Review Article

Assessments and exercises of cough strength in critically ill patients: a literature review

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Contributions: (I) Conception and design: K Liu, SM Zhang; (II) Administrative support: All authors; (III) Provision of study materials: SM Zhang, Y Muhetaer; (IV) Collection and assembly of data: None; (V) Data analysis and interpretation: SM Zhang; (VI) Manuscript writing: All authors; (VI) Final approval of manuscript: All authors.

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Background and Objective: Airway clearance is essential for maintaining patency in critically ill patients and relies on the mucociliary escalator, expiratory flow, and cough strength. A weak cough significantly increases the risk of therapy failure in patients receiving noninvasive ventilation (NIV) or high-flow nasal cannula (HFNC). This review aims to summarize current practices for assessing and exercising cough strength in critically ill patients.

Methods: A comprehensive literature search was conducted in PubMed, Embase, and ScienceDirect using specific keywords related to cough assessment and exercises. A total of 281 articles on cough assessment and 1,407 on cough exercises were identified, with 26 and 73 studies included in the review, respectively.

Key Content and Findings: By collecting literature related to cough efficacy, this narrative review describes methods for assessing cough ability and strategies for improving it. The assessment methods for cough ability include quantitative, semi-quantitative, and qualitative evaluations, each targeting different populations and having its own advantages and disadvantages. For patients whose cough ability has diminished, it is essential to implement cough training. Cough exercises focus on increasing inhaled volume, enhancing expiratory flow, and utilizing oscillation techniques to improve cough effectiveness. Choosing the appropriate training method for the patients can lead to significantly better outcomes.

Conclusions: Weak cough in critically ill patients correlates with increased risks of extubation failure and prolonged hospitalization. Employing appropriate assessment methods and individualized cough exercises is critical for improving patient outcomes in the intensive care unit (ICU) setting. Further research is needed to optimize training methods and enhance patient cooperation.

Keywords: Cough strength; cough peak flow (CPF); peak expiratory flow (PEF); semiquantitative cough strength score (SCSS); exercises

Submitted Oct 05, 2024. Accepted for publication Jan 10, 2025. Published online Feb 27, 2025.
doi: 10.21037/jtd-24-1673
View this article at: https://dx.doi.org/10.21037/jtd-24-1673

Introduction

Background

Airway clearance is crucial for maintaining airway patency in critically ill patients and depends on the mucociliary escalator, expiratory flow, and cough strength (1). In patients receiving noninvasive ventilation (NIV) or high-flow nasal cannula (HFNC) oxygen therapy to prevent intubation or reintubation, a weak cough is a significant risk factor for therapy failure (2,3). In intubated patients, a strong cough

Table 1 The search strategy summary

Items	Specification
Date of search	2023/12/31
Databases and other sources searched	PubMed, Embase and ScienceDirect
Search terms used	Cough assessment; cough intensity; cough strength; cough strength score; cough training; cough exercise
Timeframe	2000.01.01–2023.12.31
Inclusion and exclusion criteria	Inclusion criteria: RCTs, non-randomized trials, observational studies (case-control, cohort, cross-sectional studies), proof-of-concept studies, research protocols, case reports or series
	Exclusion criteria: subjects: hospitalized adult patients, language: non-English
Selection process	S.M.Z. and Y.M. searched relative articles, S.M.Z. sorted out and classified the literature and K.L. controlled the direction and content of the review
Any additional considerations, if applicable	None

alone is not a reliable predictor of successful extubation, as they may be reintubated for other reasons. However, a weak cough and large amounts of secretion are important predictors of extubation failure and reintubation (4-8). A weak cough is also associated with an increased incidence of tracheostomy, prolonged mechanical ventilation duration, extended hospital stays, and increased mortality (9-11). Critically ill patients with diseases of the airways, nerves, and muscles often exhibit a weak cough, particularly those with high-risk factors such as advanced age, obesity, smoking, diabetes, pulmonary infections, and recent surgeries (12). Therefore, assessing and exercising cough strength are especially important for managing critically ill patients.

There are significant differences between voluntary and involuntary coughs. The voluntary cough consists of three phases: the inspiratory phase, controlled by the volume of inhaled air; the compressive phase, characterized by elevated intrapulmonary pressure; and the expulsive phase, during which the glottis suddenly opens and strong coughs are produced by rapid airflow through the airways (13,14). The involuntary or protective cough consists of four phases (irritation, inspiration, compression, and expulsion) and can be induced by inhaling irritants, such as capsaicin in healthy patients, or by administering 2 mL of saline into the airways of patients with artificial airways (4,15). The primary neurophysiological difference in the mechanics of voluntary and involuntary coughs is that the latter originates in the brainstem (16,17). Notably, the expiratory and accessory muscles are more active during voluntary cough (18-20). The voluntary cough is activated to indicate the patient's strength in clearing the airways, while the involuntary cough reflects the capacity to protect the airways. This distinction is particularly important for patients at higher risk of silent aspiration and aspiration pneumonia (18,20,21).

Objective

This review aims to summarize current practices in assessing and exercising cough strength. We present this article in accordance with the Narrative Review reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1673/rc).

Methods

Literature search

We conducted a systematic search of the PubMed, Embase, and ScienceDirect using specific keywords for publications up to December 31, 2023. The search strategy included the following keywords: ("cough assessment" OR "cough intensity" OR "cough ability" OR "cough capacity" OR "cough strength" OR "cough strength score"). The search strategy summary is in *Table 1*. A total of 281 related articles were identified, and we ultimately enrolled 26 of them. The characteristics of these studies are summarized in *Table 2*. Commonly used methods for assessing cough strength are summarized in *Table 3*. We also searched for cough exercises using the keywords: ("cough training" OR "cough exercise"). A total of 1,407 related articles were identified, and we ultimately enrolled 73 of them. The characteristics

