Original Article

# A rapid shallow breathing index threshold of 85 best predicts extubation success in chronic obstructive pulmonary disease patients with hypercapnic respiratory failure

**Reza Goharani[1], Amir Vahedian-Azimi[2], Iman H. Galal[3], Leonardo Cordeiro de Souza[4], Behrooz Farzanegan[5], Farshid R. Bashar[6], Michele Vitacca[7], Seyedpouzhia Shojaei[1], Seyed M. M. Mosavinasab[8], Shunsuke Takaki[9], Andrew C. Miller[10]**

[1]Anesthesiology Research Center, Anesthesia and Critical Care Department, Loghman Hakim Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran; [2]Trauma Research Center, Nursing Faculty, Baqiyatallah University of Medical Sciences, Tehran, Iran; [3]Department of Pulmonary Medicine, Ain Shams University, Cairo, Egypt; [4]Physical Therapy College, Universidade Estáciode Sá, Rio de Janeiro, Brazil; [5]Tracheal Diseases Research Center, Anesthesia and Critical Care Department, Masih Daneshvari Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran; [6]Anesthesia and Critical Care Department, Hamadan University of Medical Sciences, Hamadan, Iran; [7]Respiratory Unit, IRCCS Fondazione S. Maugeri, Lumezzane, Italy; [8]Anesthesiology Research Center, Anesthesia and Critical Care Department, Modares Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran; [9]Department of Anesthesiology and Critical Care, Yokohama City University, Yokohama, Japan; [10]Department of Emergency Medicine, Vidant Medical Center, East Carolina University Brody School of Medicine, Greenville, NC, USA

*Contributions:* (I) Conception and design: R Goharani, A Vahedian-Azimi, IH Galal, L Cordeiro de Souza, B Farzanegan, FR Bashar, M Vitacca, S Shojaei, SMM Mosavinasab, S Takaki; (II) Administrative support: R Goharani, A Vahedian-Azimi, B Farzanegan, FR Bashar, S Shojaei, SMM Mosavinasab; (III) Provision of study materials or patients: R Goharani, A Vahedian-Azimi, B Farzanegan, FR Bashar, S Shojaei, SMM Mosavinasab; (IV) Collection and assembly of data: R Goharani, A Vahedian-Azimi, IH Galal, L Cordeiro de Souza, B Farzanegan, FR Bashar, M Vitacca, S Shojaei, SMM Mosavinasab, S Takaki; (V) Data analysis and interpretation: A Vahedian-Azimi, AC Miller; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

*Correspondence to:* Andrew C. Miller, MD. Department of Emergency Medicine, Vidant Medical Center, East Carolina University Brody School of Medicine, 600 Moye Blvd, Greenville, NC 27834, USA. E-mail: Taqwa1@gmail.com; MillerAndr17@ecu.edu.

**Background:** The rapid shallow breathing index (RSBI) is used clinically to help predict a patient's likelihood of successful liberation from mechanical ventilation (MV). However, the traditional threshold (<105 breaths/min/L) may underperform in patients with chronic obstructive pulmonary disease (COPD). We sought to determine the optimal RSBI threshold for COPD patients to improve the diagnostic accuracy for predicting successful ventilator liberation.

**Methods:** This was a prospective observational multicenter study of COPD patients [according to Global initiative for Chronic Obstructive Lung Disease (GOLD) criteria] admitted to the Medical ICUs of eight academic medical centers. All patients were intubated for hypercapnic respiratory failure and met the American Thoracic Society/European Respiratory Society guidelines to participate in a weaning trial. Ventilator weaning was conducted according to a defined protocol. RSBI was measured through the ventilator after 120 minutes of spontaneous breathing trial (SBT).

