Rapid shallow breathing index

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Abstract:

Predicting successful liberation of patients from mechanical ventilation has been a focus of interest to clinicians practicing in intensive care. Various weaning indices have been investigated to identify an optimal weaning window. Among them, the rapid shallow breathing index (RSBI) has gained wide use due to its simple technique and avoidance of calculation of complex pulmonary mechanics. Since its first description, several modifications have been suggested, such as the serial measurements and the rate of change of RSBI, to further improve its predictive value. The objective of this paper is to review the utility of RSBI in predicting weaning success. In addition, the use of RSBI in specific patient populations and the reported modifications of RSBI technique that attempt to improve the utility of RSBI are also reviewed.

Key words:

Extubation, mechanical ventilation, rapid shallow breathing index, rapid shallow breathing index rate, reintubation, weaning

Predicting successful liberation process from mechanical ventilation (MV) has always been an important clinical issue.[1,2] Both unnecessary delayed and premature liberation from MV have been shown to be associated with undesirable effects on patient outcome, prolonged MV and increased the length of stay in the Intensive Care Unit (ICU).[3,4] Premature discontinuation places additional stress on the respiratory and cardiovascular systems,[5] while unnecessary delays can lead to diaphragmatic atrophy,[6] venous thromboembolism, delirium, and pneumonia; all of which are associated with increased mortality and morbidity.[7-9] Therefore, the decision of delayed discontinuation must be balanced against a possible premature discontinuation as it has been estimated that medical patients spend 42% of the total time on MV in the discontinuation process.[10] Many of the integrated weaning indices look promising, but no index has proven to be ideal.[11] Until the description rapid shallow breathing index (RSBI) by Yang and Tobin in 1991, clinicians depended mainly on weaning predictors such as vital capacity, maximum inspiratory pressure, and minute ventilation. Yang and Tobin described RSBI as the ratio of respiratory rate (RR) to tidal volume (VT), with a threshold value of >105 breaths/min/L being highly predictive of weaning failure, while RSBI <105 breaths/min/L is associated with weaning success. Our review examines the existing literature on the utility of RSBI in predicting successful weaning. We review the utility of RSBI in specific patient populations and also examined the reported modifications of RSBI that attempted to improve the value of RSBI.

Yang and Tobin, in their original prospective cohort study on RSBI, evaluated 100 mechanically ventilated medical patients.[12] The measurement of VT was performed using a hand-held spirometer attached to the endotracheal (ET) tube while the patient breathed room air for 1-min without any ventilator assistance. The study found that an RSBI >105 breaths/min/L was associated with weaning failure, while an RSBI <105 breaths/min/L predicted weaning success with a sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of 97%, 64%, 78%, and 95%, respectively. The findings of Yang and Tobin were supported by several subsequent studies conducted by Epstein[13] and Jacob *et al*.[14] in adults, and by Thiagarajan *et al*.[15] in the pediatric population. Frutos-Vivar *et al*. had identified that the RSBI as one of the best predictor associated with extubation failure,

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with a positive fluid balance and pneumonia as the other factors.[4]

Technical Considerations in Rapid Shallow Breathing Index

RSBI is now incorporated in many ventilator algorithms and are shown on the ventilator display as one of the ventilator parameters. It has been demonstrated that RSBI calculated from values obtained by direct ventilometry and the one obtained through the values available in the display of the mechanical ventilator are highly correlated.[16]

It is important to recognize the influence of ventilator setting on RSBI. A survey of respiratory therapists found great variation in weaning techniques and was observed that some respiratory therapists use continuous positive airway pressure (CPAP), and some use pressure support ventilation (PSV) to measure the RSBI, all of which could affect the measurements obtained.[17] Shingala *et al*. compared RSBI on PSV and RSBI on spontaneous breathing with T-piece and found that RSBI on PSV was a better predictor for extubation, easier to obtain, and less stressful for the patient.[18] Another study[19] examined RSBI values under various ventilatory support settings prior to extubation. The study compared RSBI in PSV, CPAP, and T-piece in 36 patients. RSBI was significantly smaller during PSV, and CPAP compared to T-piece. While RSBI was <105 breaths/min/L in all enrolled patients on both PSV and CPAP modes, this changed during T-piece trial, as 13 out of 36 patients had an RSBI of >105 breaths/min/L. This observation was confirmed in other studies.[20,21] A recent study concluded that a threshold RSBI value of 75 breaths/min/L in PSV and 100 breaths/min/L in T-piece was more accurate for predicting successful weaning.[22]