Table 2 Studies of assessing cough strength

Author, year	Country	Study	Patients	Methods	Conclusion
2003, Smina M (22)	America	Cohort	Endotracheally intubated patients (N=95)	PEF	PEF and the rapid shallow breathing index were independently associated with extubation outcomes, while only the PEF (< or = 60 L/min) was independently associated with in-hospital mortality
2009, Gao XJ (23)	China	Prospective	Endotracheally intubated patients (N=200)	CPF	CPF is a strong and independent predictor of extubation outcome when the patient is mentally clear and has a successful SBT. When the CPF >58.5 L/min, the successful rate is high. On the contrary, when the CPF < or =58.5 L/min, the unsuccessful rate is high
2009, Beuret P (24)	France	Prospective	Endotracheally intubated patients (N=130)	PEF	The interest of measuring the PEF to predict extubation outcome in patients having successfully passed the spontaneous breathing trial
2010, Su WL (15)	China	Evaluation study	Endotracheally intubated patients (N=150)	CPFi	CPFi as an indication of cough reflex has the potential to predict successful extubation in patients who pass an SBT
2013, Lee SC (25)	Korea	Cross-sectional study	TBI (n=25) and healthy (n=48)	CPF *vs.* LCR	As LCR can be measured as a numerical value and significantly correlates with CPF, LCR can be used to estimate cough ability of patients with TBI who cannot cooperate with CPF measurement
2014, Fan L (26)	China	Prospective observational	AECOPD receiving NIV (n=261)	SCSS	AECOPD patients with weak cough had a high risk of NIV failure. SCSS, APACHE II scores, and total proteins were predictors of NIV failure. Combined, these factors increased the power to predict NIV failure
2014, Duan J (27)	China	–	Endotracheally intubated patients (N=115)	V-CPF *vs.* IV-CPF	V-CPF is noninvasive. It is much more accurate than IV-CPF as a predictor of re-intubation in cooperative patients because the IV-CPF may underestimate cough strength in patients with high V-CPF
2015, Duan J (28)	China	–	Endotracheally intubated patients (N=186)	SCSS	SCSS was convenient to measure at the bedside. It was positively correlated with CPF and had the same accuracy for predicting reintubation after planned extubation
2016, Kulnik ST (29)	UK	Clinical trial	Stroke (N=72)	CPF	Risk of pneumonia reduces with increasing CPF of voluntary and to a lesser degree with increasing CPF of reflex cough

Table 2 (*continued*)

Table 2 (*continued*)

Author, year	Country	Study	Patients	Methods	Conclusion
2017, Gobert F (30)	France	Prospective observational study	Endotracheally intubated patients (N=92)	CPF measured using the flow meter of an ICU ventilator and Vt	After dichotomization (CPF < –60 L/min or Vt >0.55 L), there was a synergistic effect to predict early extubation success
2017, Lee KK (31)	UK	–	Patients with chronic cough (N=32)	Sound power and energy of cough	Cough sound power and energy correlate strongly with physiological measures and subjective perception of cough strength. Power and energy are highly repeatable measures but the microphone position should be standardised
2018, Umayahara Y (32)	Japan	–	Healthy (N=88)	Cough sounds	The absolute error between CPFs and estimated CPFs were significantly lower when the microphone distance from the participant's mouth was within 30 cm than when the distance exceeded 30 cm
2018, Umayahara Y (33)	Japan	–	Healthy (N=58)	Young *vs.* elder	Developed device can be applied for daily CPF measurements in clinical practice
2018, Aguilera LG (34)	Spain	Retrospective	Preoperative patients (N=9)	Pes, Pga, Pcv, Pbl, Prec	Cough pressure can be measured in the esophagus, stomach, superior vena cava or rectum, since their values are similar. It can also be measured in the bladder, although the value will be slightly higher
2018, Sohn D (35)	Korea	Retrospective analysis of a prospective maintained database	Dysphagia (n=163)	Reflexive PCF	Those with reflexive cough strength less than 59 L/min may be at high risk of respiratory infections within the first 6 months after dysphagia onset
2018, Ibrahim AS (36)	Egypt	Prospective observational study	TBI (n=80)	SCSS and GCS	SCSS has shown promise in predicting successful extubation in TBI
2019, Morrow BM (37)	South Africa	Retrospective descriptive study	NMD (n=41)	PEF, FVC, CPF	Peak expiratory flow < 160 $L \cdot min^{-1}$ and FVC <1.2 L were significantly predictive of CPF <160 $L \cdot min^{-1}$ (suggestive of cough ineffectiveness), whilst PEF <250 $L \cdot min^{-1}$ was predictive of CPF <270 $L \cdot min^{-1}$, the level at which cough assistance is usually implemented
2019, Norisue Y (38)	Japan	Physiologic study	Healthy adults (n=56)	Passive cephalic movement of the diaphragm	Passive cephalic excursion of the diaphragm during the cough expiratory phase significantly predicted CPF with maximum cough effort in healthy adults
2020, Froutan R (39)	Iran	RCT	–	PEF *vs.* WCT	Using the cough PEF rate increases the likelihood of extubation success and reduces adverse effects, and is recommended to be used for extubation decision-making

Table 2 (*continued*)

Table 2 (*continued*)

Author, year	Country	Study	Patients	Methods	Conclusion
2020, O'Neill MP (40)	Durban	Prospective observational	Endotracheally intubated patients (N=42)	ΔPcuff	CPF =60 L/min equates to ΔPcuff =28 cmH_2O
2021, Chang S (41)	China	Retrospective	Postoperative lung cancer (n=560)	Preoperative PEF	A PEF value of 250 L/min was selected as the optimal cutoff value in female patients, and 320 L/min in male patients. Patients with PEF under cutoff value of either sex had higher PPCs rate and unfavorable clinical outcomes
2021, Norisue Y (42)	Japan	Prospective cohort study	Endotracheally intubated patients (n=252)	Passive cephalic excursion of the diaphragm	PCED on ultrasonography was significantly associated with CPF and extubation failure after a successful SBT
2023, Bonny V (43)	France	Prospective observational study	Endotracheally intubated patients (n=106)	Sonometric assessment of cough	A threshold of Sonoscore <67.1 dB predicted extubation failure with a sensitivity of 0.93 and a specificity of 0.82
2023, Lee KW (44)	Korea	Retrospective pilot	PD (n=219)	CPF	A PCF value ≤153 L/min was associated with an increased risk of aspiration
2023, Tabor Gray L (45)	Finland	–	Amyotrophic lateral sclerosis (n=62)	MPT	MPT is a simple clinical test that can be measured via telehealth and represents a potential surrogate marker for important respiratory and airway clearance indices
2023, Recasens BB (46)	Spain	Cohort	NMD (n=50)	CPF	The smartphone app had 94.4% sensitivity and 100% specificity to detect patients with CPF <270 L/min

PEF, peak expiratory flow; SBT, spontaneous breathing trial; CPF, cough peak flow; TBI, traumatic brain injury; LCR, laryngeal cough reflex; AECOPD, acute exacerbations of chronic obstructive pulmonary disease; NIV, noninvasive ventilation; SCSS, semi-quantitative cough strength score; Vt, tidal volume; ICU, intensive care unit; VAS, visual analogue scale; GCS, Glasgow coma scale; NMD, neuromuscular disorders; FVC, forced vital capacity; RCT, randomized controlled trial; WCT, white card test; PPCs, postoperative pulmonary complications; IMV, invasive mechanical ventilation; PCED, passive cephalic excursion of diaphragm; PD, Parkinson disease; MPT, maximum phonation time.

of these studies are summarized in *Table 4*. This search aimed to identify all studies related to the assessment and exercises of cough ability in critically ill patients.