**Results:** Ninety patients were included (39 males and 51 females). Forty-three patients (48%) were successfully extubated whereas 47 patients (52%) failed extubation. Significant differences were observed between groups for duration-of-intubation [duration of intubation (DoI); P<0.0001], spontaneous tidal volume (VT) (P=0.03), and the ratio of dynamic-to-static compliance (P=0.005). The RSBI threshold of ≤85 breaths/min/L performed best: area under curve (AUC) receiver operating characteristic (ROC) curves 0.91, sensitivity 95.6%, specificity 90.4%, positive predictive value (PPV) 95.5%, and negative predictive value (NPV) 90.6%., positive likelihood ratio (LR+) 5.48, negative likelihood ratio (LR–) 0.25, and the diagnostic accuracy 91.7%. In post-ROC analyses, DoI and hospital length-of-stay (LOS) did not impact performance.

**Conclusions:** In COPD patients intubated with hypercapnia, RSBI ≤85 breaths/min/L outperformed the widely used threshold <105 breaths/min/L, yielding a 95.5% probability of extubation success, independent

of ventilation duration or hospital LOS.

**Keywords:** Chronic obstructive pulmonary disease (COPD); mechanical ventilation (MV); respiratory failure; clinical respiratory medicine; critical care

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## Introduction

Chronic obstructive pulmonary disease (COPD) accounts for >3 million (6%) of all deaths globally (1), making it the fourth leading cause of death and the sixth leading cause of years lived with disability (2-4). Furthermore, its global burden is projected to increase in the coming decades due to continued risk factor exposure and population ageing (1,5).

COPD may be punctuated by periods of acute symptom worsening (exacerbations), with some requiring invasive mechanical ventilation (IMV) (1). Despite its advantages, ventilator-associated complications may include barotrauma, volutrauma, infections and others (6-8). Whereas it is widely agreed that expeditious liberation from IMV may limit unnecessary complications, the optimal method or technique to accomplish this remains debatable (4). For COPD patients, more than half of the time spent on the ventilator may be during the discontinuation process (4). Failed extubation may be associated with increased mortality, prolonged IMV, longer intensive care unit (ICU) and hospital length-of-stay (LOS), and higher rates of transfer to long-term-care facilities (9).

Several indices and predictors for extubation success have been reported in the literature (10-13), with the rapid shallow breathing index (RSBI) being among the most used clinically (12,14-16). The RSBI (breaths/min/L) is calculated by dividing the respiratory rate (RR) (f) by the spontaneous tidal volume ($V_T$) in Liters ($f/V_T$). For patients who otherwise meet criteria for IMV liberation, a RSBI <105 breaths/min/L suggests an increased likelihood of successful extubation (12). In a meta-analysis, the pooled sensitivity and specificity was 84% and 44% respectively, with a pooled positive likelihood ratio (LR+) of 1.49 and a pooled negative likelihood ratio (LR–) of 0.39 (17).

The reliability of the RSBI has been called into question for COPD patients, as some COPD patients have been noted to fail extubation despite a favorable RSBI (<105 breaths/min/L) (18). This has prompted some to call for more sophisticated parameters, or illness specific discriminatory thresholds for COPD patients (14,15,19). Some studies have advocated that a lower RSBI threshold may perform more optimally (20-27).

Moreover, both the timing and technique of measurement may influence outcomes. In one trial of 64 mechanically ventilated COPD patients, the RSBI [measured early during the spontaneous breathing trial (SBT)] did not accurately predict the successful outcome of a T-piece trial (18). It has been reported that in COPD patients, the RSBI measured through spirometry at the end of the SBT may be a better predictor of weaning outcome than when measured through pressure support (PS) (28). In this study we aimed to identify the highest performing RSBI threshold value for predicting successful mechanical ventilation (MV) liberation in COPD patients with hypercapnic respiratory failure.

## Methods

This was a prospective observational multicenter study of COPD patients admitted to the Medical ICUs of eight academic medical centers from Jan 1, 2013 to Feb 28, 2017. The study was approved by institutional review boards at Baqiyatallah University of the Medical Sciences (340/5/5904) and Shahid Beheshti University of the Medical Sciences (SBMU1/REC/1393/89). Each participating hospital accepted these IRBs. Consent was required and covered both study participation and publication of findings. Informed consent was required prior to cardiac arrest event and could be provided by the patient, legal guardian, or healthcare surrogate. The informed consent included permission to present and publish de-identified results. All data generated or analyzed during this study are included in this article.

