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Weaning from mechanical ventilation: a model for extubation

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Abstract *Objective:* To develop a model able to determine the right time for extubation and to validate its performance.
Design: A prospective clinical study.
Setting: 14-bed medical intensive care unit in a university hospital.
Patients: 101 patients (37 women/64 men) ventilated over more than 48 h (mean 10.4 ± 10.3 days) and considered ready to be weaned by the medical team (February 1996–February 1998).
Methods: This study included two series: a development series with 53 patients and a validation series with 48 patients. Before extubation, a weaning test was performed measuring tidal volume (V_T), respiratory rate (f), f/V_T ratio, minute ventilation, vital capacity (VC) and maximum inspiratory and expiratory pressures (MIP and MEP). The success of extubation was assessed after 48 h. Receiver operating characteristic (ROC) curves allowed the analysis of the discriminating power of each parameter. Threshold values were determined using the Youden's index. To create the best predictive model, we performed a multiple logistic regression analysis. To assess the calibration and the discrimination of the model, the Hosmer-Lemeshow goodness-of-fit test and area under ROC curves (AUC) were adopted.
Measurements and results: In a development series, 60 tests were carried out with 38 successful extubations and 22 extubation failures. The multivariate analysis found three significant variables: VC (threshold value = 635 ml), f/V_T ratio (threshold value = 88 breaths/min.l) and MEP (threshold value = 28 cmH_2O). The validation cohort included 59 tests (38 successes and 21 failures). The validation series shows a good discrimination (AUC = 0.855 ± 0.059) and calibration (goodness-of-fit test C: $p = 0.224$) of the model.
Conclusion: VC together with the f/V_T ratio and MEP offer accurate prediction of early extubation.

Key words Weaning · Mechanical ventilation · Extubation outcome · Logistic models · Receiver operating characteristic curve

Introduction

Shifting patients from mechanical ventilation (MV) to autonomous ventilation is a delicate period in the daily practice of an intensive care unit physician [1]. The decision to discontinue MV is generally based on the clinical appreciation of weanability and the physicians's experience [2–5]. It is very important to recognize as soon as possible when the patient is ready to be extubated [1]. For this purpose, several physiological indices have been employed to predict early and perfect weaning outcome [1, 2, 4, 6]. Indeed, predictors of weaning outcome are numerous and explore gas exchange, respiratory mechanics, breathing pattern and cardiovascular performance [2–4]. But the accuracy of these indices is poor and there is no consensus on their hierarchical value nor on their threshold values [2, 3, 7, 8]. The objective of this study was to develop a model to determine the right time for extubation and to validate its performance. The model was determined from classically recommended parameters during a "weaning test" (WT).

Patients and methods

This prospective study (February 1996–February 1998) included 101 patients (37 women and 64 men) who were ventilated for more than 48 h and considered ready to be weaned by the intensive care unit medical team of Avicenne Hospital, Rabat. Their mean age was 39.9 ± 16.8 years (range 15–80 years) and their Simplified Acute Physiology Score (SAPS I) was 9.9 ± 4.4 (range 1–22). Patients were ventilated for 10.4 ± 10.3 days (range 2–60 days). Indications for MV were: acute respiratory failure in 45 patients (pneumonia, acute exacerbation of chronic obstructive pulmonary disease, severe acute asthma, drowning), coma in 36 patients (central nervous system infection, stroke, status epilepticus, neuroleptic malignant syndrome, malignant hyperthermia), acute intoxication in 13 patients (paraphenylenediamine, chloralose, organic phosphate insecticides, carbamates) and a generalized tetanus in 7 patients. In 96.6 % of cases, the mode of ventilation support was initially control ventilation or assist-control ventilation. However, 14.7 % of these patients were ventilated before extubation with pressure support (PS). PS was used alone in 3.4 % of patients.