In addition, it is important to recognize that sepsis, fever, supine position, anxiety, and restrictive lung diseases increase the respiratory frequency and hence affect RSBI. Some other factors such as narrow ET tube, female gender, and suctioning are shown to increase RSBI, and the need of various thresholds are recommended.[23-25]

Skeptics of Rapid Shallow Breathing Index

Tanios *et al*. conducted a randomized controlled trial of the role of weaning predictors in clinical decision-making. The study enrolled 304 patients who were randomized to two groups; in one group the RSBI was measured but not used in the decision to wean, and in the other group, RSBI was measured and used, with a threshold of 105 breaths/min/L for weaning decision-making. Patients passing a 2-h spontaneous breathing trial (SBT) were eligible for an extubation attempt.[26] The study found that the median duration for weaning time was significantly shorter in the group where the weaning predictor was not used (2.0 vs. 3.0 days, $P = 0.04$) with no difference between the two groups in the incidence of extubation failure, in-hospital mortality rate, tracheostomy, or unplanned extubation. Other studies re-evaluated the most predictive cut-off threshold. Danaga *et al*. found that the classical cut-off value of RSBI (105 breaths/min/L) predicted only 20% of the cases that were ready for extubation while a cut-off value of 76.5 breaths/min/L provided substantial improvement in sensitivity (66%), with an acceptable loss of specificity (74%).[27]

Rapid Shallow Breathing Index in Specific Populations

While RSBI is appropriate for most ICU patients, there are certain patient populations in whom the use of RSBI may or may not accurately predict successful weaning.

Rapid shallow breathing index in chronic obstructive pulmonary disease patients

A study on weaning chronic obstructive pulmonary disease (COPD) patients found that RSBI measured early during an SBT cannot accurately predict the successful outcome in the patient population.[28] This is probably related to the ineffective inspiratory efforts, which does not trigger the ventilator leading to false positive results of RSBI <105 breaths/min/L. Therefore, a study found that 56% of the COPD patients with RSBI <80 breaths/min/L actually failed the weaning trials.[29]

Rapid shallow breathing index in cardiac patients

The value of RSBI in post cardiac surgery patient was confirmed by a study by Oribabor *et al*.[30] The study showed that the utilization of the RSBI as the sole criteria for weaning has led to significantly short mean extubation times in cardiac surgery patients without an increase in reintubation rates. In cardiac patients, in general, it is important to note the effect of positive pressure ventilation. Since positive pressure can improve cardiac function in congestive heart failure patients,[31] and this can also reduce RSBI,[32] it is important to keep in mind the effect of PSV and CPAP on RSBI values. This has been confirmed in a study of postcoronary artery bypass graft patients, as RSBI values were lower in CPAP (5 cm) than T-piece trials.[21]

Rapid shallow breathing index in neurosurgical patients

Neurosurgical patients represent a special group for weaning because the main reason for intubation is usually airway protection and not abnormal lung physiology. Not surprising therefore that RSBI is not a good predictor of successful weaning. A prospective cohort comprising 92 neurosurgical patients concluded that an RSBI <105 breaths/min/L was not associated with successful extubation, among the 15 participants who needed reintubation, only one patient exhibited an RSBI >105 breaths/min/L.[33] Another observational cohort comprising 119 traumatic brain injury (TBI) patients concluded no association between RSBI categories (<105 breaths/min/L and >105 breaths/min/L) and successful extubation in TBI patients.[34]