COPD diagnosis was in accordance with the global initiative for chronic obstructive lung disease (GOLD) criteria (1); a post-bronchodilator forced expiratory volume in one second ($FEV_1$) to forced vital capacity (FVC) ratio <0.70 in patients with appropriate symptoms and significant exposures to noxious stimuli (1). All patients were intubated for hypercapnic respiratory failure [partial pressure of carbon dioxide ($PaCO_2$) ≥50 mmHg and pH

 

≤7.35] and met the American Thoracic Society/European Respiratory Society guidelines to participate in a weaning trial (29). Ventilator weaning was conducted according to the defined protocol. Pre-defined weaning criteria included: (I) patent upper airway; (II) ability to protect airway (defined by mental status and presence of adequate gag and cough reflexes); (III) ability to clear secretions; (IV) decreasing secretion burden requiring suction not more frequently than every 2 hours; (V) level of support [fraction of inspired oxygen ($F_iO_2$) <50%; positive end-expiratory pressure (PEEP) =5]; and (6) hemodynamic stability not requiring chemical (vasopressors, inotropes) or mechanical (e.g., intra-aortic balloon pump, extracorporeal life support) circulatory support.

The inclusion criteria were: (I) MV ≥24 hours and (II) no sedatives or low dose sedation (midazolam 1–2 mg/hour or fentanyl 25–100 mcg/hour). Patients were excluded if: (I) did not meet pre-defined weaning criteria, (II) Glasgow Coma Score (GCS) <10, (III) inadequate cough reflex, (IV) self-extubation, (V) neuromuscular disease, (VI) acute coronary syndrome, (VII) cardiac failure, (VIII) end-stage renal disease, or (IX) for hemodynamic instability or signs of systemic infection/reinfection during the weaning process.

All patients were ventilated using Dräger Evita® XL or Evita® 4 ventilators (Dräeger Medical, Inc., Germany). Weaning and extubation readiness was determined by the respiratory therapist (RT) using pre-defined criteria and the result of a T-piece SBT. Before the T-piece trial, medical therapy was optimized, and patients' airway secretions were suctioned. All patients were initially placed on PS =0 $cmH_2O$, PEEP =0 $cmH_2O$, and $F_iO_2$ ≤0.4 for 3 minutes, and assessed for any signs of distress: RR >30 breaths/minute, arterial oxygen saturation ($S_aO_2$) <90%, heart rate (HR) >140 breaths/minute, a sustained increase or decrease of HR of >20%, systolic blood pressure (BP) >200 mmHg or <80 mmHg, agitation, anxiety, or diaphoresis without other identified cause. If the patients maintained adequate mentation, hemodynamic stability, and adequate oxygenation and cough reflex without signs of respiratory distress while on no/low-dose sedation, a 120 min T-piece SBT was initiated (30). The decision to return to MV was made by the RT and attending intensivist (both independent of research team and blinded to results) based on signs of poor tolerance: $S_aO_2$ < 90% with $F_iO_2$ > 0.4; $P_aCO_2$ > 55 mmHg or increased by ≥10 mmHg; arterial pH <7.33; RR >35 breaths/min or increased by 50% for ≥5 minutes; HR >140 beats/min or increased/decreased by >20%; mean arterial pressure (MAP) >130 or <70 mmHg; or the presence of agitation, diaphoresis, disorientation, or depressed mental status (31). Patients demonstrating one of these signs during the SBT were considered a failed wean and returned to ventilatory support (32). For those completing the 120-minute SBT, the RSBI was measured through the ventilator without PS; continuous positive airway pressure (CPAP) =0 $cmH_2O$; PS =0 $cmH_2O$) for one minute. Patients tolerating the 120 min SBT without signs of distress or hemodynamic instability were extubated (33). Successful weaning from MV was defined as complete respiratory autonomy for at least 48 hours (34).

### *Data collection*

The data collection tool was a two-part checklist including demographic variables (age, sex, smoking history) and ventilation parameters (intubation hours, hospitalization hours, spontaneous RR and $V_T$).

