# Evaluation of the diagnostic performance and cut-off value for the rapid shallow breathing index in predicting extubation failure*

## Avaliação do desempenho diagnóstico e do valor de corte para o índice de respiração rápida e superficial na predição do insucesso da extubação

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## Abstract

**Objective:** To evaluate the diagnostic performance of the rapid shallow breathing index (RSBI) in predicting extubation failure among adult patients in the intensive care unit and to determine the appropriateness of the classical RSBI cut-off value. **Methods:** This was a prospective study conducted in the adult intensive care unit of the Botucatu School of Medicine *Hospital das Clínicas*. The RSBI was evaluated in 73 consecutive patients considered clinically ready for extubation. **Results:** The classical RSBI cut-off value (105 breaths/min/L) presented a sensitivity of 20% and a specificity of 95% (sum = 115%). Analysis of the receiver operator characteristic (ROC) curve revealed a better cut-off value (76.5 breaths/min/L), which presented a sensitivity of 66% and a specificity of 74% (sum = 140%). The area under the ROC curve for the RSBI was 0.78. **Conclusions:** The classical RSBI cut-off value proved inappropriate, predicting only 20% of the cases of extubation failure in our sample. The new cut-off value provided substantial improvement in sensitivity, with an acceptable loss of specificity. The area under the ROC curve indicated that the discriminative power of the RSBI is satisfactory, which justifies the validation of this index for use.

**Keywords:** Adult; Intensive care; ROC curve; Ventilator weaning; Diagnosis; Respiration, artificial.

## Resumo

**Objetivo:** Avaliar o desempenho diagnóstico do índice de respiração rápida e superficial (IRRS) na predição do insucesso da extubação de pacientes adultos em terapia intensiva e verificar a adequação do valor de corte clássico para esse índice. **Métodos:** Estudo prospectivo realizado na unidade de terapia intensiva de adultos do Hospital das Clínicas da Faculdade de Medicina de Botucatu, através da avaliação do IRRS em 73 pacientes consecutivos considerados clinicamente prontos para extubação. **Resultados:** O IRRS com valor de corte clássico (105 ciclos/min/L) apresentou sensibilidade de 20% e especificidade de 95% (soma = 115%). A análise da curva *receiver operator characteristic* (ROC) demonstrou melhor valor de corte (76,5 ciclos/min/L), o qual forneceu sensibilidade de 66% e especificidade de 74% (soma = 140%), e a área sob a curva ROC para o IRRS foi de 0,78. **Conclusões:** O valor de corte clássico do IRRS se mostrou inadequado nesta casuística, prevendo apenas 20% dos pacientes com falha na extubação. A obtenção do novo valor de corte permitiu um acréscimo substancial de sensibilidade, com aceitável redução da especificidade. O valor da área sob a curva ROC indicou satisfatório poder discriminativo do índice, justificando a validação de sua aplicação.

**Descritores:** Adulto; Cuidados intensivos; Curva ROC; Desmame do respirador; Diagnóstico; Respiração artificial.

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## Introduction

Although invasive mechanical ventilation (MV) is required in nearly half of all patients under intensive care,[1] it is associated with a number of complications, especially when it is used for prolonged periods. Pneumonia is the most common complication of MV. However, MV can also increase the risk of tracheal lesion, of lung injury inherent to the MV itself, of increased dependence of the ventilator and of death.[2] Therefore, it has been suggested that the ventilatory support should be discontinued as rapidly as possible.[2-4] However, its premature discontinuation can lead to the need for re-intubation.[5,6]

Re-intubation occurs after approximately 20% of all extubations[7] and is associated with a greater risk of nosocomial pneumonia, greater mortality rates, longer intensive care unit (ICU) stays and longer exposure to MV, as well as increasing the chance of tracheostomy.[5-8]

The use of protocols based on daily clinical evaluation, such as the spontaneous breathing protocol, as well as protocols based on physiological parameters or predictive indices, is recommended in order to accurately predict the outcome of the extubation.[9-12]

Many predictive indices have been described in order to identify patients capable of resuming spontaneous ventilation. However, few indices have proven to have satisfactory diagnostic power and be easily applied.[13,14] The rapid shallow breathing index (RSBI) is the index most often used in MV weaning, and is expressed by the ratio between respiratory rate (RR) and tidal volume (TV).[13,15] Values of RSBI > 105 breaths/min/L have been established as being predictive of unsuccessful weaning and extubation failure.[16] Although its diagnostic power has been questioned in many studies,[17-23] the RSBI is easy to apply at the bedside and it is considered the most accurate index. Few studies have re-evaluated the classical cut-off value proposed for this index,[24-26] and rarely has this evaluation been carried out based on the best values of sensitivity and specificity with the calculation of the receiver operating characteristic (ROC) curve.[27,28]

In this context, the objective of our study was to evaluate the diagnostic performance of the RSBI in predicting the risk of re-intubation in critical patients, and, principally, to determine the appropriateness of the classically used cut-off value in the patient sample studied.