Rapid shallow breathing index in patients with tracheostomy

A prospective cohort of 191 patients with tracheostomy and on prolonged MV concluded RSBI as a good predictor of 1-h SBT tolerance, with 97 breaths/min/L as the RSBI threshold with a maximum accuracy of 81.7%.[35]

Rapid shallow breathing index in pediatric patients

RSBI was described in the adult population, and the cut-off points have been generated for that population. In the pediatric population, the performance and outcomes of RSBI have been debated and questioned.[36-38] The results of a pediatric survey reflected the limited and conflicting literature on RSBI in children.[39]

Rapid shallow breathing index in burn patients

A study on burn patients identified that RSBI is predictive of successful extubation, although cough peak flow (CPF) and ET secretions in patients who passed SBT were highly predictive.[40] Therefore, CPF and ET secretions should be used in conjunction with RSBI in this population, and generally in any population with a poor cough and increased secretions.

Patients on prolonged mechanical ventilation

In a retrospective cohort study of patients receiving prolonged MV, RSBI was measured daily, with weaning per protocol. Initial, mean, and final RSBI; RSBI ≤105; rate of change; and variability were assessed. The study found that isolated RSBI measurements do not accurately predict successful weaning from, but RSBI trends may have prognostic value.[41]

Patients on non-invasive ventilation (NIV)

The RSBI may also have a role in predicting successful weaning from noninvasive ventilation (NIV). An initial assisted RSBI of >105 breaths/min/L in NIV patients was associated with the need for intubation and increased in-hospital mortality.[42] Another study evaluated the use of RSBI in non-intubated COPD patients and concluded that higher RSBI values in these patients with COPD exacerbations predicted the need for NIV.[43]

Modifications in Rapid Shallow Breathing Index

There have been increasing interest in maximizing the predictive value of RSBI. The use of serial RSBI and RSBI rate has been proposed.

Serial rapid shallow breathing index

The use of serial RSBI comes from the observation that breathing pattern in some patients may be stable at the beginning of SBT but deteriorate later. This deterioration is ascribed to poor respiratory muscle endurance or worsening of pulmonary mechanics that may not be present during the initiation of weaning.[44] Hence, some studies later focused on the serial assessment of RSBI and at various intervals. Chatila *et al*. reported that RSBI measured at 30 min of an SBT was a better predictor of weaning outcome than RSBI at the start of weaning initiation.[45] Krieger *et al*. summarized that serial measurements of RSBI may be more useful in the weaning process.[25] Another study about serial RSBI measurement and weaning outcome in critically ill patients concluded that RSBI measured at the completion of SBT was superior to that measured at the start of weaning.[46] However, the value of serial RSBI has not been shown consistently. In patients, who already had a successful SBT with initial RSBI <105 breaths/min/L, serial RSBI measurements during 120 min of SBT were unable to detect extubation failure.[47] Shah *et al*. concluded that RSBI does not change significantly during a 90 min SBT during serial measurement done at 1, 30, 60, and 90 min of SBT.[48]

Rapid shallow breathing index rate

RSBI rate refers to the rate of change in RSBI in serial measurement. Segal *et al*. studied serial RSBIs during weaning and looked into RSBI rate hypothesizing the rate of change in RSBI is more predictive of successful weaning, as respiratory failure is a dynamic phenomenon. In this prospective cohort, 2 h of SBT was given, and the variables were measured periodically during SBT. RSBI rate was calculated by the formula: (RSBI-2 – RSBI-1)/RSBI-1 × 100 and the identified threshold was 20%. Of 30 patients, 21 were successfully extubated, 3 were reintubated within 24 h, and six remained intolerant to the SBT. The study found that the RSBI rate <20% has a sensitivity of 90.4% and specificity of 100% in predicting weaning success. It had a PPV of 100% and an NPV of over 81%.