### *Statistical analysis*

The sample size calculation was performed using STATA®14 (StataCorp LLC, College Station, USA). The sample size was based upon data from the pilot study where the sensitivity and specificity of RSBI to predict extubation success were 0.97 and 0.94 respectively, and the LR+ was 16.6. Assuming an Alpha of 0.05 and a power of 0.9, the necessary sample size for the unsuccessful and successful extubation groups was 44 and 43 respectively.

Statistical analyses were performed using Statistical Package for Social Sciences software (SPSS for Windows, version 22.0; SPSS Inc., Chicago, USA), med calculator 13.1.0.0 (MedCalc Software bvba, Seoul, Republic of Korea) and 2×2 tables. Data were summarized using mean ± standard deviation (SD) for quantitative variables and frequency (%) for qualitative variables. Demographic data including gender, smoking, COPD severity, use of home oxygen therapy, rates of treatment with non-invasive ventilation (NIV), admission brain natriuretic peptide (BNP), high sensitivity C-reactive protein (hsCRP), ventilator associated pneumonia, and post-hypercapnic alkalosis were compared with Chi-square test. Variables including age, intubation duration, hospital LOS, RR, $V_T$, partial pressure of oxygen ($P_aO_2$)/$F_iO_2$ ratio, $P_aO_2$/partial oxygen pressure of mixed alveolar gas ($P_{ALV}O_2$) ratio, movement index, FVC, $FEV_1$, $FEV_1$/FVC, and forced expiratory flow at 25–75% ($FEF_{25-75}$) were compared using the student T-test. APACHE II scores were compared using

 

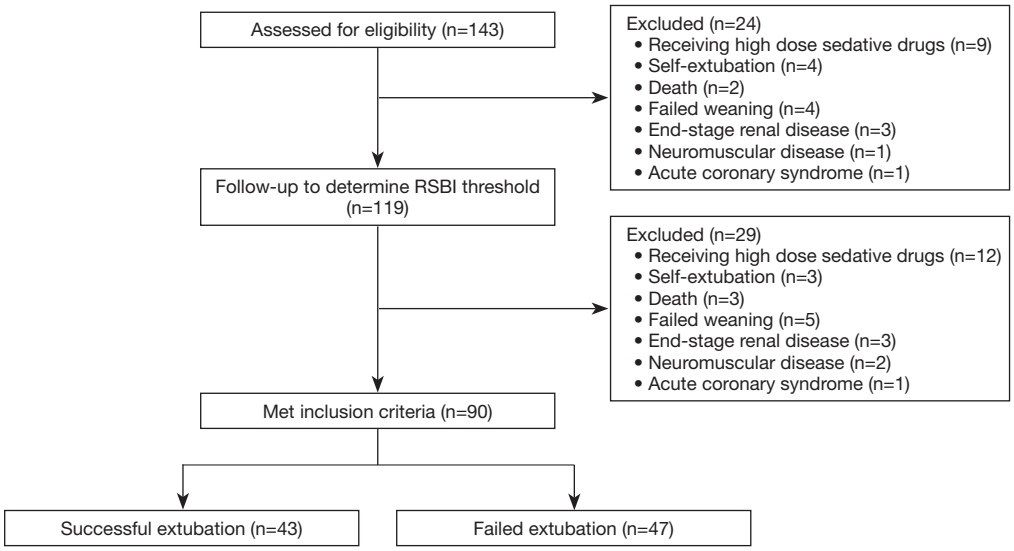


**Figure 1** Flow diagram of patients.

the likelihood ration test. Duration of midazolam infusion was compared using the *t*-test for equality of means.

To assess the prognostic value of the RSBI, receiver operating characteristic (ROC) curves was drawn. For each ROC curve analysis, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), diagnostic accuracy, LR+, and LR–, probability for weaning success when test is positive and probability for weaning success when test is negative of the index were used to predict the weaning outcome in the data set. Hanley *et al.* method was used to calculate the area under curve (AUC) for index and then the methods developed by the same authors were used to compare the AUCs (35). Bayes' theorem was used to compute the weaning outcome the probability for weaning success when test is positive and negative (post-test probability) in the data set to assess the performance of test in predicting success weaning (36). In all analyses, P<0.05 were considered significant.