## Methods

A prospective observational study was carried out in the Adult ICU of the Botucatu School of Medicine *Hospital das Clínicas* from September of 2007 to September of 2008, in order to validate the RSBI. The study was approved by the research ethics committee of the institution (OF: 37/2007-CEP).

The inclusion criteria were MV through orotracheal intubation and meeting the weaning and extubation criteria, that it, the RSBI was evaluated only in patients who were ready to be extubated, in accordance with the criteria adopted by the unit, as follows: resolution of the event that prompted the use of MV; decreased artificial ventilation parameters—positive end-expiratory pressure (PEEP) $\leq$ 5 $cmH_2O$, $FiO_2 \leq 0.4$ obtaining $SpO_2 > 90\%$, RR $\leq$ 10 breaths/min and pressure support ventilation $\leq$ 10 $cmH_2O$ in order to obtain a TV $\geq$ 5 mL/kg and a minute volume $\leq$ 10; hemodynamic stability—heart rate (HR) $\leq$ 120 bpm, systolic blood pressure (SBP), 90-180 mmHg; integrity of the respiratory drive; negative fluid balance and normal levels of serum electrolytes (calcium, magnesium, potassium, sodium and iron); complete weaning from sedation and vasoactive drugs; absence of fever; appropriate arterial blood gas analysis and pH (pH, 7.35-7.45 and $PaCO_2$, 35-45 mmHg); oxygen index ($PaO_2/FiO_2$) $\geq$ 200 mmHg; pulmonary auscultation and X-ray images suggesting no acute pulmonary disease; hemoglobin $\geq$ 8 g/dL; presence of cough reflex; MIP $\leq -20$ $cmH_2O$; no imminent need for surgical intervention; as well as tolerance to the spontaneous breathing test, carried out using a T-piece during 30-120 min; the following parameters were used to define intolerance to the test: RR > 35 breaths/min, $SpO_2 < 90\%$, HR > 140 bpm, SBP > 180 mmHg or < 90 mmHg, as well as signs of agitation, sweating or altered level of consciousness.[15]

During the study period, 398 patients were admitted to the ICU. Of those, 264 received orotracheal intubation and 105 died prior to initiation of the weaning protocol. Of the remaining 159 patients, 86 either did not meet the inclusion criteria or met at least one of the exclusion criteria. Therefore, we included 73 consecutive patients (≥ 18 years of age), regardless of the cause of ICU admission.

The patients were evaluated after bronchial hygiene, shortly before the moment of extubation, in the semi-recumbent supine position and under vital sign monitoring. Tracheostomized patients were excluded, as were patients who did not give written informed consent, as well as those who did not meet the weaning and extubation criteria.

Immediately after the ventilator had been disconnected, the RSBI was measured in accordance with a technique previously described,[16] using a digital spirometer (Ohmeda, Oxnard, CA, USA), properly calibrated, during 1 min of spontaneous breathing. After the RR and the expiratory volumes had been recorded, the patients were reconnected to the respirator. Mean spontaneous TV was calculated by dividing the sum of the exhaled volumes (minute volume) by the RR. The RSBI value was obtained by dividing the RR by the mean spontaneous TV. The decision of extubation was not influenced by the RSBI result, since the team had no knowledge of the values obtained.

Extubation failure was defined as the need for re-institution of the artificial ventilation and for re-intubation within 48 h after the orotracheal tube removal, regardless of the cause.

The following variables were recorded: sex, age, duration of MV, duration of ICU stay, as well as the Acute Physiology and Chronic Health Evaluation (APACHE) II score, applied at ICU admission.

Parametric variables were expressed as mean ± standard deviation, and nonparametric variables were expressed as median (25th-75th interquartile range). Sample size was calculated for an $\alpha$ error = 0.05 and a $\beta$ error = 0.20 (statistical power = 0.80) resulting in an ideal sample size of 68 patients in order to detect a 30% to 10% difference in the re-intubation index, according to the presence or absence of a high RSBI value.

A ROC curve was drawn, and the area under that curve was calculated, as was the 95% CI, in order to detect the best cut-off value for the index. Areas under the curve for which the 95% CI was < 0.5 were considered statistically significant. The ROC curve provides a sensitivity/specificity ratio for each cut-off value of an index. The cut-off value that presented the highest sum of sensitivity and specificity was established as the best RSBI cut-off value.[29] We calculated sensitivity, specificity, positive predictive value, negative predictive value, positive likelihood ratio, negative likelihood ratio and accuracy for the RSBI, using the classical cut-off value as well as the new cut-off value, according to standardized formulas.[30] In addition, we calculated the 95% CI for each of those measures, considering RSBI values > 105 breaths/min/L (the cut-off value proposed in the literature)[16] and RSBI values > 76.5 breaths/min/L (the new value obtained) predictive for intubation.