In another prospective observational study of Segal *et al*.,[49] 63 out of 72 patients were successfully extubated (24 h postextubation window period), by using RSBI rate as a weaning predictor. RSBI was assessed in every 30 min of the 2-h trial. Initial RSBI was similar in extubation success and extubation failure groups (77.0 ± 4.8, 77.0 ± 4.8, $P \geq 0.05$). RSBI remained the same in subsequent intervals of the successfully extubated group, whereas, the values of RSBI were in the increasing trend (either due to increased RR or decreased VT) in extubation failure group. They concluded that the percent change of RSBI during SBT was a better predictor of successful extubation than a single determination of RSBI.

In the above trial, 24 were COPD patients and 10 out of 24 (41.66%) continued ventilator support. Of note, breathing trials were performed using T-piece, where it has been identified already that RSBI values will be on a higher side in T-piece group, compared to that of RSBI values in the ventilator-supported group.[18]

Conclusion

RSBI is an important predictor of weaning outcome. Serial RSBI and RSBI rate have better predictive value than a single RSBI measurement. However, interpretation of RSBI values must take in consideration certain technical aspects, such as the ventilator settings as well as the patient population. RSBI should not be used universally in all populations to predict successful extubation. In certain patient populations, particularly in whom the primary problem is related to airway protection, increased secretions and poor cough, liberation from MV should not rely solely on RSBI, but on other parameters such as cough adequacy and a number of secretions [Tables 1-3].

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Conflicts of interest

There are no conflicts of interest.

Table 1: Studies on RSBI in general medical-surgical ICU patients

Reference number	Author and year	Population	Study design	Technique of RSBI measurement	Comparison	Outcome	Main finding
[12]	Yang and Tobin 1991	Medical patients (*n*=100)	Retrospective derivation cohort (*n*=36) and prospective validation cohort (*n*=64)	T-piece	RSBI was compared to CROP index	Weaning success was defined as the ability to sustain SB for ≥24 h	RSBI <105 breaths/min/L had a sensitivity of 0.97, specificity of 0.64, PPV of 0.78 and NPV of 0.95 in predicting weaning success. RSBI was a better predictor of weaning outcome than CROP index
[13]	Epstein 1995	Medical and surgical patients (*n*=94)	Prospective study	T-piece	The relationship between RSBI and extubation outcome was analyzed	Extubation was considered successful if SB could be sustained for >72 h	RSBI <100 breaths/min/L had a PPV of 0.83 in predicting successful extubation
[14]	Jacob *et al.* 1997	Surgical patients (*n*=183)	Prospective study	CPAP, PSV, and T-piece	Comparison of RSBI (at start of wean and at 30 min), NIF, and VE	Weaning success was defined as unassisted breathing for more than 24 h	The sensitivity of initial RSBI was 0.97, RSBI at 30 min was 0.96, VE was 0.76 and NIF was 0.96.The specificity of Initial RSBI was 0.33, RSBI at 30 min was 0.31, VE was 0.40 and NIF was 0.07.The initial RSBI and RSBI at 30 min didn't show significant predictive information, but RSBI was a better predictor of weaning outcome than the NIF and VE
[15]	Thiagarajan *et al.* 1999	Pediatric patients (*n*=227)	Prospective study	CPAP	RSBI and CROP were evaluated	Extubation was considered successful if SB could be sustained for >72 h	A RSBI value of ≤8 breaths/ml/kg had a sensitivity of 74% and specificity of 74%, whereas a CROP value of ≥0.15 ml/kg/breaths/min had a sensitivity of 83% and specificity of 53% for extubation success. RSBI and CROP indices predict extubation success more accurately than failure
[16]	Lessa *et al.* 2010	Cardiac surgery patients (*n*=22)	Prospective study	PSV and digital ventilometry	RSBI measurement through PSV and digital ventilometer was compared		A significant difference was observed between the RSBI obtained from the ventilator and by the digital ventilometer (P=0.011)
[17]	Soo Hoo and Park 2002	Respiratory therapists (*n*=102)	Survey		A questionnaire survey was conducted to characterize the different weaning approaches by respiratory therapists		90% of the reported parameters during various weaning approaches were MIP, VT, RR, and VE. RSBI was specifically reported by only 20%. There were a great variability in the modes (T-piece, CPAP, PSV) used to collect weaning parameters like RR, VT, VE, MIP
[18]	Shingala *et al.* 2009	Medical patients (*n*=42)	Prospective randomized trial	T-piece and PSV	RSBI-PSV was compared with RSBI on RSBI-SB		Mean RSBI-PSV was 59.40 breaths/min/L compared to mean RSBI-SB of 72.60 breaths/min/L. Difference in RSBI-PSV compared to RSBI-SB was 13.20 with SD of 24.74 and SE of mean 3.91. Correlation between RSBI-PSV and RSBI-SB was 0.83. RSBI-PSV was significantly lower, but was highly correlated with RSBI-SB
[19]	El-Khatib *et al.* 2008	Medical patients (*n*=36)	Prospective study	T-piece, CPAP (40% and 21%) and PSV	Compared RSBI in all patients with CPAP, PSV, and T-piece		RSBI was significantly lower during PSV (46±8 breaths/min/L), CPAP (63±13 breaths/min/L), and CPAP-R/A (67±14 breaths/min/L) versus T-piece (100±23 breaths/min/L). RSBI during PS, CPAP and CPAP-R/A were significantly lower than RSBI during T-piece