Eligibility criteria

We included the following types of literature: randomized controlled trials, non-randomized trials, observational studies (case-control, cohort, and cross-sectional studies), proof-of-concept studies, research protocols, and case reports or series. Studies were eligible if they met these criteria: Subjects: Hospitalized adult patients. Language: Publications in English, including full-text articles or abstracts.

Data abstraction

Two independent evaluators reviewed all selected studies based on the inclusion criteria outlined above. In cases of discrepancies in data extraction or assessment, a single investigator was consulted to resolve the inconsistencies. The following information was extracted from each study: author(s), publication year, country, study type, sample size, patient characteristics (e.g., medical conditions), assessment method, conclusions/results and other relevant information.

Table 3 Summary of cough assessment methods

Assessment methods	Patients (ET/Tra/no-tube)	High-risk	Advantages	Disadvantages
CPF/PEF (4,15,22-25,27,30,35,37,41,44,47-55)	No-tube: CPF; ET/Tra: PEF	Healthy adults: CPF <270 L/min Neuromuscular disease patients: CPF <160 L/min After extubation: CPF <160 L/min Mechanical ventilation patients: PEF <60 L/min	Easy, noninvasive, widely used, quantified	Accuracy varies among instruments
SCSS (4,26,28,36,56-59)	All	Score <3	Easy, noninvasive	Subjective Requires experienced evaluators
WCT (4,39,57)	ET/Tra	Negative	Easy, noninvasive, high sensitivity	Subjective Cannot evaluate passive cough
Diaphragm ultrasound (38,42,60-65)	All	–	Easy, noninvasive, widely used, quantified	Easily influenced by age, sex, and height. Differences between males and females
ΔPcuff (40)	ET/Tra	28 cmH_2O equals to CPF 60 L/min; <20 cmH_2O predicts extubation failure	Easy, noninvasive, quantified	Easily influenced by size and position of the artificial airway
Cough sound (31-33,45,46)	No-tube	–	Easy, noninvasive, quantified	Related to distance between the microphone and patient's mouth
Sonoscore (43)	ET	<61.7 dB	Easy, noninvasive, quantified	No more related data/studies
EMG (66,67)	All	–	Quantified	Invasive Influenced by activities of the heart and other muscles
Pes, Pgas, Pcv, Pbla, Prec (34)	All	–	Quantified	Invasive Cautious in post thoracic/abdominal surgeries patients

ET, endotracheal intubation; Tra, tracheotomy tube; CPF, cough peak flow; PEF, peak expiratory flow; SCSS, semiquantitative cough strength score; WCT, white card test; EMG, electromyography; Pes, esophageal pressure; Pgas, internal gastric pressure; Pcv, central venous pressure; Pbla, bladder pressure; Prec, rectal pressure.

Assessing cough strength

Cough peak flow (CPF) and peak expiratory flow (PEF)

CPF measures the maximum expiratory flow during a patient's cough after a complete deep inspiration, with the glottis first closed and then opened. CPF is regarded as the gold standard for assessing cough strength and is significantly influenced by disease status and the overall physical condition of patients (24,27). A CPF <270 L/min indicates a weakened cough in healthy adults, while a CPF <160 L/min in patients with neuromuscular disorders and dysphagia is associated with a high risk of infectious pneumonia (44). Additionally, patients with a CPF <160 L/min immediately after extubation are at high risk of reintubation (48-50). PEF measures the maximum expiratory flow after a complete deep inspiration through an open glottis, and is therefore generally lower than CPF. In intubated patients, CPF

Table 4 Studies of cough exercises

Year, author	Groups	Patient	Results
1996, Nakamura S (68)	Flutter	Chronic respiratory diseases (N=17)	Flutter can increase the expectoration of sputum and can relieve related symptoms
2000, Savci S (69)	AD *vs.* ACBT	COPD (N=30)	Autogenic drainage is as effective as the ACBT in cleaning secretions and improving lung functions
2003, Toussaint M (70)	IPV *vs.* without IPV	DMD (N=8)	IPV increases the effectiveness of assisted mucus clearance techniques
2004, Berney S (71)	Head-down tilt	Endotracheally intubated patients (N=20)	Head-down tilt and manual hyperinflation increase sputum production and improve PEF
2004, Winck JC (72)	Different pressure of MIE	Chronic ventilatory failure (N=29)	MIE may be a potential complement to noninvasive ventilation for a wide variety of patient groups
2004, Sancho J (73)	MIE	ALS (N=26)	MIE is able to generate clinically effective PCFMI-E (>2.7 L/s) for stable patients with ALS, except for those with bulbar dysfunction who also have a MIC >1 L and PCFMIC <2.7 L/s who probably have severe dynamic collapse of the upper airways during the exsufflation cycle
2006, McCarren B (74)	Vibration *vs.* Acapella, Flutter, PEP, percussion	CF (N=18)	Mean peak expiratory flow rate of vibration was greater
2006, Kang SW (55)	Unassisted PCF *vs.* three different techniques of assisted PCF	DMD (N=32)	Combined assisted cough technique (both manual and volume assisted PCF) significantly exceeded manual assisted PCF and volume assisted PCF
2006, Lange DJ (75)	HFCWO *vs.* control	ALS (N=46)	In patients with impaired breathing, high-frequency chest wall oscillation decreased fatigue and showed a trend toward slowing the decline of forced vital capacity
2007, Spivak E (76)	Self-controlled	Tetraplegia (N=10)	Abdominal FES failed to improve respiratory function in this study, but applying FES to abdominal muscles by EMG from the patient's muscle may promote caregiver-free respiration and coughing
2009, Durmuş D (77)	Conventional *vs.* Global Posture Reeducation *vs.* control	Ankylosing spondylitis (N=51)	Both exercises are efficient in improving pulmonary functions. Improved in pulmonary function tests were greater in the patients who performed the exercise according to global posture reeducation method
2009, Chatwin M (78)	CPT+MIE *vs.* CPT	NIV (N=8)	The device appeared to be safe and well tolerated, and may provide additional benefit to patients with neuromuscular disease and upper-respiratory-tract infection
2010, Barros GF (79)	RMT *vs.* control	CABG (N=38)	RMT performed in this phase was effective to restore the ventilatory capacity in the following parameters: MIP, MEP, PEF and tidal volume, in this group of patients
2010, Neligan PJ (80)	NIV *vs.* COT	OSA (N=40)	NIV given immediately after extubation significantly improves spirometric lung function at 1 hour and 1 day postoperatively
2010, Sutbeyaz ST (81)	IMT *vs.* breath training *vs.* control	Stoke (N=45)	IMT improves exercise capacity, sensation of dyspnea and quality of life
2011, Pangborn J (82)	IS *vs.* control	Sickle cell anaemia (N=49)	Locally designed incentive spirometry improved PEF