This study included two series, a development series (February 1996–February 1997) with 53 patients (20 women and 33 men) and a validation series (March 1997–February 1998) with 48 patients (17 women and 31 men). Patients included in the study had all received MV for more than 48 h. Both series of patients were treated by the same team of nurses and physicians. In both series, the decision to extubate patients was taken by the medical team according to a clinical and biological approach which was based on all of the following criteria of weanability: improvement or resolution of the underlying cause requiring MV, good level of consciousness with cessation of all sedative agents, body temperature < 38 °C, spontaneous breathing rate < 35 breaths/min, arterial oxygen saturation > 90 % for a fractional inspired oxygen ≤ 0.4, hemodynamic stability and no biological anomaly prohibiting spontaneous breathing (electrolyte disorders, acid-base disturbances, hemoglobin < 10 g%).

Before extubation, after 2 min of spontaneous breathing a WT measured respiratory frequency (f; breaths/min), tidal volume (V_T; ml and ml/kg), minute ventilation (V_E; l/min), vital capacity (VC; ml and ml/kg), maximal inspiratory pressure (MIP; cmH_2O) and maximal expiratory pressure (MEP; cmH_2O). The f/V_T ratio (breaths/min.l) was also determined.

F, V_T, V_E and VC were measured using a spirometer with turbine captor (Ohmeda). Five values were noted for each parameter and their mean calculated. Pressures were measured with a manometer connected to the patient's tracheal tube. MIP was obtained via the one-way valve technique [9]. A unidirectional valve permitting only expiration was attached to the airway to ensure that inspiratory efforts were made at a low lung volume (residual volume). The period of occlusion was maintained for 20 s and the most negative pressure recorded was taken as the MIP. MEP was measured during a maximal expiratory effort against an obstructed airway. This maneuver was recorded with maximum encouragement to approach total lung capacity by a spontaneous deep inspiration that significantly decreases intrathoracic pressure and increases lung volume.

The results were not communicated to the medical team which decided on the extubation. Extubation was performed in the usual manner immediately after WT without a T-piece trial. Following extubation, supplemental oxygen by face mask with chest physiotherapy was delivered. Patients were considered successfully extubated if, after 48 h, they did not need reintubation. Failure of extubation was defined as the inability to support spontaneous breathing for more than 48 h after extubation. The patients could have several extubations and each extubation, with its WT, was included in the study because it was considered as a new event requiring the same criteria of weanability. In the development series, the set of mean value for the WT parameters was compared between the successfully extubated group (group 1) and the failed one (group 2); then their best threshold values were defined. The hierarchical classification of different parameters has allowed us to release a model whose discrimination and calibration ability was assessed in the validation series.

This study was approved by the ethics committee of the Moroccan Association of Emergency and Reanimation.

Results are presented as mean ± SD. For univariate analysis, comparisons of differences in variables between groups were performed using the chi-square test of Fisher's exact test (small samples) for categorical variables and Student's *t*-test for continuous variables. A *p* value below 0.05 was set for significance. For each index, predicting successful extubation was assessed according to: Sensitivity (Se = True success/[True success + False success]), Specificity (Sp = True failure/[False failure + True failure]), positive predictive value (PPV = True success/[True success + False failure]) and negative predictive value (NPV = True failure/[False success + True failure]).

Threshold values were defined for the different WT variables with Youden's index (J). This index constitutes an objective approach to determine the optimal threshold value that offered the best equilibrium between Se and Sp. Youden's index is given by: $J = Se + Sp - 1$, where $Se = 1 - \beta$ (β = false positive error) and $Sp = 1 - \alpha$ (α = false negative error). By rearranging the equation, we obtained: $J = 1 - (\alpha + \beta)$. Indeed, J has its maximal value when $(\alpha + \beta)$ has the lowest value. In other words, the optimal cutoff point must associate low false-positive and low false-negative errors.

To create the best predictive model, we performed a multiple logistic regression analysis (SPSS version 7.5, 1996) [10].

Receiver operating characteristic (ROC) curves, formed by the plot of all possible pairs of false-positive and true-positive rates, were constructed for all indices. The area under the curves was calculated and compared by the nonparametric method of Hanley and McNeil [11, 12]. To estimate the discriminative power of the model, we used the area under the ROC curve. A model was considered to discriminate well when this area was above 0.80. To assess the calibration of the model, the Hosmer-Lemeshow goodness-of-fit test was adopted [10]. The model was not calibrated well if the goodness-of-fit statistic was significant ($p < 0.05$).