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Table 1: Contd...

Reference number	Author and year	Population	Study design	Technique of RSBI measurement	Comparison	Outcome	Main finding
[20]	Patel *et al.* 2009	Medical patients (*n*=60)	Prospective study	CPAP and T-piece	RSBI measured during CPAP and T-piece weaning were compared		RSBI was significantly less when measured on 5 cm H_2O CPAP, compared to T-piece: the medians and interquartile ranges were 71 (52-88) breaths/min/L in CPAP and 90 (59-137) breaths/min/L in T-piece (P<0.001). No significant difference was observed in the value of RSBI obtained using ventilator versus manual breathing
[21]	El-Khatib *et al.* 2002	Cardiac surgery patients (*n*=33)	Prospective study	CPAP and SBT in R/A	Compared RSBI using CPAP with different FiO_2 and SBT in R/A		The average RSBIs were significantly lower under Group 1 (34±13) and Group 2 (36±14) which are CPAP Supported, compared to Group 3 (71±24), which is SBT in R/A. There was no significant difference in RSBI between Group 1 and 2. Changes in FiO_2 did not show any effect on RSBI values but CPAP may influence RSBI
[22]	Zhang and Qin 2014	Medical patients (*n*=208)	Prospective study	PSV and T-piece	RSBI threshold was compared in PSV and T-piece SBT		An RSBI of 75 breaths/min/L in PSV and 100 breaths/min/L in T-piece yielded a diagnostic accuracy of 87% and 82%, respectively
[25]	Krieger *et al.* 1997	Elderly medical patients (*n*=59)	Retrospective - 10 patients Prospective - 49 patients	T-piece	This study was based on another study published in 1992 (Breitenbucher, Ershowsky, and Krieger) in which the researchers determined that an RSBI <130 breaths/min/L accurately predicted weaning success in patients 70 years old and older with medical diagnoses	Weaning failure was defined as requiring the reinstitution of MV within 48 h after extubation	At the beginning of weaning trial, RSBI <130 breaths/min/L had a diagnostic accuracy of 0.84, sensitivity of 0.92, specificity of 0.57, PPV of 0.87 and NPV of 0.67. Three hours later, the diagnostic accuracy was 0.92, sensitivity was 0.93, specificity was 0.89, PPV was 0.97 and NPV was 0.80 A threshold value of <130 breaths/min/L is more appropriate for elderly population than previously published values of <105 breaths/min/L
[26]	Tanios *et al.* 2006	Multidisciplinary patients (*n*=304)	Randomized control trial	T-piece	Compared the inclusion and exclusion of RSBI in the decision of weaning	The outcome of study was weaning time, defined as the duration of MV from the first daily screening until reaching a study end point (extubation, 21 days from enrolment, tracheostomy, death, or withdrawal of care)	The median duration for weaning time was significantly shorter in the group where the weaning predictor was not used (2.0 vs. 3.0 days, P=0.04). There was no difference in regard to the extubation failure, in-hospital mortality, tracheostomy, or unplanned extubation. RSBI has prolonged the weaning time and did not confer survival benefit or reduce the incidence of extubation failure or tracheostomy