Table 4 (*continued*)

Table 4 (*continued*)

Year, author	Groups	Patient	Results
2011, Chicayban LM (83)	Flutter *vs.* control	Endotracheally intubated patients (N=20)	Flutter Valve improves lung secretion removal, mucus production, respiratory mechanics, and arterial oxygenation
2012, Matheus GB (84)	IMT *vs.* control	CABG (N=47)	Muscle training was performed to retrieve TV and VC in the PO3, in the trained group
2012, Nery FPOS (85)	CPAP *vs.* control	Lung resection (N=30)	When compared to breathing exercises, CPAP increases the 6MWD in postoperative lung resection patients, without prolonging air leak through the chest drain
2013, Cleary S (86)	Manual breath stacking technique *vs.* control	ALS (N=29)	Lung volume recruitment may be an effective treatment for improving coughing and pulmonary function in individuals with ALS
2013, Venturelli E (87)	TPEP *vs.* control	Chronic lung disease (N=98)	Temporary positive expiratory pressure improves lung volumes and speeds up the improvement of bronchial encumbrance in patients with lung diseases and hypersecretion
2013, McBain RA (88)	Cough training combined with FES	SCI (N=15)	Six weeks of cough training further increases gastric and esophageal cough pressures and expiratory cough flow during stimulated cough maneuvers
2014, Kim J (89)	Exercise *vs.* control	Stoke (N=20)	Exercise of the respiratory muscles using an individualized respiratory device had a positive effect on pulmonary function and exercise capacity and may be used for breathing rehabilitation in stroke patients
2014, Mellies U (90)	Titration from 10 to 40mbar using IPPB/LIAM	Healthy (N=60)	A submaximal insufflation is ideal for generating the best individual PCF even in patients with severely reduced compliance of the respiratory system. Optimum insufflation capacity can be achieved using IPPB or LIAM with moderate pressures
2014, Lacombe M (91)	IPPB+MAC *vs.* MIE *vs.* MIE+MAC	Neuromuscular (N=18)	PCF was higher with IPPB + MAC
2014, Kulnik ST (92)	IMT *vs.* EMT *vs.* sham RMT	Stoke (N=60)	RMT is effective for improving cough strength, IMT is effective for improving MIP and EMT is effective for improving MEP. RMT is effective for reducing the incidence of pneumonia
2014, Liu X (93)	Fibrobronchoscopic drainage	AECOPD (N=102)	The application of fibrobronchoscopy in the extubated AECOPD patients with low CPF can reduce the rate of re-intubation, avoid the prolonged ventilation, but cannot reduce the time of ICU stay
2014, Tokuda M (94)	TENS *vs.* control	Abdominal surgery (N=49)	TENS is a valuable treatment to alleviate postoperative pain and improve pulmonary functions (i.e., VC, CPF) in patients following abdominal surgery
2014, Esguerra-Gonzales A (95)	CPT *vs.* HFCWO	Lung transplant (N=45)	Lung function (measured by Spo2/FiO2) improves with HFWCO after lung transplantation. dyspnea and PEF did not differ significantly between treatment types, HFCWO may be an effective, feasible alternative to CPT
2014, Aslan GK (96)	RMST *vs.* sham	Neuromuscular diseases (N=26)	Respiratory muscle strength improved by inspiratory and expiratory muscle training in patients with slowly progressive neuromuscular disease

Table 4 (*continued*)

Table 4 (*continued*)

Year, author	Groups	Patient	Results
2014, Amelina EL (97)	Vibration-compression therapy *vs.* CPT	CF (N=31)	Incorporation of vibration-compression therapy (Vest vibro drainage) into the combination treatment of adult patients with CF results in significantly improved bronchial patency and more effective abolishment of an exacerbation
2014, Guimarães FS (98)	ERCC *vs.* control	Endotracheally intubated patients (N=20)	Although ERCC increases expiratory flow, it has no clinically relevant effects from improving the sputum production and respiratory mechanics in hypersecretive mechanically ventilated patients
2015, Liao LY (99)	Respiratory rehabilitation exercise training package *vs.* control	AECOPD (N=61)	Respiratory rehabilitation exercise training package reduced symptoms and enhanced the effectiveness of the care of elderly inpatients with AECOPD
2015, Postma K (100)	Resisted IMT *vs.* control	SCI (N=40)	Improvement in respiratory muscle strength is associated with improvement in cough capacity in persons with recent spinal cord injury who have impaired pulmonary function
2015, Kulnik ST (101)	Expiratory *vs.* inspiratory *vs.* sham training	Stroke (N=82)	Respiratory muscle function and cough flow improve with time after acute stroke. Additional inspiratory or expiratory respiratory muscle training does not augment or expedite this improvement
2015, Reyes A (102)	Training *vs.* control	Huntington’s disease (N=18)	A home-based respiratory muscle training program appeared to be beneficial to improve pulmonary function in manifest Huntington's disease patients but provided small effects on swallowing function, dyspnoea and exercise capacity
2016, Zeren M (103)	IMT *vs.* control	Atrial fibrillation (N=38)	Inspiratory muscle training can improve pulmonary function, respiratory muscle strength and functional capacity in patients with atrial fibrillation
2016, Choi JY (104)	IS *vs.* control	Spastic cerebral palsy (N=50)	The use of IS for enhancing pulmonary function and breath control for speech production
2016, Tallner A (105)	E-training *vs.* control	MS (N=126)	E-training had no effect on HrQoL but did on muscle strength, lung function, and physical activity
2016, Hegland KW (106)	EMST	Ischemic stroke (N=14)	EMST improves expiratory muscle strength, reflex cough strength, and urge to cough
2016, Kim SM (107)	Unassisted *vs.* manually assisted following a MIC maneuver *vs.* MIE assisted *vs.* manual thrust+MIE	NMD (N=40)	MI-E alone was more effective than manual assistance following an MIC maneuver, MI-E used in conjunction with manual thrust improved PCF even further
2016, Toussaint M (70)	Home-ventilator group *vs.* resuscitator-bag group	DMD (N=52)	Both methods achieved mean air stacking-assisted cough peak flow values of >160 L/min
2016, Jo MR (108)	Intervention *vs.* control	Stoke (N=42)	The increase in maximal expiratory pressure plays an important role in improving the cough capacity of stroke patients
2017, Dwyer TJ (109)	control *vs.* treadmill exercise *vs.* Flutter	CF (N=24)	A single bout of treadmill exercise and Flutter® therapy were equally effective in augmenting mucus clearance mechanisms