## Results

Of the 73 patients evaluated, 44 were male and 29 were female. The mean age was 53 ± 17 years, the mean period on MV was 4 days (range, 1-8 days), the mean length of ICU stay was 7 days (range, 3-12 days), and the mean APACHE II score was 13.8 ± 7.74. All patients had been on MV for at least 12 h, and 64 of those had been on MV for at least 24 h. All patients used endotracheal tubes with a diameter > 7.5 mm. The mean value found for the RR/TV index was 63 ± 32.7 breaths/min/L. Of the 73 patients, 51 were admitted to the ICU for surgical reasons (70%), whereas 22 (30%) were admitted to the ICU due to clinical diagnosis. No patient presented signs of instability or any type of complication during the RSBI determination. The frequency of re-intubation in our study was

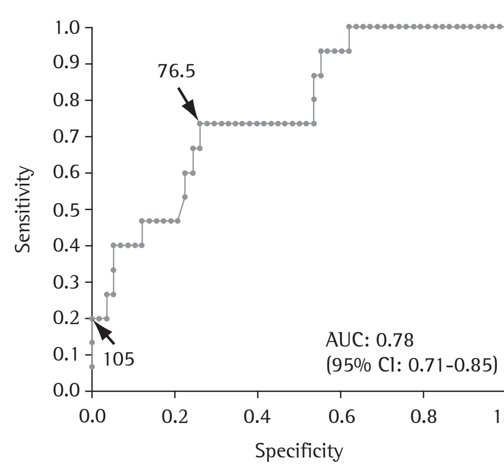


**Figure 1** - Receiver operator characteristic (ROC) curve for the rapid shallow breathing index, with indications of the cut-off values, based on the area under the curve (AUC).

**Table 1 –** Diagnostic performance of the rapid shallow breathing index for the classical cut-off value and for the new cut-off value obtained.

| Cut-off value | Sensitivity | Specificity | PPV | NPV | PLR | NLR | Accuracy |
|---|---|---|---|---|---|---|---|
| RSBI[a] > 105 | 0.20 (0-0.40) | 0.95 (0.89-1.00) | 0.50 (0.10-0.90) | 0.82 (0.73-0.91) | 4 (0.90-17.85) | 0.84 (0.65-1.09) | 0.79 |
| RSBI[a] ≥ 76.5 | 0.66 (0.42-0.90) | 0.74 (0.63-0.85) | 0.40 (0.21-0.59) | 0.89 (0.83-0.95) | 2.53 (1.44-4.45) | 0.46 (0.22-0.96) | 0.73 |

PPV: positive predictive value; NPV: negative predictive value; PLR: positive likelihood ratio; and NLR: negative likelihood ratio. Range in parentheses. [a]Values in breaths/min/L.

20% (15/73), and, in all of those cases, extubation failure occurred within 48 h after the removal of the artificial airway. The causes of the extubation failure were the following: sepsis, in 3 cases; fatigue, in 3; congestive heart failure, in 3; airway obstruction, in 2; cardiogenic shock, in 1; pulmonary thromboembolism, in 1; aspiration of gastric content, in 1; and undetermined, in 1.

Of the 15 patients who required re-intubation, only 3 presented an RSBI value > 105 breaths/min/L, and 12 presented an RSBI value ≤ 105 breaths/min/L (predictive of success).[16] Among the 58 extubated patients, 55 presented an RSBI ≤ 105 breaths/min/L, and 3 presented an RSBI > 105 breaths/min/L. The sum of sensitivity and specificity for this cut-off value was 115%.

Using the method of identifying the greatest sum of sensitivity and specificity in order to establish the best cut-off value,[29] an RSBI value ≥ 76.5 breaths/min/L was obtained as the best cut-off value, which presented a sum of sensitivity and specificity of 140%, with the area under the ROC curve = 0.78 (95% CI: 0.71-0.85; Figure 1).

With the new cut-off value, 10 of the 15 re-intubated patients presented an RSBI ≥ 76.5 breaths/min/L (predictive of re-intubation). Of the 58 patients successfully extubated, 43 presented an RSBI < 76.5 breaths/min/L and 15 presented an RSBI ≥ 76.5 breaths/min/L With the new cut-off value, sensitivity was substantially increased (from 20% to 66%). The positive and negative predictive values for the classical cut-off value were 50% and 82%, compared with 40% and 89%, respectively, for the new cut-off value. The positive and negative likelihood ratio values obtained for the classical cut-off value were 4 and 0.84, compared with 2.53 and 0.46, respectively, for the new cut-off value. The diagnostic testing values for the RSBI with the classical and new cut-off values are shown in Table 1.