Results

During the study period, a total of 157 patients were ventilated over more than 48 h and 56 among them were not included in the protocol (accidental extuba-

Table 1 Characteristics of patients in the development and validation series (*SAPS I* Simplified Acute Physiology Score, *MV* mechanical ventilation)

	Development cohort ($n = 53$)	Validation cohort ($n = 48$)	p value
Age (years)	43.4 ± 18.1	35.9 ± 14.4	0.02
Sex (women/men)	20/33	17/31	NS
SAPS I	11.2 ± 3.9	8.3 ± 4.5	0.001
MV duration (days)	8.7 ± 8.9	12.1 ± 10.9	NS
Etiology:			
Acute respiratory failure	24	21	NS
→ (COPD)	(12)	(5)	NS
Coma	19	17	NS
Intoxication	7	6	NS
Generalized tetanus	3	4	NS

Table 2 Comparison between successful extubation group (group 1, group 1′) and failed extubation group (group 2, group 2′) in the development and validation series

	Development cohort ($n = 60$ tests)			Validation cohort ($n = 59$ tests)		
	Group 1 ($n = 38$)	Group 2 ($n = 22$)	p value	Group 1′ ($n = 37$)	Group 2′ ($n = 22$)	p value
Age (years)	41.3 ± 17.6	45.8 ± 18.2	NS	36.4 ± 14.3	34.3 ± 14.9	NS
Sex (women/men)	14/24	10/12	NS	12/27	8/15	NS
SAPS I	11.1 ± 3.8	11.7 ± 4.5	NS	8.7 ± 4.4	7.2 ± 4.2	NS
MV duration (days)	7.8 ± 5.9	10.3 ± 12.6	NS	12 ± 9.8	12.8 ± 13	NS
Etiology:						
Acute respiratory failure	15	13	NS	17	8	NS
→ (COPD)	(7)	(8)	(NS)	(3)	(2)	(NS)
Coma	13	8	NS	13	12	NS
Intoxication	7	0	NS	4	1	NS
Generalized tetanus	3	1	NS	3	1	NS

tion, death, home mechanical ventilation). All patients meeting our criteria of weanability were extubated. In other words, all patients screened were extubated. The general characteristics of patients in the two series are given in Table 1. Comparison between the two series showed significant differences in age and SAPS I.

In the development series, 60 tests were carried out for 53 patients. The successful extubation group (group 1, $n = 38$) and the failed extubation group (group 2, $n = 22$) are also comparable in term of age, sex, SAPS I, MV duration and etiology (Table 2). In univariate analysis, average values of all parameters of the WT were statistically different between the two groups (Table 3). The best couple of Se-Sp was obtained by placing the threshold value to 28 breaths/min for f; 333 ml and 4.5 ml/kg for V_T; 88 breaths/min.l for the f/V_T ratio; 635 ml and 12.5 ml/kg for VC; 9.9 l/min for V_E; – 25 cmH_2O for MIP and 28 cmH_2O for MEP. Threshold values and accuracy of the WT indices are given in Table 4.

All areas under the ROC curves were above 0.7 except for V_T (ml/kg) and especially V_E (Table 4). The best areas (> 0.80) were obtained for V_T (ml), VC (ml) and the f/V_T ratio. No statistical difference was found between areas of those indices ($p > 0.05$).

Among the different weaning indices, the multivariate analysis found three significant variables: VC (ml), f/V_T ratio and MEP (Table 5). If the three criteria were met, the probability of successful extubation was 96.8 %. On the other hand, 83.3 % of patients were correctly classified by the model. The performance of the model was tested on an independent set of 48 patients. The validation cohort consisted of 59 tests. The successful extubation group (group 1′; $n = 37$) and the failed extubation group (group 2′; $n = 22$) were also comparable in term of age, sex, SAPS I, MV duration and etiology (Table 2).