Table 4 (*continued*)

Table 4 (*continued*)

Year, author	Groups	Patient	Results
2018, Nicolini A (110)	CPT+IPV *vs.* CPT+ HFCWO *vs.* CPT	COPD (N=60)	Both IPV and HFCWO can improve lung function, muscular strength, dyspnea, and scores on health status assessment scales, and IPV performs better
2018, Jung JH (111)	MIE *vs.* control	NMD and pneumonia (N=27)	Increased peak cough flow after MIE application persists for at least 45 minutes
2018, Li P (112)	Acapella *vs.* control	Video-assisted thorascopic surgery (N=69)	The application of OPEP device during the perioperative period was valuable in decreasing PPCs and enhancing recovery
2018, Reyes A (113)	IMT *vs.* EMT *vs.* control	PD (N=31)	EMT program was more beneficial than IMT program for improving MEP and voluntary PCF
2019, Oliveira ACO (114)	Without MCC *vs.* other three with MCC	Endotracheally intubated patients (N=10)	The PEEP-ZEEP maneuver, without MCC, resulted in an expiratory flow bias superior to that necessary to facilitate pulmonary secretion removal. Combining MCC with the PEEP-ZEEP maneuver increased the expiratory flow bias, which increases the potential of the maneuver to remove secretions
2019, Jang KW (115)	Mechanical inspiration and expiration exercise *vs.* control	Subacute stoke (N=36)	Mechanical inspiration and expiration exercise had a therapeutic effect on velopharyngeal incompetence in subacute stroke patients with dysphagia
2019, Alves WM (116)	RST *vs.* control	PD (N=28)	Sixteen weeks of strength training improves the inspiratory and expiratory muscle strength and QoL of elderly with Parkinson disease
2019, Xavier VB (117)	Experimental *vs.* control	Adolescents with idiopathic scoliosis (N=40)	The experimental group also improved more than the control group on several respiratory measures, including FEV1, MIP, PEF
2019, Zeren M (103)	IMT+CPT *vs.* CPT	CF (N=36)	Combining IMT with chest CPT failed to provide further improvements, except for MIP
2020, Riboldazzi G (118)	Standard therapy *vs.* EFA	PD (N=25)	EFA® technology in Parkinson's patients with dysphagia to reduce the risk of respiratory complications
2020, Sundar KM (119)	CPAP *vs.* sham CPAP	Chronic cough and OSA (N=22)	Treatment of comorbid OSA in patients with chronic cough improved cough quality of life measures following treatment of OSA with CPAP in this pilot study
2021, Nicolini A (120)	MIE+EFA *vs.* MIE	ALS (N=30)	The cough-assist device with EFA technology performed better than a traditional MIE device in ALS patients regarding respiratory function and cough efficacy, although number of exacerbations and acceptability of the two devices was similar
2021, Allam NM (121)	CPT *vs.* TCPT+HFCWO	Smoke inhalation injury (N=60)	Pulmonary function increased in both groups, they increased significantly in group with HFCWO posttreatment
2021, Schindel CS (122)	CPAP (PEEP 10 cmH_2O) *vs.* CPAP with minimum PEEP at 1 cmH_2O	Severe therapy-resistant asthma (N=13)	The results suggest that the use of CPAP before physical exercise increases exercise duration
2022, Aydoğan Arslan S (123)	IMT *vs.* control	Stroke (N=21)	IMT improved inspiratory muscle strength and trunk control
2021, Cabrita B (124)	IMT	Neuromuscular diseases (N=21)	Significant improvements on pulmonary muscles function and might be considered as an adjunct treatment to neuromuscular treatment
2021, Emirza C (125)	EMST *vs.* sham	CF (N=28)	EMST could improve PCF, MIP, MEP, treatment burden, digestive symptoms, functional exercise capacity and vitality domains of QoL in patients with CF

Table 4 (*continued*)

Table 4 (*continued*)

Year, author	Groups	Patient	Results
2021, Srp M (126)	EMST *vs.* non-training	MS (N=35)	EMST improves expiratory muscle strength and voluntary cough strength in severely disabled MS patients
2021, Liu GX (127)	Effective *vs.* ineffective	Underwent lung surgery (N=153)	PEF can be used as a quantitative indicator of cough ability. Chest wall compression could improve cough ability for patients who have ineffective cough
2022, Hung TY (128)	AWT *vs.* AWT + CM *vs.* control	PMV (N=40)	AWT can significantly improve lung function, respiratory muscle strength, and cough ability in the PMV patients. AWT + CM can further improve their expiratory muscle strength and cough ability
2022, Martí JD (129)	Different pressure sets	Pigs (N=6)	MI-E appeared to be an efficient strategy to improve mucus displacement during invasive ventilation, particularly when set at +40/-70 cmH_2O
2022, Çelik M (130)	HFCWO *vs.* control	COVID-19 (N=100)	High-frequency chest wall oscillation device contributed to the improvement of oxygenation by providing significant improvement as observed in the pulmonary function tests of the patients
2023, Bito SAF (131)	High-intensity RMT *vs.* control	PD (N=34)	High-intensity respiratory muscle training improves muscle strength, functional outcomes, and quality of life in individuals with PD
2023, Basbug G (132)	IMT *vs.* control	Adolescent Idiopathic Scoliosis (N=36)	FEV1, PEF, MIP, MEP and 6MWT distance significantly improved in both groups. IMT group also showed significant improvement in FVC
2023, Plowman EK (133)	RST *vs.* sham	Amyotrophic lateral sclerosis (N=45)	RST represents a proactive rehabilitative intervention that could increase physiologic capacity of specific breathing and airway clearance functions during the early stages of ALS
2023, Ji X (134)	ACBT *vs.* routine care	Lung cancer (N=64)	ACBT combined with the Watson Theory of Human Caring can better restore LF in patients with LC following surgery, so as to promote rapid recovery and reduce postoperative complications
2023, Troche MS (135)	EMST *vs.* smTAP	PD and dysphagia (N=65)	The efficacy of smTAP to improve reflex and voluntary cough function, above and beyond EMST, the current gold standard
2023, Srp M (126)	EMST	Multiple system atrophy (N=15)	After the training period, MEP significantly increased, non-significant differences in vPCF after 8 weeks of EMST
2023, Yoo SD (136)	Transcranial magnetic stimulation *vs.* control	Supratentorial cerebral infarction (N=145)	The combination of conventional rehabilitation and transcranial magnetic stimulation in the subacute period may be helpful in improving voluntary cough function