## Results

Out of 143 eligible patients, 90 met inclusion criteria. The patient flow diagram is shown in *Figure 1*. The data were normally distributed as determined by the one-sample Kolmogorov Simonov test (P>0.05). *Table 1* details the demographic and clinical characteristics of all included patients. A slight female predominance was observed (57%) (*Table 1*). The mean (± SD) patient age was 63.77 (±10.66) years. Tobacco use, and COPD severity did not differ between groups. Slightly more than half of all patients (52.2%) failed extubation. Those successfully extubated on first attempt were more likely to be on home oxygen, treated with NIV pre-intubation, and to have an elevated C-reactive peptide (CRP) and BNP, *Table 1*. Patients failing extubation were more likely to have experienced ventilator-associated pneumonia (VAP). Neither the incidence of post-hypercapnic alkalosis nor duration of midazolam infusion differed between groups. The non-parametric comparison between patients extubated successfully versus those that failed extubation showed that only DoI, spontaneous $V_T$ (mL), and the ratio of dynamic-to-static compliance (movement index) showed significant differences (*Table 1*) (P<0.0001, P=0.03 and P=0.005, respectively), whereas RR, $P_aO_2/F_iO_2$ ratio, FVC, $FEV_1$, $FVC/FEV_1$, and $FEF_{25-75}$ did not differ between groups (*Table 1*).

For RSBI, the area under the ROC curves was 0.91 (*Figure 2*). The point of optimal performance was ≤85 breaths/min/L, and performance characteristics are shown in *Table 2*. This threshold yielded a sensitivity (95.6%), specificity (90.4%), PPV (95.5%), NPV (90.6%), LR+ (5.48), LR– (0.25), and the diagnostic accuracy (91.7%). No differences were found between the DoI or hospital LOS on the performance of the RSBI ≤85 breaths/min/L.

## Discussion

COPD patients requiring MV have a high mortality, with up to one-third dying despite MV support (37-41). It has

 

**Table 1** COPD patients' demographic & clinical characteristics

| Characteristics | Total | Successful extubation | Failed extubation | P value |
|---|---|---|---|---|
| Sample, n [%] | 90 | 43 [48] | 47 [52] | |
| Age, years[a] | 63.77 (±10.66) | 64.09 (13.04) | 63.34 (10.36) | 0.762[c] |
| Gender, n [%] | | | | 0.324[d] |
| Male | 39 [43] | 18 [42] | 23 [49] | |
| Female | 51 [57] | 25 [58] | 24 [51] | |
| Smoking, n [%] | | | | 0.086[d] |
| > one pack/month | 61 [68] | 28 [65] | 33 [70] | |
| < one pack/month | 29 [32] | 15 [35] | 14 [30] | |
| COPD severity, n [%] | | | | 0.099[d] |
| Mild | 5 [6] | 3 [7] | 2 [4] | |
| Moderate | 35 [39] | 25 [58] | 10 [21] | |
| Severe | 35 [39] | 10 [23] | 25 [54] | |
| Very severe | 15 [17] | 5 [12] | 10 [21] | |
| Home oxygen therapy, yes, n [%] | 19 [21] | 13 [30] | 6 [13] | 0.043[d] |
| APACHE II score[a] | 15.77 (2.82) | 14.7 (2.3) | 16.8 (2.9) | 0.03[e] |
| Treated with NIV, n [%] | | | | |
| Pre-intubation | 33 [37] | 24 [56] | 9 [19] | 0.0001[d] |
| Post-extubation | 20 [22] | 9 [21] | 11 [23] | 0.778[d] |
| Admission BNP >200 pg/mL, n [%] | 26 [29] | 18 [42] | 8 [17] | 0.009[d] |
| Admission hsCRP > 100 mg/L, n [%] | 27 [30] | 19 [44] | 8 [17] | 0.005[d] |
| VAP, n [%] | 13 [14] | 5 [12] | 8 [17] | 0.467[d] |
| Post-hypercapnic alkalosis, n [%] | 17 [19] | 7 [16] | 10 [21] | 0.545[d] |
| Midazolam infusion duration, min[a] | | 827 [133] | 887 [362] | 0.306[f] |
| Intubation duration, hours[a] | 108.50 (24.37) | 119.95 (22.29) | 98.02 (21.47) | <0.0001[c] |
| Hospital length-of-stay, days[a] | 15.07 (16.41) | 16.98 (19.29) | 13.32 (13.20) | 0.293[c] |
| Spontaneous respiratory rate (bpm)[a] | 30.54 (3.56) | 30.81 (3.45) | 30.30 (3.67) | 0.495[c] |
| Spontaneous tidal volume (mL)[a] | 292.18 (84.91) | 311.74 (67.08) | 274.28 (95.68) | <0.05[c] |
| $P_aCO_2$ (mmHg)[a] | 61.41 (4.13) | 61.83 (4.02) | 61.02 (4.24) | 0.352[c] |
| $P_aO_2/F_iO_2$ ratio[a] | 237.28 (30.42) | 235.64 (27.67) | 238.77 (32.96) | 0.628[c] |
| $P_aO_2/P_{ALV}O_2$ ratio[a] | 237.28 (30.42) | 276 (0.08) | 286 (0.04) | 0.191[c] |
| Movement index[b] | 0.50 (0.07) | 0.52 (0.06) | 0.48 (0.06) | <0.01[c] |
| FVC | 2.2 (0.4) | 2.4 (0.3) | 2.2 (0.22) | 0.192[c] |
| $FEV_1$ | 1.8 (0.3) | 1.9 (0.2) | 1.7 (0.2) | 0.422[c] |
| $FEV_1$/FVC (%) | 65.0 (3.1) | 67.0 (2.0) | 66.0 (2.0) | 0.232[c] |
| $FEF_{25–75}$ (%) | 37.0 (5.0) | 40.0 (5.0) | 35.0 (6.0) | 0.654[c] |