The discriminatory performance of the model was good as reflected by the areas under the ROC curves (Fig. 1). The Hosmer-Lemeshow goodness-of-fit test revealed a good calibration of the model in the develop-

Table 3 Comparison of indices between successful extubation group (group 1) and failed extubation group (group 2) in the development series (*f* respiratory rate, V_T tidal volume, *VC* vital capacity, V_E minute ventilation, *MIP* maximal inspiratory pressure, *MEP* maximal expiratory pressure)

	Group 1 (*n* = 38 tests)	Group 2 (*n* = 22 tests)	*p* value
f (breaths/min)	24.1 ± 5.9	28.8 ± 5.8	0.04
V_T (ml)	391 ± 131	284 ± 79	0.0011
V_T (ml/kg)	6.6 ± 2.4	5 ± 1.8	0.013
f/V_T (breaths/min.l)	69.3 ± 29.8	111.3 ± 44	$4\ 10^{-5}$
VC (ml)	894 ± 378	550 ± 184	0.0002
VC (ml/kg)	14.7 ± 6.1	9.6 ± 3.4	0.0013
V_E (l/min)	9 ± 2.6	7.7 ± 1.5	0.037
MIP (cmH_2O)	31.9 ± 9.9	26.9 ± 7.7	0.046
MEP (cmH_2O)	52.8 ± 20.1	36.1 ± 23	0.005

Table 4 Threshold values, accuracy and area under the receiver operating characteristic curve (AUC) of the weaning test parameters in the development series (*f* respiratory rate, V_T tidal volume, *VC* vital capacity, V_E minute ventilation, *MIP* maximal inspiratory pressure, *MEP* maximal expiratory pressure, *Se* sensitivity, *Sp* specificity, *PPV* positive predictive value, *NPV* negative predictive value, *SE* standard error)

	Threshold values	Se	Sp	PPV	NPV	AUC ± SE
f (breaths/min)	< 28	64	71.1	56	77.1	0.708 ± 0.072
V_T (ml)	≥ 333	81.8	68.4	60	86.7	0.830 ± 0.059
V_T (ml/kg)	> 4.5	50	92.1	78.6	76.1	0.688 ± 0.074
f/V_T (breaths/min.l)	< 88	77.3	78.9	68	85.7	0.809 ± 0.062
VC (ml)	≥ 635	76.2	77.8	66.7	84.8	0.812 ± 0.063
VC (ml/kg)	≥ 12	85.7	58.3	54.5	87.5	0.786 ± 0.067
V_E (l/min)	< 9.9	100	31.6	45.8	100	0.341 ± 0.071
MIP (cmH_2O)	< – 25	59.1	75	59.1	79.1	0.715 ± 0.072
MEP (cmH_2O)	≥ 28	52.4	91.7	78.6	71.7	0.726 ± 0.073

Table 5 Predictive model by multivariate logistic regression analysis (*VC* vital capacity, *f* respiratory rate, V_T tidal volume, *MEP* maximal expiratory pressure, *SE* standard error, *OR* odds ratio, *CI* confidence interval)

Variable	*β*	SE	OR	95% CI	*p*
VC ≥ 635 (ml)	2.185	0.8142	8.89	1.803 to 43.857	0.0073
f/V_T < 88 (breaths/min.l)	2.279	0.8290	9.77	1.924 to 49.590	0.0060
MEP ≥ 28 (cmH_2O)	2.833	0.9659	16.99	2.560 to 112.860	0.0034
Constant	– 3.898	1.1433			0.0007

ment series (C = 2.553; *df* 4; *p* = 0.635) and validation series (C = 8.202; *df* 6; *p* = 0.224) (Table 6, Fig. 2).