AD, autogenic drainage; ACBT, active cycle breath technology; COPD, chronic obstructive pulmonary disease; IPV, intrapulmonary percussion ventilation; DMD, Duchenne muscular dystrophy; PEF, peak expiratory flow; MIE, mechanical insufflation exsufflation; ALS, amyotrophic lateral sclerosis; CPF, cough peak flow; MIC, maximum insufflation capacity; PEP, positive expiratory pressure; HFCWO, high frequency chest wall oscillation; FES, functional electrical stimulation; IMT, inspiratory muscle training; CPT, chest physical therapy; NIV, noninvasive ventilation; MEE, maximal expiratory effort; CABG, coronary artery bypass graft surgery; TPEP, therapeutic positive expiratory pressure; SCI, spinal cord injury; IPPB, intermittent positive pressure breath; LIAM, lung insufflation assist maneuver; MAC, manually assisted coughing; AECOPD, acute exacerbations of chronic obstructive pulmonary disease; ICU, intensive care unit; TENS, transcutaneous electrical nerve stimulation; VC, vital capacity; R(M)ST, respiratory (muscle) strength training; CF, cystic fibrosis; ERCC, expiratory rib cage compression; MS, multiple sclerosis; NMD, neuromuscular disease; PPC, postoperative pulmonary complication; PD, Parkinson disease; MCC, manual chest compression; PEEP, positive end expiratory pressure; ZEEP, zero end expiratory pressure; FEV1, forced expiratory volume in first 1 second; MIP, maximum inspiratory pressure; MEP, maximum expiratory pressure; 6-MWT, 6 meter walking test; FVC, forced vital capacity; IS, incentive spirometer; EMST, expiratory muscle strength training; AWT, abdominal weight training; CM, cough machine; PMV, permanent mechanical ventilation; EFA, expiratory flow accelerator; CPAP, continuous positive airway pressure; OSA, obstructive apnea; OPEP, oscillating positive expiratory pressure; RMT, respiratory muscle training; IMV, invasive mechanical ventilation; COT, conventional oxygenation therapy; EMG, electromyography; LF, lung function; LC, lung cancer; smTAP, sensorimotor training for airway protection; vPCF, voluntary peak cough flow.

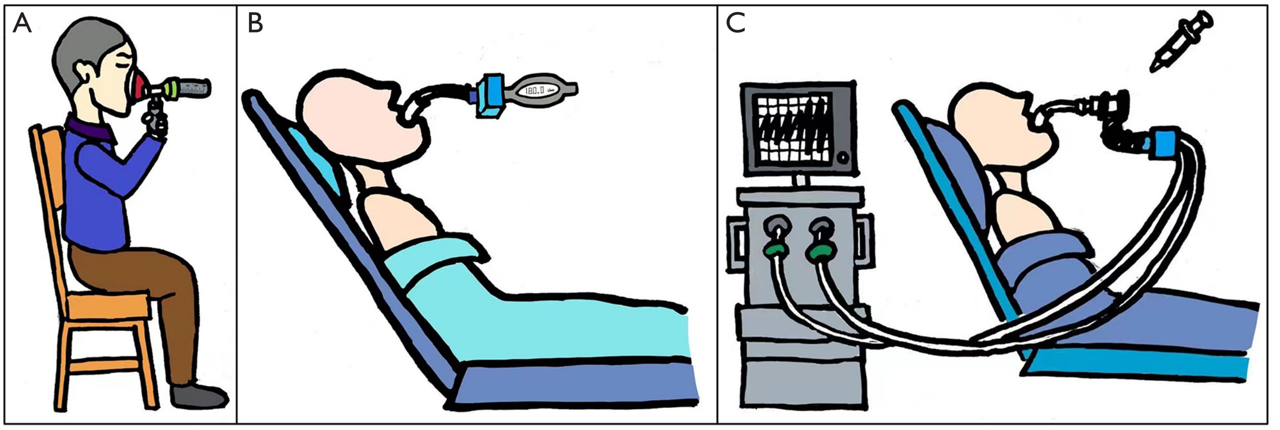

Figure 1 Methods for measurement of CPF and PEF. (A) CPF of non-intubated patients; (B) PEF of intubated patients with separate flowmeter; (C) PEF of intubated patients with built-in flowmeter. CPF, cough peak flow; PEF, peak expiratory flow.

and PEF are often used interchangeably in several studies (23-25,35,41). In fact, PEF is more suitable for assessing cough strength in intubated and tracheostomized patients because the artificial airway inhibits glottis closure, thus affecting the compressive phase of cough (48). Compared to other methods for assessing cough intensity, a PEF <60 L/min is the strongest predictor of extubation failure and is independently associated with in-hospital mortality in critically ill patients (4,22).

Plethysmography is the most accurate method for calculating CPF; however, it can be challenging to use with patients in the intensive care unit (ICU). A flowmeter is preferable for measuring CPF/PEF at the bedside, although accuracy can vary among different instruments (51). In non-intubated patients, CPF can be measured using a flowmeter and a mask. In intubated or tracheostomized patients, PEF can be directly measured using built-in flowmeters in the ventilator, based on the flow-time curve generated during pressure support ventilation [pressure support: 6–8 cmH_2O; positive end-expiratory pressure (PEEP): <5 cmH_2O] when patients exert maximum effort to cough. This method is more convenient for patients with artificial airways (30). PEF can also be measured using a separate flowmeter connected to the ventilator pipeline, and its accuracy is typically superior to that of built-in instruments (4). For patients who cannot cooperate, involuntary cough can be induced by administering 2 mL of saline into the airway and then connecting the flow spirometer as quickly as possible (15,27). Occasionally, 2 mL of saline may not be sufficient to induce involuntary cough in patients, and an additional injection of normal saline may be considered (52). The effectiveness of voluntary versus involuntary coughs in assessing PEF remains controversial. Some studies have found that PEF obtained during voluntary cough, rather than involuntary cough, is a better predictor of reintubation (27). However, Almeida *et al.* reported no significant difference in reintubation rates among the voluntary cough, saline stimulus, and suction tube stimulus groups (53). Common methods for measuring CPF/PEF are summarized in *Figure 1*.

All factors that can influence any of the four phases of the cough reflex can theoretically also influence CPF/PEF (37). Moreover, forced vital capacity and maximum inspiratory pressure are both highly sensitive to decreased cough strength (54). However, unlike CPF/PEF, the following volume and pressure measurements—including forced vital capacity, forced expiratory volume in the first second, vital capacity, functional residual capacity, maximum inspiratory pressure, and maximum expiratory pressure—are not predictive of extubation failure (54,55).

