = 5	**Population:** 5 male patients with cervical SCI, mean age 37 years, AIS A (n = 5), time since injury 3 years. **Intervention:** Fully implantable lower thoracic SCS cough system was surgically placed to improve bowel management. SCS was applied at home, every 30 s for 5-10 min.	1. Consequent to muscle reconditioning, daily use of SCS resulted in the gradual increase in airway pressure generation over the course of the initial 4-17 weeks after which this parameter plateaued. Measured with 40-V stimulation (50Hz, 0.2ms pulse width), airway pressure increased during

	Participants used the device 2-3 times/d, on a chronic basis to maintain expiratory muscle strength; for evacuation of secretions or airway clearance as needed; and during bowel routines at their discretion during a 21-week period. For each participant stimulus parameters were set at values resulting in maximal airway pressure generation. **Outcome Measures:** Airway pressure generation (achieved spontaneously, and with SCS at FRC, TLC and TLC with maximal expiratory effort), and weekly completion of Bowel Routine Log (including bowel management, medications taken, use of mechanical methods, frequency of bowel-related activities, and use of SCS) were collected at week 0 (first day of stimulation) and at weeks 4, 8, 12, 17, and 21 after initiation of SCS.	SCS at FRC, TLC, and TLC with maximum expiratory effort. As expected, pressure generation increased with increasing stimulus amplitude between 10 and 40 V after the reconditioning period.
DiMarco et al. 2022 USA Pre – post Level 4 N = 29	**Population:** 29 patients with traumatic SCI and significant paresis of their expiratory muscles, 26 males and 3 females, mean age at implantation 42.5 years, ASIA A (n = 28) and ASIA B (n = 1); and mean time since injury 10 years. **Treatment:** Patients received SCS and were divided in two groups according with the type of the electrodes used (wire electrodes (WE), n = 12; and disc electrodes (DE), n = 17). Electrodes were implanted between T9 and T11 spinal levels; total duration of stimulation ranged between 0.6 and 0.8 s and pulse	1. Following the reconditioning program, with both types of electrodes, SCS (at FRC, TLC, and TLC with individual effort) resulted in substantial increases in airway pressure and peak airflow compared to spontaneous efforts ($P < 0.05$). There was no significant difference between use of the DE vs. the WE. 2. There were linear relationships between airway pressure and peak airflow for both types of electrodes (with no significant differences between DE and WE).

	duration was 0.2 ms; and stimulus frequency was set at 50 Hz. Participants were instructed to apply stimulation every 30 s for 5 – 10 min, 2 or 3 times/day, and when, as required, for evacuation of secretions. **Outcome Measures:** Airway pressure and peak airflow generation achieved with SCS; clinical parameters including ease in raising secretions, incidence of acute respiratory tract infections (RTI) and side effects were collected at baseline and during outpatient visits every 4–5 weeks during the first 28 weeks, then at 3-month intervals for 6 months, and after 1 year.	3. Following use of SCS, the need for suctioning or assisted cough fell to 0.56 ± 0.20 and 0.55 ± 0.21 for DE and WE, respectively representing unaware or rare need for use of these maneuvers comparing with baseline ($P < 0.05$ for each). 4. The number of RTI fell from an average of 1.3 ± 0.3 and 1.3 ± 0.5 / year to 0.3 ± 0.1 and 0.1 ± 0.1 / year for the DE and WE, respectively ($P < 0.01$ for each). 5. The only significant side effect was the occurrence of autonomic dysfunction which occurred in 11 of the 29 patients; 5 in the DE and 6 in the WE groups ($P > 0.05$).
Nygren-Bonnier et al. 2018 Sweden Pre – post Level 4 N = 20	**Population:** 10 ventilatory independent patients with SCI; mean time since injury 20.5 (5-42) years; 9 males and one female; mean age 42.5 (24-64) years; C5 AIS B (n = 1), C6 AIS A (n = 5), C6 AIS B (n = 2), C7 AIS B (n = 1), and C8 AIS B (n = 1). 10 participants able to perform glossopharyngeal insufflation (GI) acted as reference group. **Intervention:** Performing the glossopharyngeal breathing procedure in a single session. **Outcome Measures:** TLC, VC, RV, PCO_2, PO_2, mean arterial blood pressure, mouth airway pressure and HR were collected in a sitting position at baseline, in a sitting position with GI, in a supine position with GI, and finally in a sitting position after the intervention.	1. Comparing to baseline, the non-SCI group (with respect to the SCI group) performing GI in a sitting position had a higher increase in TLC ($P < 0.01$), VC ($P < 0.001$), Paw ($P < 0.001$), and HR ($P < 0.05$), a higher decrease in MAP ($P < 0.001$), and there was no difference in RV. 2. While performing GI in a sitting compared to a supine position, TLC, mean arterial blood pressure, HR, and mouth airway pressure remained unchanged in the SCI group whereas RV decreased in the supine position ($P < 0.01$). The difference in RV in a sitting compared to a supine position also differed between the groups ($P < 0.01$) and the able-bodied group had a higher HR in a