[a], mean (SD); [b], dynamic compliance/static compliance; [c], student *t*-test; [d], chi-square test; [e], likelihood ratio test; [f], *t*-test for equality of means. COPD, chronic obstructive pulmonary disease; NIV, non-invasive ventilation; BNP, brain natriuretic peptide; hsCRP, C-reactive protein; VAP, ventilator-associated pneumonia; $P_aCO_2$, partial pressure of carbon dioxide; $P_aO_2$, partial pressure of oxygen; $F_iO_2$, fraction of inspired oxygen; $P_{ALV}O_2$, partial oxygen pressure of mixed alveolar gas; FVC, forced vital capacity; $FEV_1$, forced expiratory volume in 1 second; $FEF_{25–75}$, expiratory flow at 25–75%.

 

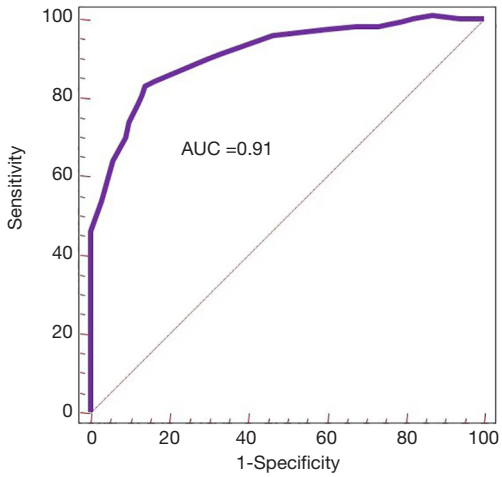


**Figure 2** Receiver operating curve for the rapid shallow breathing index. AUC, area under curve.

**Table 2** Performance of RSBI threshold of 85 breaths/min/L in COPD patients

| Parameter | RSBI |
|---|---|
| Sensitivity (%) | 95.6 |
| Specificity (%) | 90.4 |
| PPV (%) | 95.5 |
| NPV (%) | 90.6 |
| LR+ test | 5.48 |
| LR– test | 0.25 |
| Diagnostic accuracy (%) | 91.7 |
| Probability of ventilator liberation success if test is negative (%) | 9.4 |
| Probability of ventilator liberation success if test is positive (%) | 95.5 |
| Prevalence (%) | 44.4 |
| Area under curve ± standard error (%) | 0.91±0.06 |