Semiquantitative cough strength score (SCSS)

The SCSS, first proposed by Khamiees *et al.* in 2001, is an objective measurement of cough strength ranging from 0 to 5, as follows: 0= no cough on command, 1= audible movement of air without an audible cough, 2= weakly audible cough, 3= clearly audible cough, 4= strong cough, and 5= multiple sequential strong coughs. It can be used to assess cough strength in patients with or without an artificial airway (56,57). The SCSS is useful for bedside assessments and is highly repeatable among experienced respiratory therapists. When comparing SCSS with PEF, an SCSS score of 3 corresponds to a PEF of 60 L/min (28). The predictive power of the SCSS is slightly lower than that of PEF, although its specificity is higher (4,58,59). Notably, the SCSS, when combined with another relevant index of extubation outcomes, such as the Glasgow Coma Scale, can provide a more reliable predictive model (36). The SCSS can also be used to assess non-intubated patients and predict the failure of NIV (26).

White card test (WCT)

The WCT is used to assess cough strength in patients with artificial airways. The WCT requires the patient to cough 3–4 times toward a white card placed approximately 1–2 cm in front of the endotracheal cannula. If secretions are present or the card becomes wet, it is considered a positive result, providing an initial impression of the amount and characteristics of the secretions (39). The extubation failure rate associated with negative WCT results is three times greater than that associated with positive results (57). However, compared to PEF, a PEF <60 L/min is a superior predictor of extubation failure compared to a negative WCT result (39). Although relatively few studies have reported direct comparisons between the WCT and SCSS, the WCT is generally more accurate (4). Additionally, it is important to note that a positive WCT result may be influenced by the evaluator's subjective judgment, particularly when the card is only slightly wet, which presents a disadvantage of the WCT.

Diaphragm ultrasound

Diaphragm ultrasound is a noninvasive and convenient imaging modality that is highly repeatable and can be easily performed in the ICU. It can be used to assess cough strength in patients with or without artificial airways (60). The passive excursion of the diaphragm refers to the distance it moves from its original position during end-expiration to end-inspiration (38,61). Passive diaphragm excursion during expiration in healthy adults has been shown to significantly correlate with CPF when coughing with maximum effort (42). Furthermore, diaphragm excursion is greater during involuntary cough than during voluntary cough (62). Diaphragm thickening fraction (DTF) refers to the change in diaphragm thickness when the patient breathes deeply with maximum effort and is calculated as follows: [(end-inspiration thickness) – (end-expiration thickness)]/(end-expiration thickness). DTF correlates with diaphragmatic activity and reflects the work of breathing of the diaphragm (63,64). However, no studies have investigated the association between DTF and cough strength. Based on current evidence, diaphragm ultrasound is inappropriate as a sole criterion for assessing cough strength, as the results are influenced by sex, age, height, position during the examination, and the technician's experience (65).

Cuff pressure change (ΔP_{cuff})

The difference between peak and baseline cuff pressure is defined as ΔP_{cuff} (40). Generally, a cuff pressure gauge (cuff manometer) is used to monitor changes in the pressure of laryngeal masks and intubation tubes before and after coughing. It can only assess cough strength in patients with artificial airways. ΔP_{cuff} is highly correlated with PEF, and the cutoff value for predicting extubation failure is reportedly 28 cmH_2O (40). However, changes in cuff pressure can be influenced by bronchial and lung compliance, the measurement method, and the diameter of the cannula.

Other methods

Cough sound power and energy are strongly correlated with physiological measures, such as esophageal pressure and CPF, as well as the subjective perception of cough strength (31,46). This method can be used to assess cough strength in patients without artificial airways. Umayahara *et al.* (32) established a model to accurately calculate CPF based on cough sounds collected using a microphone positioned less than 30 cm from the patient's mouth (33). This method could be particularly useful for non-intubated patients using speaking valves. Maximum phonation time is also a surrogate marker for respiratory function and airway clearance indices (45). However, more evidence is needed for its application in the ICU.

Sonoscore is the average decibel level of three consecutive coughs performed with maximum effort. Currently, there is only one related study that involved patients receiving invasive mechanical ventilation (43). The results indicated that a Sonoscore <67.1 dB was able to predict extubation failure.

Electromyography (EMG) is a useful modality for evaluating respiratory muscle activity and can be used to assess cough strength in patients with or without artificial airways. During voluntary coughing, EMG signals increase for the rectus, oblique, transverse abdominal, internal intercostal, and external anal sphincter muscles (66,67). EMG activity of the abdominal wall is related to cough flow, expired volume, and cough sound amplitude (137). However, EMG is a valuable diagnostic tool for patients with good motor

Table 5 Summary of cough assessment methods

Principles	Breath-stacking	IS	Early mobilization	RMT	FES/TENS	NIV	VCM	IPPB	OPEP*	FET	ACBT	AD	MI-E	Vibration and percussion	HFWCO	IPV	MetaNeb
Increase inhaled volume	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓			✓	✓
Increase expiratory flow				✓	✓				✓	✓	✓	✓	✓			✓	✓
Airway oscillation									✓					✓	✓	✓	✓

OPEP* including PEP bottle, PEP-Mask, Thera-PEP, Acapella, Flutter, RC Cornet, Aerobike, *et al.* IS, incentive spirometer; RMT, respiratory muscle training; FES, functional electrical stimulation; TENS, transcutaneous electrical nerve stimulation; NIV, noninvasive ventilation; VCM, volumetric cough mode; IPPB, intermittent positive pressure breath; OPEP, oscillating positive expiratory pressure; FET, forced expiratory technology; ACBT, active cycle breath technology; AD, autogenic drainage; MI-E, mechanical insufflation-exsufflation; HFCWO, high frequency chest wall oscillation; IPV, intrapulmonary percussion ventilation.

function but reduced cough strength (66). It can effectively assess cough threshold and power in both healthy adults and individuals with spinal cord injuries (66,138). Compared to concentric needle electrodes, surface electrodes are better suited for obtaining accurate measurements of whole-muscle EMG activity (67).

Esophageal pressure varies with intrathoracic pressure; therefore, cough intensity is highly correlated with changes in esophageal pressure. Contraction of the abdominal muscles generates positive gastric pressure during coughing. Changes in internal gastric pressure, central venous pressure, bladder pressure, and rectal pressure are similar to those in esophageal pressure and also reflect cough strength, although small discrepancies exist among these parameters (34). These pressure-related indices can be used to assess cough strength in patients with or without artificial airways. Monitoring changes in pressure requires invasive catheterization, and the pressure sensor only functions correctly when the catheter is properly positioned.