		sitting position compared to the SCI group, (P < 0.01). 3. Mean arterial blood pressure, HR, and mouth airway pressure responded in similar way in both groups in a sitting as well as a supine position.
Molgat-Seon et al. 2017 Canada Pre – post Level 4 N = 12 (2 with cervical SCI)	**Population:** 12 people with respiratory muscle weakness (maximal inspiratory mouth pressure <30% predicted; age = 29 ± 3 yrs), including 2 with C5 SCI, and 12 healthy controls (age = 29 ± 2 yrs) **Treatment:** LVR with manual resuscitation bag delivered to maximum tolerated mouth pressure. **Outcome Measures:** Maximum insufflation capacity; respiratory system compliance (pulse method); PCF; PEF during LVR; lung volumes (TLC, VC, IC, FRC, ERC, RV).	1. In the respiratory muscle weakness group, LVR increased respiratory system compliance 40% above baseline, no change in control group. 2. Peak expired flow during LVR increased ~1l/s 3. No change in unassisted PEF or PCF. 4. LVR had no effect on lung volumes.
Jeong & Yoo 2015 Korea RCT PEDro = 6 Level 1 N = 26	**Population:** 26 participants with cervical SCI Mean (SD) age*: 47.6 (11.7) years *data prior to exclusion, N=30 **Treatment:** Experimental group (14, Exp): 20 repetitions of air stacking twice a day Control group (12, Ctrl): 20 repetitions of incentive spirometry twice a day. **Outcome Measures:** FVC, FEV_1, PCF.	1. Between-group – significant increase in FVC and PCF in experimental group compared to controls. 2. Within-group – significant difference in FVC and PCF at 6 weeks (compared to baseline) in experimental group; only FVC significantly different at 6 weeks in controls.
	Effect Sizes: Forest plot of standardized mean differences (SMD ± 95%C.I.) as calculated from pre- and post-intervention data.	

		
Torres-Castro et al. 2014 Chile Cross-sectional Level 5 N = 15	**Population:** Fifteen in-patients with complete tetraplegia (C4–C6, AIS A) were included. Median age was 33 years (16–56). **Treatment:** PCF was measured during four different interventions: spontaneous maximal expiratory effort (MEE); MEE while receiving Assisted Cough (MEE-AC); MEE after Air Stacking with a manual resuscitation bag (AS-MEE); and MEE with AS and AC (AS-MEE-AC). **Outcome Measures:** PCF.	1. We observed significant differences in PCF while applying MEE-AC and AS-MEE compared with MEE. 2. The difference in PCF value was greatest using the AS-MEE-AC techniques combined. 3. The application of combined techniques (AS-MEE-AC) can reach near normal PCF values. This is a low-cost, simple and easily applied intervention that could be introduced to all patients with tetraplegia.
Pillastrini et al. 2006 Italy RCT PEDro = 3 Level 2 N = not reported	**Population:** Complete cervical SCI, control group mean(SD) age 52.2(17.6) yrs; experimental group age 31.5(16.1) yrs. Number of participants not reported. **Treatment:** Experimental group = Manual respiratory kinesitherapy (included chest therapy techniques such as postural drainage, assisted coughing, Ambu bag to provide positive pressure) coupled with MIE (portable machine which inflates lung with positive pressure and assists coughing with negative pressure); control group = manual kinesitherapy only. **Outcome Measures:** FVC, FEV_1 and PEF.	1. Experimental group showed significant increases in FVC, FEV_1 and PEF. 2. Use of MIE is shown to be an effective adjunct to manual chest therapy techniques, since it makes it possible to achieve adequate bronchio-pulmonary clearance.