RSBI, rapid shallow breathing index; COPD, chronic obstructive pulmonary disease; PPV, positive predictive value; NPV, negative predictive value; LR+, positive likelihood ratio; LR–, negative likelihood ratio.

been estimated that for COPD patients, more than half of MV time is spent during the discontinuation process (4). Successful ventilator liberation remains a critical component of patient care in the ICU, yet clinical judgment alone is insufficient to predict success (36,42,43).

### *Extubation success*

Neuromuscular drive has been previously associated with successful ventilator liberation. This may be measured by airway occlusion pressure (P0.1), negative inspiratory force (NIF), maximal inspiratory pressure MIP, or the RSBI (34). The RSBI is among the most used clinical indices for predicting extubation success from a SBT (11,12,14-16,36,42,44), however its accuracy for identifying COPD patients likely to successfully extubate has been questioned as some COPD patients with a favorable RSBI (<105 breaths/min/L) have been noted to fail extubation (18). This has prompted some to call for either more sophisticated parameters or illness specific discriminatory thresholds for COPD patients (14,15). Our findings similarly call into question the appropriateness of the RSBI <105 breaths/min/L threshold for COPD patients. We found that the threshold of ≤85 breaths/min/L yielded the optimal sensitivity, specificity, PPV, NPV, LR+ and LR– for extubation success, with an AUC of 0.91. Elsewhere it has been reported that the percentage of successful weaning COPD patients rose from 34% to 60% by applying the RSBI threshold of <85 rather than <105 breaths/min/L (20). Similarly, a Taiwanese study reported the optimal RSBI threshold for COPD to be <79 breaths/min/L (21). Moreover, multiple non-randomized studies from China, Egypt, and Iran have further suggested that RSBI thresholds <85 breaths/min/L may better identify COPD patients likely to succeed with extubation (19-28). In another study of 152 COPD patients, El Khoury *et al.* reported that use of RSBI ≥70 (when the $P_aO_2/F_iO_2$ was ≥200) identified patients at a higher risk of reintubation (70% sensitivity, 56% specificity; AUC 0.69) (45). For those COPD patients that fail extubation despite a favorable RSBI, Purro *et al.* reported that most showed ineffective inspiratory efforts which artificially lowered the RSBI, or did not increase breathing frequency, but P0.1 and P0.1/$V_T$/inspiratory time were as high as in other ventilator dependent patients (46).

Further validation is needed, however the COPD-specific RSBI threshold of ≤85 breaths/min/L may be a higher-performing tool for determining success of ventilator liberation in patients with COPD in hypercapnic respiratory failure.

### *Duration of MV*

Many variables have been assessed to aid prognostication of

 

outcomes in patients with acute exacerbations of COPD on MV, but few have withstood the test of time. Longer DoI has been reported with concurrent sepsis, VAP, advanced age, post-hypercapnic alkalosis and higher APACHE II score (47,48). Each of these was similar between groups in this study, except APACHE II score, which was slightly higher in the failed extubation group. That said, the APACHE II score has not been widely reported to correlate with weaning success or DoI.

The longer DoI observed in the successfully extubated group in is study was likely due to a confluence of factors including higher rates of initial high sensitivity hs-CRP >100 mg/L, BNP >200 pg/mL, and higher rates of pre-morbid home oxygen therapy in the successfully extubated group (49,50). Additionally, those in the successfully extubated group were more often treated with NIV prior to intubation. Whereas NIV may reduce intubation rates in COPD (51), patients saved from intubation were not included in this study. It remains unclear whether selecting out such patients significantly impacted outcomes in this study. Additionally, higher rates of chronic hypoxia may have lengthened the time needed to fulfill extubation requirements or tempered the aggression with which clinicians pushed such patients for ventilator liberation. Lastly, the longer hospital LOS in the successfully extubated group should be interpreted considering the system from whence the data arises. In Iran, systems for outpatient rehabilitation remain underdeveloped, thus many of those activities are undertaken in the inpatient setting and patients with significant outpatient needs may remain in the hospital longer.