## Discussion

The classical RSBI cut-off value was not able to identify most patients in need of re-intubation. Using the greatest sum of sensitivity and specificity,[29] it was possible to determine a new cut-off value for RSBI. We defined an RSBI ≥ 76.5 breaths/min/L as predictive of re-intubation. This ensured a substantial increase in sensitivity, allowing the identification of more than 50% of the patients in need of re-intubation.

In our view, there was a slight increase in the risk of prolonging the MV in relation to the enormous risk of re-intubation using the classical cut-off value, which presented a sensitivity of only 20%. Therefore, 80% of the patients who need re-intubation were not identified by the classical cut-off value for the RSBI, which proved inefficacious at this cut-off value. We consider re-intubation to be an event that has a considerably greater impact than does prolonged ventilation, since re-intubation, in addition to the other problems it causes, is associated with increased risk of pneumonia as well as with greater mortality.

The use of the new cut-off value decreased the positive likelihood ratio by 36.7% (from 4.00 to 2.53), whereas it decreased the negative likelihood ratio by 45% (from 0.84 to 0.46). Therefore, the decrease in the positive likelihood ratio was smaller than was that in the negative likelihood ratio, values closer to zero being more favorable for the latter. However, we emphasize the focus on the importance of the sensitivity value obtained, which represented the capability of the test to detect the risk of re-intubation and was very low when the classical value was used.

In our study, we considered the need for reinstitution of the MV and re-intubation in the period within 48h after extubation in order to characterize extubation failure. Our protocol differs from those used in some other studies, in which periods of 24 h or 72 h were used.[18,21] However, the protocol adopted is consistent with that employed by most authors.[20,25,27] In addition, no case of extubation failure occurred after 48 h following extubation in our patient sample.

Our concern in this study was to determine the need for establishing new cut-off values specific to the patient sample studied, respecting the techniques used in obtaining those indices, since the cut-off value can differ according to the type of patient sample studied and the incorrect reproduction of the technique can lead to inaccurate diagnostic test results.

The failure of MV weaning is considered principally a result of the imbalance between respiratory muscle strength and the increased respiratory demand. Muscle weakness and fatigue, especially when combined with increased respiratory work load, are associated with a rapid, shallow breathing pattern.[18] Therefore, it is significant that the RSBI during spontaneous breathing was predictive of the MV weaning outcomes in the present study. Although it has been questioned by some authors, the RSBI is still the most widely used index—and has been since its creation.[13,15] Based on a systematic review on predictive indices, the RSBI was considered the most promising parameter for the prediction of weaning outcome. However, the best cut-off value established in that review was 65 breaths/min/L, different from that established in the original study.[13]

The less than satisfactory results obtained in some studies might have been influenced by the heterogeneous methodology applied when obtaining data. In addition, few studies referring to the RSBI have established a satisfactory cut-off value for the studied groups,[24-26] and only two studies have determined the RSBI based on the ROC curve for best sensitivity and specificity.[27,28] Most such studies have been conducted based on the value proposed in the literature (105 breaths/min/L), which proved inappropriate for use in our patient sample.

It is recommended that the determination of the ideal moment for extubation be based on several parameters, in addition to daily clinical evaluation. This clinical evaluation, in isolation, has proven inefficacious in predicting extubation outcome.[9,10] The use of predictive indices has an auxiliary role in the decision-making process, providing more information regarding the clinical condition of the patient.

The RSBI is rapidly determined and easily interpreted, factors that are indispensible in intensive care. In addition, the RSBI is a low cost method, and its determination does not depend on the cooperation of the patient or on the diagnosis, which permits it to be used in a broad range of patients. As long as it is correctly determined (appropriate conditions of the measurement devices and knowledge about the technique to obtain the indices, in addition to precision in recording data), its application can play a supporting role in the decision of whether to remove the endotracheal tube from the critical patient, avoiding the negative impacts of re-intubation (principally the risk of pneumonia and the increased mortality rate).[7]

The exclusion of tracheostomized patients from the patient sample might represent a limitation to this study, reducing its external validity. The chronicity of some patients is a factor to be considered, since those will probably present alterations in the RSBI.[24] The results of some studies suggest differences related to age or time on MV.[25] In the present study, these aspects were not assessed. Further studies involving larger patient samples are needed in order to carry out that analysis.

The results obtained did not permit validation of the use of the RSBI with the classical cut-off value (105 breaths/min/L), since that value was not in line with the best cut-off value determined in our study. The values of the diagnostic tests showed that few of the re-intubated patients were identified when the classical RSBI cut-off value was used. When we adjusted the cut-off value for the patient sample evaluated, the sensitivity of the RSBI increased substantially. This highlights the need for reviewing the RSBI cut-off value in different patient samples and justifies new investigations, with the evaluation of the cut-off value in subgroups of patients, especially considering the feasibility of the RSBI.

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