Discussion

Several indices evaluating the ventilatory pump have been proposed to predict weaning from prolonged MV. These indices include: f [13], f/V_T ratio [2], VC [14], MIP [9, 15, 16], V_E [15], P0.1 or airway occlusion pressure at 0.1 s [6, 16–20], work of breathing [21, 22] and gastric intramural pH [7]. These predictive indices were evaluated in several studies whose results are conflicting because of their methodologic variability and population differences [2, 4, 23, 24]. Therefore, there is no consensus on the hierarchical value or threshold values of these indices [3]. Indeed, none of these parameters can predict correctly the capacity of the patient to support spontaneous breathing due to the fact that none of them as a high sensitivity or specificity [3, 6, 8, 21]. The poor predictive values of weaning indices have encouraged some authors to group them in order to improve their predictive power [3] or to propose integrated indices such as the CROP index (which includes compliance, rate, oxygenation and pressure) [2], a weaning index based on ventilatory endurance and the efficiency of gas exchange [25], the P0.1/MIP ratio [20, 26, 27] or again (f/V_T). (P0.1) where P0.1 slighty improves the specificity of the f/V_T ratio in predicting weaning [6]; however, the results are not always reproducible. Del Rosario et al. [27] suggest that parameters allowing the assessment of respiratory muscle

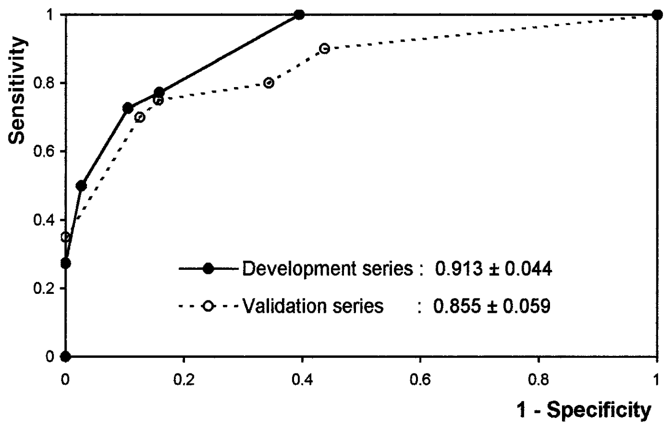

Fig. 1 Areas under ROC curves (± SE) of the predictive model

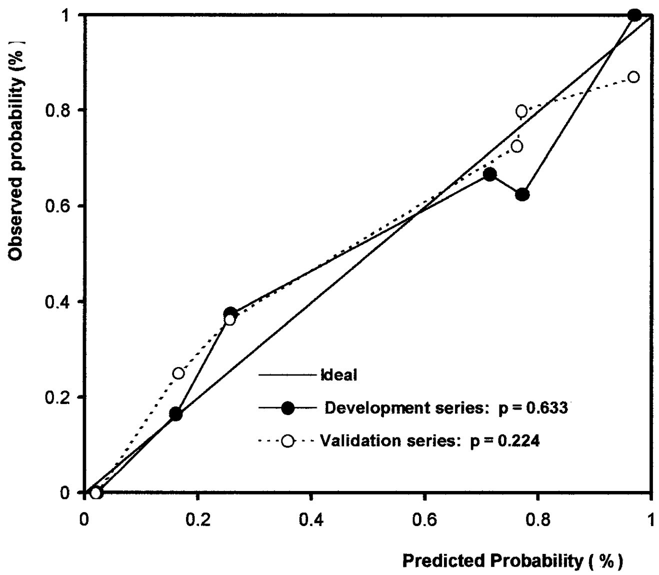

Fig. 2 Calibration curves. Correspondence between actual and predicted chance of successful extubation in the development and validation series

endurance may help physicians and can facilitate weaning.

The current study analyzes simple weaning criteria to determine those that are associated with weaning outcome. We have noted a difference in age and SAPS I between the development and validation series, but both groups must not necessarily be identical. In fact, the strength of a model is greater when it is validated on different populations. The different threshold values found in this study for the weaning indices are near to thresholds found in the literature. For these threshold values, this study analyzes the effect of association of indices whose predictive power is the most important. Indeed, it is found that the combination of three indices constitutes the best extubation model: VC, which informs on the patient's reserve to support a supplementary workload; f/V_T ratio, which is an indicator of rapid shallow breathing; and MEP, which reflects the capacity to produce an efficient cough. The performance of this model is satisfactory with a strong discrimination power and good calibration in the development and validation series.