### *RSBI technique*

It remains unclear to what degree the technique of RSBI measurement impacts the accuracy of the measurement. For example, in the original work by Yang and Tobin, the RSBI was measured one-minute before the SBT with a hand-held spirometer attached to the end of the endotracheal tube (12). However, in common clinical practice the RSBI is calculated on PS without disconnecting the patient from the ventilator. Some have argued that this may influence results, whereas others have found no significant change (32,52). In one study, the AUC values (for successful liberation) of the RSBI measured through the ventilator on PS =5 $cmH_2O$ and CPAP =5 $cmH_2O$ was similar to measurements using the handheld spirometer (0.80 *vs.* 0.81) (43). However, another study reported that RSBI values measured on CPAP =0 $cmH_2O$ were significantly lower with a handheld spirometer (52). This difference was attributable to the base flow delivered by some ventilators. Some have concluded that RSBI measured through spirometry at the end of SBT is a better predictor of weaning outcome than RSBI measured under pressure support (28). Although we used the ventilator to measure the RSBI, we did so at the end of the SBT without pressure support like Youssef *et al.* in a way that most accurately reflects routine clinical practice.

### *RSBI validity*

Literature has been controversial surrounding the utility of the SBT to predict successful ventilator liberation. In some studies, the SBT served as a high-performance predictor in weaning success (53,54), while in others it failed to account or accurately predict the consequences of tube removal in terms of upper airway patency, lower airway protection, secretion clearance, and continued stimulation of spontaneous respiration (55). Furthermore, some patients who tolerate a SBT under spontaneous or supported breathing scenarios (CPAP =5 $cmH_2O$ and PS =5 $cmH_2O$) may develop respiratory dysfunction post-extubation that necessitates intervention (non-invasive or invasive ventilation) (43). Extubation failure rates in patients who passed an SBT have been reported at 16–20% (56,57). Thus, it should be noted that addition of the RSBI to the SBT, with all the listed challenges in the literatures, is a more precise tool than SBT alone.

The RSBI has also had its detractors. A meta-analysis conducted by the American College of Chest Physicians/American Association for Respiratory Care (AARC)/American College of Critical Care Medicine Task Force concluded that the RSBI has low accuracy as a weaning predictor (55). However, Tobin and Jubran raised significant criticism on these results. The authors indicated several methodological biases such as the inclusion of studies that were conducted in non-homogenous patient populations, and the evaluation of RSBI both as a predictor of the SBT or as a predictor of extubation (44).

Ineffective triggering (ITI) ≥10% or ITI <10% is a common problem early during MV and has been associated with increased morbidity, including longer MV duration, shorter ventilator-free survival, longer LOS, and lower likelihood of home discharge. One limitation of this study is that it was not designed to assess for rates of ITI (58). Additionally, we do not have echocardiogram data to accompany the BNP data to aid in risk stratification. Lastly, data on comorbid malignancy was not collected, and is thus

 

not available to aid data interpretation.

## Conclusions

The traditionally used RSBI threshold of <105 breath/min/L may not be appropriate for COPD patients on MV. In COPD patients intubated with hypercapnia, RSBI ≤85 breaths/min/L yields a 95.5% probability of ventilator liberation success, independent of ventilation duration or hospital LOS. This COPD-specific threshold improves the performance of the RSBI for predicting successful ventilator liberation.

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## Footnote

*Conflicts of Interest*: The authors have no conflicts of interest to declare.

*Ethical Statement*: The study was approved by institutional review boards at Baqiyatallah University of the Medical Sciences (340/5/5904) and Shahid Beheshti University of the Medical Sciences (SBMU1/REC/1393/89). Each participating hospital accepted these IRBs. Consent was required and covered both study participation and publication of findings. Informed consent was required prior to cardiac arrest event and could be provided by the patient, legal guardian, or healthcare surrogate. The informed consent included permission to present and publish de-identified results.

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