Butler et al. 2011 Australia Pre-post Level 4 N= 11	**Population:** 11 people with SCI (8M 3F); mean(SD) age 45(5); YPI 9.2(4.1); SCI at or above T6 **Treatment:** Bilateral posterolateral surface ES of abdominal expiratory muscles at 50Hz, abdominal binder **Outcome Measures:** Measures of lung function (IC, VC, FVC, FEV_1) gastric pressure (Pga), Pes.	1. Abdominal stimulation increased Pga and Pes during voluntary efforts and during coughing 2. During cough, stimulation significantly increased PEFR by 36(SD 5)%, mean expiratory flow by 80(8)%, expired lung volume by 41(16)% and FEV_1 by 39(12)%. 3. Wearing an abdominal binder increased IC by 17% and VC by 14%. 4. No additional improvement to any respiratory measures during cough with addition of binder to stimulation were found.
Crew et al. 2010 USA Case series Level 4 N = 40	**Population:** 40 patients with tetraplegia; 33 AIS A or AIS B; 14 acute SCI (mean (SD) age 50.3(11.2), YPI 2.3(1.7)) and 26 chronic SCI (58.3(12.9), YPI 22.5(15.1)). **Treatment:** MIE device for outpatient use. **Outcome Measures:** Medical record review (respiratory hospitalization rates/cause).	1. There was a non-significant reduction of respiratory hospitalization rates/year. 2. There was one instance of pulmonary embolus hospitalization post-MIE. 3. Non-smokers averaged 0.14(0.16) respiratory hospitalizations/year, significantly different from smokers (0.41(0.36)). Post-MIE, smokers' respiratory hospitalizations/year decreased significantly to 0.19(0.32).
Nygren-Bonnier et al. 2009 Sweden Pre – post Level 4 N = 25	**Population:** 25 patients with SCI between C4-C8 and ventilatory independent; 20 males and 5 females; mean age 47 (21 – 70) years; ASIA A (n = 12), ASIA B (n = 11), and ASIA C (n = 2); injury level C4 (n = 6), C5 (n = 4), C6 (n = 9), C7 (n = 5), and C8 (n = 1). **Treatment:** The participants performed 10 cycles of glossopharyngeal pistoning (breathing) in a sitting or	1. VC, ERV, FRC, RV, TLC, and alveolar ventilation all increased significantly after the training period ($P < 0.05$). 2. Mean GI volume above VC increased a 28% (0.88 ± 0.5 l). 3. PCF changed using GI from 395 ± 83 l min^{-1} to 424 ± 101 l min^{-1}, ($P = 0.057$). 4. No changes were shown in diffusion capacity, MIP or MEP.

	supine position four times a week, for 8 weeks. 5/25 participants could not exceed their VC when trying to perform GI; therefore, they were excluded from analysis. **Outcome Measures:** Spirometry (VC, ERV, FRC [measured with nitrogen washout], RV, and TLC, diffusion capacity, and alveolar ventilation); GI volume; mouth pressure (MIP and MEP); PCF; chest expansion; self-reported adherence; perceived tension in the chest (Borg CR-10 scale); and subjective ability to cough and to clear secretion were measured before and after training period.	5. After training, chest expansion increased significantly during maximal inhalation from RV to TLC and also on gulping to TLC_{GI}; 6. Some participants learned the GI technique immediately, whereas others took up to 3 weeks. Training compliance was 87% with a perceived tension on the Borg CR-10 scale during GI of 4 / 10. 7. Participants occasionally reported that during, or shortly after performing GI, temporary symptoms such as dizziness (90%), local paresthesia (35%) and tension in the chest (25%) occurred. Three participants reported episodes of syncope during GI and two reported that they were close to syncope. 8. The participants significantly improved their rating of the two questions concerning cough function and ability to clear secretions. a. Ability to cough: The average reply moved from median 7 (range: 1.5–10; strongly affected) to 3.5 (range: 2–10; P<0.01; moderately affected). b. Ability to clear secretion: The average reply changed from median 7 (range: 0–10; strongly affected) to 4 (range: 1–9; P<0.01; moderately affected).