If the measure of f/V_T ratio is independent of the patient's cooperation [2], it is not so with VC and MEP, which can sometimes underestimate the real capacities of the patient. VC is rarely proposed as a reliable predictive factor [4]. For thresholds of 10 to 15 ml/kg, the Se varies from 0 to 50 % and the Sp from 72 to 85 % [24, 28, 29]. In our series, the Se of this index is 86 % but the Sp is only 58 %; this rate is greatly improved when VC is not corrected for the patient's weight.

The discrimination power and threshold value of the f/V_T ratio are variously appreciated [7, 16, 20, 24, 30]. Yang and Tobin [2], reported that an f/V_T ratio greater than 105 breaths/min.l was the most accurate predictor of weaning success with an Se of 97 %, an Sp of 64 %, a positive predictive value of 78 %, a negative predictive value of 95 % and an area under the curve of 0.89 ± 0.05. The main advantages of this parameter remain the facility measure and the exemption of the patient's cooperation and effort [2]. According to Lee et al. [31], a low f/V_T ratio would not be reliable because the underlying pathophysiology may be the cause of rapid shallow breathing without giving rise to respiratory failure.

Few authors have considered the effect of MEP in the estimate of weaning outcome [4]. The model reported in this study has the advantage of integrating this parameter, which reflects a patient's ability to cough. The cough is a defensive mechanism designed to rid the conducting air passages of secretions. The pressure during a maximal expiratory effort against an obstructed airway reflects the force available for a successful cough [4]. Despite the presence of an endotracheal tube, maximal cough pressure of about 80 cmH_2O can still be generated. For Bach and Saporito [32], the ability to generate a peak cough flow greater than 160 l/min is necessary for the successful extubation of a patient with neuromuscular disease.

The rate of reintubation in the current study was 37 % (36.7 % in the development series and 37.2 % in the validation series). In several articles, this rate goes from 0 to 38 % and is generally below 20 % [5, 24, 31–35]. The patients who failed varied considerably from one study to another one [5]. Three arguments can explain our reintubation rate. First, this study is characterized by the variability of population and MV indications. Besides, the mean duration of MV exceeds a week and the highest rates of reintubation were observed especially among patients who benefit from prolonged MV [16, 31]. The prolonged MV reflected the

Table 6 Hosmer-Lemeshow goodness-of-fit test C for the predictive model

Probability	*n*	Successful extubation		Failed extubation	
		Observed	Expected	Observed	Expected
Development cohort					
– 0.0199	6	0	0.12	6	5.88
– 0.1654	6	1	0.97	5	5.03
– 0.2564	8	3	2.05	5	5.95
– 0.7540	9	6	6.44	3	2.56
– 0.7710	8	5	6.17	3	1.83
– 0.9677	23	23	22.28	0	0.74
Total	60	38	38.03	22	21.99
Chi-square = 2.5526		*df* = 4	*p* = 0.635		
Validation cohort					
– 0.0199	5	0	0.10	5	4.90
– 0.1654	4	1	0.66	3	3.34
– 0.2564	11	4	2.82	7	8.18
– 0.7540	11	8	7.88	3	2.45
– 0.7710	5	4	3.86	1	1.14
– 0.9677	23	20	22.26	3	0.74
Total	59	37	37.58	22	21.42
Chi-square = 8.2022		*df* = 6	*p* = 0.224		

severity of underlying conditions, the severity of respiratory failure or respiratory muscle atrophy induced by prolonged inactivity [31]. This situation is essentially observed among medical patients who are difficult to wean from MV. Second, it was noted that only criteria of weanability and medical staff judgment were used for extubation and that WT parameters were not considered in the decision to extubate. Third, extubation in the current protocol was done immediately after WT without a spontaneous breathing trial (T-piece). More studies demonstrate that a T-piece was able to yield a low reintubation rate [33, 35]. It has been shown that the addition of a T-piece test may make it easier to differentiate between patients who can be extubated and those who need progressive withdrawal from MV. But in most weaning studies, patients in the failed extubation group are reventilated prior to extubation, thus compromising the evaluation of the predictive values of the weaning indices applied. The duration of a T-tube trial is variable, often 2 h [1, 4, 5, 8, 18, 24, 31, 33, 35–37], but 30 min is probably as efficacious [35]. For Leitch et al., it was not demonstrated that the T-tube is associated with a better chance for successful weaning [24]. The aim of our study was not to show T-piece usefulness, but the results can be assessed with the addition of a spontaneous breathing test to verify if our model's performance can be improved.