RSBI = Rapid shallow breathing index, ICU = Intensive Care Unit, CROP index = Compliance, resistance, oxygenation, pressure index, CPAP = Continuous positive airway pressure, PSV = Pressure support ventilation, NIF = Negative inspiratory force, VE = Minute ventilation, SB = Spontaneous breathing, SBT = Spontaneous breathing trial, FiO_2 = Fraction of inspired oxygen, MV = Mechanical ventilation, PPV = Positive predictive value, NPV = Negative predictive value, MIP = Maximal inspiratory pressure, VT = Tidal volume, RR = Respiratory rate, SD = Standard deviation, SE = Standard error, R/A = Room air

Table 2: Studies on RSBI in special ICU populations

Reference number	Author and year	Population	Study design	Technique of RSBI measurement	Comparison	Outcome	Main finding
[28]	Boutou *et al.* 2011	COPD patients (*n*=64)	Prospective study	T-piece	To evaluate 2 threshold values of RSBI (105 and 130) to predict a successful weaning trial in COPD patients	Successful weaning based on stable hemodynamics, blood gases, and vitals after 30 min of SBT	The 2 threshold values that were evaluated had a low specificity (0.381 for <105 breaths/min/L and 0.667 for <130 breaths/min/L), low sensitivity (0.636 for <105 breaths/min/L and 0.545 for <130 breaths/min/L), and low diagnostic accuracy (0.468 for <105 breaths/min/L and 0.656 for <130 breaths/min/L) in predicting a successful T-piece trial outcome RSBI measured early during an SBT cannot accurately predict the successful outcome of a T-piece trial in COPD patients
[29]	Purro *et al.* 2000	COPD patients and postcardiac surgery patients (*n*=39)	Prospective study	T-piece		Successful weaning was considered as spontaneous breathing without ventilator support	Weaning was failed in patients with RSBI >105 breaths/min/L and 56% of COPD patients with RSBI <80 breaths/min/L. Those who failed despite a low RSBI either showed ineffective inspiratory efforts, which artificially lowered RSBI (*n*=8), or did not increase respiratory frequency (*n*=5)
[33]	Vidotto *et al.* 2008	Neurosurgical patients (*n*=92)	Prospective study	PSV and T-piece		Extubation failure, when patients needed reintubation within 48 h	Ninety-two patients were extubated, and failure occurred in 16%. Out of those 15 extubation failure, only one presented RSBI over 105 breaths/min/L. The best cutoff value for RSBI observed was 62, but with low specificity (0.53) and negative predictive values (0.29)
[34]	dos Reis *et al.* 2013	Traumatic brain injury patients (*n*=119)	Prospective cohort study	Wrights spirometer		Successful extubation means no reintubation in 48 h	RSBI did not exhibit a difference between the groups with successful and failed extubation; (73.5±33.1 and 83.8±21.3) *P*=0.25 Among the 15 patients that needed reintubation, only 2 patients (13.3%) exhibited an RSBI >105 breaths/min/L RSBI was not associated with successful in the patients with TBI
[35]	Chao and Scheinhorn 2007	Tracheostomy patients (*n*=191)	Prospective observational study	Flow-by			An RSBI threshold of 80 had a sensitivity of 62.4% and specificity of 88.5% Increasing the RSBI threshold to 97 increased the sensitivity by 15% while sacrificing specificity by 4% The optimal RSBI threshold was 97 breaths/min/L, where accuracy was maximal RSBI was a good predictor of 1 h SBT tolerance
[36]	Newth *et al.* 2009		Systematic review				
[37]	Farias *et al.* 2002	Medical and surgical infants and children (*n*=418)	Prospective study	T-piece		Extubation failure was defined as needing reintubation within 48 h after extubation	The ROC curve for VT, RR, PImax, and RSBI measured within the first 5 min of breathing were 0.54, 0.56, 0.57 and 0.57, respectively. The ROC curve did not increase significantly when the above indices were remeasured before extubation An RSBI of more than or equal to 11 breaths/min/ml/kg measured at the end of the SBT is 3 times more likely to occur in a patient who will fail extubation than it is to occur in a patient who will be successfully extubated
[38]	Venkataraman *et al.* 2000	Infants and pediatric patients (*n*=312)	Prospective descriptive study	PSV		Extubation failure was defined as reintubation within 48 h of extubation in the absence of upper airway obstruction	The extubation failure rate was 16% and indices like RSBI and CROP was not considered as a good predictor of outcome as in adult studies