Clearance and expectoration of mucus, including mucociliary transport, sputum weight (dry and wet), and sputum volume, are commonly used as primary or secondary outcomes in studies assessing the effectiveness of cough exercise tools (139). These measures also serve as supplementary indicators of cough ability. Current research shows that improved cough ability is often linked to increased sputum production (all $P<0.05$) (140). Measuring sputum volume at a single time point has inherent limitations and may not fully capture the patient overall cough capacity. To address this, dynamic observation over a specific time frame may be needed to assess sputum output as a measure of cough capacity. Additionally, due to individual variability, improvements in cough ability should be evaluated by comparing each patient's performance before and after the intervention.

Most available data on assessing cough strength focus on healthy individuals or well-defined groups, such as the elderly, intubated patients, and those with neuromuscular disorders. However, clinical data remain limited for patients with glottic insufficiency or dysphagia after extubation.

Cough exercises

Given the consequences of weak cough, timely and early training in cough and expectoration is essential for patients at high risk of cough decline, as well as for those who already have reduced cough strength. Increased cough strength can enhance lung function and improve outcomes (29,141-143) (*Table 4*). Although various methods exist for cough training in critically ill patients, all are based on three fundamental principles: increasing inhaled volume, increasing expiratory flow, and oscillation (144). Commonly used methods for cough exercises are summarized in *Table 5*.

Increase inhaled volume

Inhaled volume is the most important indicator of respiratory health in adult patients with either a single or continuous cough (86,90,145). Furthermore, maximum inspiratory pressure is more significantly associated with cough strength than maximum expiratory pressure for both voluntary and involuntary coughs. Therefore, increasing inspiratory muscle strength and inspiratory volume is essential for enhancing cough strength (70). Intermittent positive pressure breathing (91), NIV (80), and continuous positive airway pressure (85,122) can all passively increase inhaled volume and are effective. Some home ventilators can achieve these effects effectively (70). Voluntary exercise tools, such as the incentive spirometer (IS), have been shown to significantly increase maximum inspiratory capacity in both hospitalized and discharged patients (104,146-148). Notably, the effectiveness of the IS largely depends on the patient's effort, and the addition of a reminder bell can lead to significant improvements (49,82,149). Additionally, it is important to avoid the adverse consequences of excessive use (150). Early mobilization, inspiratory muscle strength training, and certain forms of electrical muscle stimulation (94,136) can also improve inhaled volume in critically ill patients, as well as in those with neuromuscular diseases and postoperative patients (79,81,84,151). The inhaled volume of patients receiving mechanical ventilation can be increased by augmenting the conveying volume through the volumetric cough mode of the ventilator, thereby gradually raising the inhaled volume to provide a convenient target for the patient (49).

Increase expiratory flow

Exercising the expiratory muscles can effectively increase expiratory flow and improve cough capacity, particularly in patients with neuromuscular diseases (92,96,99-103,105,106,108,115,116,123,124). Setting resistance during the expiratory phase through positive expiratory pressure therapy can achieve a similar effect to PEEP for training the expiratory muscles (87,117,119,144). Different devices have specific requirements for patients during use; for example, the patient must be in either an upright or sitting position when using a flutter device (68,83,109). Some cough training methods, such as forced expiratory technology, active cycle of breathing techniques (134), autogenic drainage (69), and mechanical insufflation-exsufflation (72,73,78,111,120,129), can enhance both inspiratory volume and expiratory flow, thereby increasing expectoration and facilitating the expulsion of sputum (152,153). Despite insufficient evidence, mechanical insufflation-exsufflation is commonly used in patients with neuromuscular diseases to aid expectoration (154). Expiratory muscle training can also enhance muscle strength and cough capacity (125,126,131-133,155), and it seems to be more effective for improving CPF compared to inspiratory muscle training (113). In addition to mechanical aids, manual aids can also facilitate increased expiratory airflow, including expiratory rib cage compression (98), manual chest compression (114), expiratory flow acceleration (118) and abdominal wall compression, among others (71,76,77,88,89,127,128,135).

Oscillation

Oscillations in the airway or external to the chest wall can effectively transmit to the airway to facilitate sputum release (156). High-frequency oscillation can effectively increase tidal volume and inspiration duration, reduce respiratory rate, and result in deeper and slower breaths (95,97,110,121,130,157). Consequently, mean PEF will be greater (74). Commonly used techniques in the ICU include clapping and vibration, oscillating positive expiratory pressure (OPEP) (112), high-frequency chest wall oscillation (75), and intrapulmonary percussion ventilation (IPV) (158-162). Aside from IPV, there is no significant difference in the use of these devices; however, IPV is more effective and beneficial for airway clearance (160,163). The MetaNeb® System (Hill-Rom Holdings, Inc., Chicago, IL, USA) was recently introduced for the mobilization of secretions, lung expansion therapy, and the treatment and prevention of pulmonary atelectasis (164).

All of the above-mentioned means and methods of improving cough ability are not strictly contraindicated. All airway clearance techniques have a good safety profile when the patient is generally stable (139). For patients who can cooperate and have good compliance, they can take tools or methods with high autonomy to exercise, such as IS, OPEP, etc. If the patient is difficult to cooperate or has poor compliance, it would be more suitable for these patients to receive passive expectoration methods, such as IPV, MI-E, airway suction, etc. (93).

Currently, cough exercises are widely used in clinical practice; however, optimal effects are often not achieved because most of these techniques maintain rather than improve patient status (107,165). Cough exercises should be encouraged for critically ill patients; however, many do not tolerate prolonged training, necessitating the presence of a respiratory therapist or physical therapist. Furthermore, there is a lack of high-quality evidence regarding the appropriate power, frequency, and duration for cough exercises in critically ill patients (144,166). Therefore, further research is warranted to develop individualized training methods and parameters, as well as to enhance patients' tolerance and cooperation.

Conclusions

Weak cough in critically ill patients is linked to an increased risk of extubation failure, prolonged mechanical ventilation, longer ICU and hospital stays, and higher mortality. Therefore, it is crucial to select appropriate methods for assessing and exercising cough strength in ICU patients. CPF/PEF, SCSS, and WCT are relatively simple and widely used methods. The key elements of cough exercises typically include increasing inhaled volume, enhancing expiratory flow, and incorporating oscillation. Developing personalized programs and effective action plans is essential for cough exercises which largely depends on patient cooperation and persistence.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1673/rc

Peer Review File: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1673/prf

Funding: This study was financially supported by grants from the Foundation for Young Researchers of Zhongshan Hospital (grant No. 2021ZSQN22).

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-1673/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Cite this article as: Zhang SM, Muhetaer Y, Liu K. Assessments and exercises of cough strength in critically ill patients: a literature review. J Thorac Dis 2025;17(2):1080-1102. doi: 10.21037/jtd-24-1673