In conclusion, the study reported here proposed a practical extubation strategy which can help in withdrawal from MV. This model offers accurate prediction of early extubation and indicates the probability that a patient can tolerate extubation. Our model appears simple, tolerable, easily measurable and has a high sensitivity and specificity. It must be extensively evaluated, especially in association with different weaning techniques. We have started to use these variables in a new prospective study, with and without a T-piece, to show that this model could be useful.

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References

1. Mancebo J (1996) Weaning from mechanical ventilation. Eur Respir J 9: 1923–1931
2. Yang KL, Tobin MJ (1991) A prospective study of indexes predicting the outcome of trials of weaning from mechanical ventilation. N Engl J Med 324: 1445–1450
3. Conférences de consensus en Réanimation (1992) Le sevrage. Reanim Urg 1: 159–238
4. Tobin MJ, Alex CG (1994) Discontinuation of mechanical ventilation. In: Tobin MJ (ed) Principles and practice of mechanical ventilation. McGraw-Hill, New York, pp 1177–1206
5. Esteban A, Alia I (1998) Clinical management of weaning from mechanical ventilation. Intensive Care Med 24: 999–1008
6. Sassoon CSH, Mahutte CK (1993) Airway occlusion pressure and breathing pattern as predictors of weaning outcome. Am Rev Respir Dis 148: 860–866