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Table 2: Contd...

Reference number	Author and year	Population	Study design	Technique of RSBI measurement	Comparison	Outcome	Main finding
[39]	Mhanna *et al.* 2014	Pediatric critical care physicians (*n*=417/945)	Cross-sectional survey				The majority of the responders, 83% (344/414), do not perform a RSBI prior to extubation; and among the 17% (70/414) of physicians who perform a RSBI, 51% (36/70) perform the test with a pressure support that is adapted to the size of the endotracheal tube, 54% (31/57) consider the upper limit of 10 breaths/min/mL/kg as acceptable for extubation and the majority consider 12 breaths/min/mL/kg as acceptable Most physicians less often consider RSBI for extubation readiness
[40]	Smailes *et al.* 2013	Burn patients (*n*=125)	Prospective study	T-piece	RSBI, CPF and ET secretions were assessed	Patients who remain extubated at 48 h are classified as a successful extubation	CPF was significantly positively correlated with extubation success (0.38), whereas ET secretions and RSBI are significantly negatively correlated (−0.43 and −0.23, respectively). The strongest association is between ET secretions and extubation outcome, and the weakest is between RSBI and extubation outcome
[41]	Verceles *et al.* 2012	Long-term medical patients (*n*=52)	Retrospective observational cohort	CPAP	Assessed initial, mean, and final RSBI; RSBI <105; rate of change and variability		Only the mean RSBI and the RSBI on the last day of weaning predicted success, whereas RSBI variability and rate of change were different between the groups RSBI measurements do not predict successful weaning from prolonged ventilation
[42]	Berg *et al.* 2012	Medical patients (*n*=101)	Prospective observational study	Noninvasive ventilation	Assessed RSBI as an indicator of NIV failure and intubation	The primary outcome was failure of NIV, as determined by intubation during hospital stay The secondary outcome was in-hospital mortality	Of 83 patients with an aRSBI <105 breaths/min/L, 26 (31%) required intubation, compared to 10/18 (55%) with an aRSBI >105 breaths/min/L When comparing mortality, 7/83 patients (8.4%) with an aRSBI <105 breaths/min/L died, compared to 6/18 (33%) patients in the group with an aRSBI >105 breaths/min/L An aRSBI of >105 breaths/min/L is associated with need for intubation and increased in-hospital mortality

RSBI = Rapid shallow breathing index, ICU = Intensive Care Unit, COPD = Chronic obstructive pulmonary disease, PSV = Pressure support ventilation, CPAP = Continuous positive airway pressure, CPF = Cough peak flow, ET = Endotracheal, NIV = Noninvasive ventilation, SBT = Spontaneous breathing trial, TBI = Traumatic brain injury, ROC curve = Receiver operating characteristic curve, CROP = Compliance, resistance, oxygenation, pressure, aRSBI = Assisted Rapid shallow breathing index, VT = Tidal volume, RR = Respiratory rate, PImax = Maximal inspiratory mouth pressure