DiMarco et al 2009 USA Post-test Level 4 N = 9	**Population:** 9 patients with SCI (age range 23-52 yrs). **Treatment:** Lower thoracic SCS at T9, T11, and L1 levels. **Outcome Measures:** Peak airflow and airway pressure generation.	1. Supramaximal SCS resulted in high peak airflow rates (ranging from 5.8 to 8.6L/s) and large airway pressure (ranging from120 to 144 cm H_2O) during stimulation at each electrode lead. 2. Maximum airflow rates and airway pressure were achieved with combined stimulation of any two leads. 3. At TLC, mean(SD) PEFR and airway pressure generation were 8.6(1.8) L/s and 137(30)cm H_2O.
Gollee et al. 2008 UK Pre-post Level 4 N = 4	**Population:** 4 people with tetraplegia (ages 16, 37, 45, and 49, level of injury C4-C6). **Treatment:** Surface FES of abdominal wall muscles. **Outcome Measures:** Spirometry, end-tidal CO_2 ($EtCO_2$).	1. Significant increase in V_T during quiet breathing (range 0.05-0.23 L). 2. Significant increase in CPF (range 0.04 – 0.47 L/s). 3. Respiratory rate during quiet breathing decreased in all participants when stimulated. 4. V_E increased by 1.05-2.07 L/min. 5. No significant changes in $EtCO_2$.
Kang et al. 2006 Korea Prospective controlled trial Level 2 N = 40	**Population:** 40 patients with traumatic cervical SCI. **Treatment:** Compared four types of coughs: unassisted PCF inspiratory assist cough flow abdominal thrust cough flow inspiratory assist & abdominal thrust cough flow. **Outcome Measures:** Spirometry, MIP, MEP.	1. MIP more so than MEP showed stronger relationships with PEF during cough maneuvers. 2. All three assisted techniques (2, 3 & 4) showed higher PEFRs. The combined assist (4) showed significantly higher values than the inspiratory or abdominal thrust assist.
Estenne et al. 2000 Belgium Pre-post Level 4 N = 16	**Population:** 16 participants: (8 SCI, 8 non-SCI matched for age, sex, height and weight controls), all 8 SCI participants had complete tetraplegia, C4-	1. Maximal stimulation increased Pga to 76.0(11.7) in controls and 29.9(3.7) cmH_2O in SCI participants. 2. The cumulative thickness of the four abdominal muscles

	C7, mean(SD) age SCI: 39(3.1) yrs; controls: 38(1.8) yrs **Treatment:** Magnetic stimulation of abdominal muscles. **Outcome Measures:** Pga.	was 34% smaller in the people with SCI than in control participants and correlated positively with changes in Pga induced by stimulation.
Garstang et al. 2000 USA Pre – post Level 4 N = 18	**Population**: 18 patients with SCI (C1-T3), 88% were C5 or higher. **Methods:** Surveyed preference for: suctioning or maximal in/exsufflation. **Outcome Measures:** Not specified.	1. Maximal in/exsufflation was less irritating, less painful, less tiring, less uncomfortable. All were clinically significant changes (except less tiring). 2. 16 of 18 patients preferred maximal in/exsufflation and one preferred suctioning; 1 patient had no preference. 3. When surveyed, average time from maximal in/exsufflation was 146 days and from suctioning was 253 days.
Linder 1993 USA Prospective controlled trial Level 2 N = 11	**Population:** 11 people with complete SCI (C4 and below), mean(SD) age: group 1 = 38(11.4) years, group 2 = 36.7(7.2) yrs, average time since injury: group 1 = 12.3, group 2= 18years **Treatment:** Group 1: assisted coughing by: 1) manual assist; or 2) FES. Group 2: assisted coughing by a portable abdominal binder incorporating electrodes. **Outcome Measures:** MEP.	1. In group 1, the MEP significantly increased with FES (mean difference in MEP between spontaneous and FES assisted cough was 33.3 cm H_2O). 2. In group 2, the portable FES device increased MEP from 32.3 to 58 cm H_2O, when compared to spontaneous cough.