7. Mohsenifar Z, Hay A, Hay J, Lewis MI, Koerner SK (1993) Gastric intramural pH as a predictor of success or failure in weaning patients from mechanical ventilation. Ann Intern Med 119: 794–798
8. Lessard MR, Brochard LJ (1996) Weaning from ventilatory support. Clin Chest Med 17: 475–489
9. Marini JJ, Smith TC, Lamb V (1986) Estimation of inspiratory muscle strength in mechanically ventilated patients: the measurement of maximal inspiratory pressure. J Crit Care 1: 32–38
10. Hosmer DW, Lemeshow S (1989) Applied logistic regression. Wiley, New York
11. Hanley JA, McNeil BJ (1982) The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology 143: 29–36
12. Hanley JA, McNeil BJ (1983) A method of comparing the areas under receiver operating characteristic curves derived from the same cases. Radiology 148: 839–843
13. Morganroth ML, Morganroth JL, Nett LM, Petty TL (1984) Criteria for weaning from prolonged mechanical ventilation. Arch Intern Med 144: 1012–1016
14. Sahn SA, Lakshminarayam S, Petty TL (1976) Weaning from mechanical ventilation. JAMA 235: 2208–2212
15. Sahn SA, Lakshminarayam S (1973) Bedside criteria for discontinuation of mechanical ventilation. Chest 63: 1002–1005
16. Capdevila X, Perrigault PF, Ramonatxo M, Roustan JP, Peray P, d'Athis F, Prefaut C (1998) Changes in breathing pattern and respiratory muscle performance parameters during difficult weaning. Crit Care Med 26: 79–87
17. Sassoon CS, Mahutte CK, Light RW (1987) Airway occlusion pressure: an important indicator of successful weaning in patients with chronic obstructive pulmonary disease. Am Rev Respir Dis 135: 107–113
18. Murciano D, Boczkowski J, Lecocguic Y, Milic Emili J, Pariente R, Aubier M (1988) Tracheal occlusion pressure: a simple index to monitor respiratory muscle fatigue during acute respiratory failure in patients with chronic obstructive pulmonary disease. Ann Intern Med 108: 800–805
19. Conti G, De Blasi R, Pelaia P, Benito S, Rocco M, Antonelli M, Bufi M, Mattia C, Gasparetto A (1992) Early prediction of successful weaning during pressure support ventilation in chronic obstructive pulmonary disease patients. Crit Care Med 20: 366–371
20. Capdevila XJ, Perrigault PF, Perey PJ, Roustan JP, d'Athis F (1995) Occlusion pressure and its ratio to maximum inspiratory pressure are useful predictors for successful extubation following T-piece weaning trial. Chest 108: 482–489
21. Levy MM, Miyasaki A, Langston D (1995) Work of breathing as a weaning parameter in mechanically ventilated patients. Chest 108: 1018–1020
22. Kirton OC, DeHaven CB, Morgan JP, Windsor J, Civetta JM (1995) Elevated imposed work of breathing masquerading as ventilator weaning intolerance. Chest 108: 1021–1025
23. Yang KL (1992) Reproducibility of weaning parameters. A need for standardization. Chest 102: 1829–1832
24. Leitch EA, Moran JL, Grealy B (1996) Weaning and extubation in the intensive care unit. Clinical or index-driven approach? Intensive Care Med 22: 752–759
25. Jabour ER, Rabil DM, Truwitt JD, Rochester DF (1991) Evaluation of a new weaning index based on ventilatory endurance and the efficiency of gas exchange. Am Rev Respir Dis 144: 531–537
26. Fernandez R, Cabrera J, Calaf N, Benito S (1990) P0.1/PI Max: an index for assessing respiratory capacity in respiratory failure. Intensive Care Med 16: 175–179
27. Del Rosario N, Sassoon CS, Chetty KG, Gruer SE, Mahutte CK (1997) Breathing pattern during acute respiratory failure and recovery. Eur Respir J 10: 2560–2565
28. Milbern SL, Downs JB, Jumper LC, Modell JH (1978) Evaluation of criteria for discontinuing mechanical ventilation support. Arch Surg 113: 1441–1443
29. Tahvanainen J, Salmenpera M, Nikki P (1983) Extubation criteria after weaning from intermittent mandatory ventilation and continuous positive airway pressure. Crit Care Med 11: 702–707
30. Stroetz RW, Hubmayr RD (1995) Tidal volume maintenance during weaning with pressure support. Am J Respir Crit Care Med 152: 1034–1040
31. Lee KH, Hui KP, Chan TB, Tan WC, Lim TK (1994) Rapid shallow breathing (frequency-tidal volume ratio) did not predict extubation outcome. Chest 105: 540–543
32. Bach JR, Saporito LR (1996) Criteria for extubation and tracheostomy tube removal for patients with ventilatory failure. A different approach to weaning. Chest 110: 1566–1571
33. Brochard L, Rauss A, Benito S, Conti G, Mancebo J, Rekik N, Gasparetto A, Lemaire F (1994) Comparison of three methods of gradual withdrawal from ventilatory support during weaning from mechanical ventilation. Am J Respir Crit Care Med 150: 896–903
34. Saura P, Blanch L, Mestre J, Valles J, Artigas A, Fernandez R (1996) Clinical consequences of the implementation of a weaning protocol. Intensive Care Med 22: 1052–1056
35. Esteban A, Alia I, Gordo F, Fernandez R, Solsona JF, Valverdu I, Macias S, Allegue JM, Blanco J, Carriedo D, Leon M, De la Cal MA, Taboada F, Gonzalez de Velasco J, Palazon E, Carrizosa F, Tomas R, Suarez J, Goldwasser R, for the Spanish Lung Failure Collaborative Group (1997) Extubation outcome after spontaneous breathing trials with T-tube of pressure support ventilation. Am J Respir Crit Care Med 156: 459–465
36. Esteban A, Frutos F, Tobin MJ, Alia I, Solsona JF, Valverdu I, Fernandez R, De la Cal MA, Benito S, Tomas R, Carriedo D, Macias S, Blanco J, for the Spanish Lung Failure Collaborative Group (1995) A comparison of four methods of weaning patients from mechanical ventilation. N Engl J Med 332: 345–350
37. Ely EW, Baker AM, Dunagan DP, Burke HL, Smith AC, Kelly PT, Johnson MM, Browder RW, Bowton DL, Haponik EF (1996) Effect on the duration of mechanical ventilation of identifying patients capable of breathing spontaneously. N Engl J Med 335: 1864–1869