Table 3: Studies about variants in RSBI, including serial RSBI and RSBI rate

Reference number	Author and year	Population	Study design	Technique of RSBI measurement	Comparison	Outcome	Main finding
[45]	Chatila *et al.* 1996	Medical patients (*n*=100)	Prospective study	CPAP, pressure support mode, and T-piece	The study compared spontaneous RSBI, NIF, and VE at the onset of weaning, and the RSBI again after 30-60 min of weaning	Weaning success was defined as spontaneous breathing for more than 24 h	The RSBI measured at the start of weaning had a sensitivity of 0.89, specificity of 0.41, PPV of 0.72, and NPV of 0.68. However, the RSBI measured after 30-60 min of weaning had a sensitivity of 0.98, specificity of 0.59, PPV of 0.83, and NPV of 0.94. RSBI measured at 30 min is superior to the RSBI in the 1st min of weaning. RSBI was a better predictor of successful weaning than VE
[46]	Kuo *et al.* 2006	Medical and surgical patients (*n*=172)	Prospective study	T-piece	RSBI was assessed during 1st min of SBT and at the termination of SBT	Weaning was considered as successful if patients could maintain spontaneous breathing at 48 h after extubation	Logistic regression revealed that final RSBI was superior to initial RSBI and various physiologic indices in predicting weaning outcome. For the 118 extubated patients, the mean area under the ROC curve for final RSBI and initial RSBI was 0.83 and 0.63, respectively. Using a threshold value of 105 breaths/min/L, the sensitivity, specificity, accuracy and likelihood ratio for weaning outcome were 0.91, 0.25, 0.85 and 1.38 for final RSBI and 0.89, 0.16, 0.60 and 1.06 for initial RSBI, respectively
[47]	Teixeira *et al.* 2008	Medical and surgical patients (*n*=73)	Prospective study	T-piece	RSBI was evaluated during 1st min, 30th min and 120th min of SBT	Weaning was classified as successful if patients could maintain spontaneous breathing at 48 h after extubation	The RSBI-30 increased as compared with RSBI-1 (79±24 vs. 68±30, *P*=0.01) but did not differ from RSBI-120 (79±44 vs. 81±42, *P*=0.79). The RSBI-1 was lower in successful extubation as compared with extubation failure patients (62±29 vs. 82±15, *P*=0.01). Serial RSBI measurements during 120 min of SBT were unable to detect extubation failure in patients following a successful SBT with initial RSBI lower than 105 breaths/min/L
[48]	Shah *et al.* 2004	Medical patients (*n*=164)	Prospective study	CPAP		Evaluated whether RSBI changes significantly (20 point increase from baseline and crosses 100) from the beginning to the end of a 90-min SBT	The mean RSBIs of successfully extubated patients were 65, 63, 64, and 65 at 1, 30, 60, and 90 min, respectively. The mean RSBIs of patients who failed extubation were 101, 80, 81, and 82 at 1, 30, 60, and 90 min, respectively Of the successfully extubated 141 patients, only 4 (2.8%) had a significant change in RSBI. Of the 23 who failed extubation five tolerated less than 5 min of the SBT. Of the remaining 18 patients, only 1 (5.6%) had a significant change in RSBI during the SBT. The RSBI does not change significantly during a 90 min SBT in relation with 1, 30 and 60 min
[49]	Segal *et al.* 2010	Medical, surgical and cardiac patients (*n*=72)	Prospective observational study	T-piece		Extubation was considered successful if maintained spontaneous breathing >24 h after extubation	With a 2 h SBT the optimal threshold was a rate of change of 20% between 2 RSBI values (sensitivity=0.89, specificity=0.89) Percentage change of RSBI during SBT is a better predictor of successful extubation than a single determination of RSBI

RSBI = Rapid shallow breathing index, PPV = Positive predictive value, NPV = Negative predictive value, CPAP = Continuous positive airway pressure, NIF = Negative inspiratory force, VE: Minute ventilation, SBT = Spontaneous breathing trial, ROC curve = Receiver operating characteristic curve, RSBI-1 = RSBI at 1st min, RSBI-30 = RSBI at 30th min, RSBI-120 = RSBI at 120th min

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