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Predicting Success in Weaning From Mechanical Ventilation*

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We identified 65 observational studies of weaning predictors that had been reported in 70 publications. After grouping predictors with similar names but different thresholds, the following predictors met our relevance criteria: heterogeneous populations, 51; COPD patients, 21; and cardiovascular ICU patients, 45. Many variables were of no use in predicting the results of weaning. Moreover, few variables had been studied in > 50 patients or had results presented to generate estimates of predictive power. For stepwise reductions in mechanical support, the most promising predictors were a rapid shallow breathing index (RSBI) < 65 breaths/min/L (measured using the ventilator settings that were in effect at the time that the prediction was made) and a pressure time product < 275 cm H_2O/L/s. The pooled likelihood ratios (LRs) were 1.1 (95% confidence interval [CI], 0.95 to 1.28) for a respiratory rate [RR] of < 38 breaths/min and 0.32 (95% CI, 0.06 to 1.71) for an RR of > 38 breaths/min, which indicate that an RR of < 38 breaths/min leaves the probability of successful weaning virtually unchanged but that a value of > 38 breaths/min leads to a small reduction in the probability of success in weaning the level of mechanical support. For trials of unassisted breathing, the most promising weaning predictors include the following: RR; RSBI; a product of RSBI and occlusion pressure < 450 cm H_2O breaths/min/L; maximal inspiratory pressure (Pımax) < 20 cm H_2O; and a knowledge-based system for adjusting pressure support. Pooled results for the power of a positive test result for both RR and RSBI were limited (highest LR, 2.23), while the power of a negative test result was substantial (*ie*, LR, 0.09 to 0.23). Summary data suggest a similar predictive power for RR and RSBI. In the prediction of successful extubation, an RR of < 38 breaths/min (sensitivity, 88%; specificity, 47%), an RSBI < 100 or 105 breaths/min/L (sensitivity, 65 to 96%; specificity, 0 to 73%), Pımax, and APACHE (acute physiology and chronic health evaluation) II scores that are obtained at hospital admission appear to be the most promising. After pooling, two variables appeared to have some value. An RR of > 38 breaths/min and an RSBI of > 100 breaths/min/L appear to reduce the probability of successful extubation, and Pımax < 0.3, for which the pooled LR is 2.23 (95% CI, 1.15 to 4.34), appears to marginally increase the likelihood of successful extubation. Judging by areas under the receiver operator curve for all variables, none of these variables demonstrate more than modest accuracy in predicting weaning outcome. Why do most of these tests perform so poorly? The likely explanation is that clinicians have already considered the results when they choose patients for trials of weaning.

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Key words: extubation; mechanical ventilation; meta-analysis; methods; modes; reintubation; systematic reviews; weaning

Abbreviations: APACHE = acute physiology and chronic health evaluation; CABG = coronary artery bypass grafting; CI = confidence interval; CVICU = cardiovascular ICU; FIO_2 = fraction of inspired oxygen; LR = likelihood ratio; NIF = negative inspiratory force; OR = odds ratio; $P_{0.1}$ = airway pressure 0.1 s after the occlusion of the inspiratory port of a unidirectional balloon occlusion valve; Pımax = maximal inspiratory pressure; ROC = receiver operating characteristic; RR = respiratory rate; RSBI = rapid shallow breathing index

Critical-care clinicians must carefully weigh the benefits of rapid liberation for mechanical ventilation against the risks of premature trials of spontaneous breathing and extubation. The need for accurate prediction applies to all phases of weaning, beginning with reductions in mechanical support, as patients are increasingly able to support their own breathing, followed by trials of unassisted breathing, which often precede extubation, and ending with extubation.

Patients may fail to wean as a result of impaired respiratory center drive or, more frequently as a result of neuromuscular abnormalities including respiratory muscle fatigue, impaired lung mechanics, or impaired gas exchange capability. Patients may successfully be weaned to minimal levels of respiratory support but may still fail extubation as a result of airway abnormalities. Based on experimental data in healthy individuals[1] and animals,[2] and based on observational data from patients that suggest the development of respiratory muscle fatigue during unsuccessful weaning,[3–6] some investigators postulate that failed trials of discontinuation of mechanical ventilation may precipitate respiratory muscle injury and, ultimately, prolong the duration of mechanical ventilation. Therefore, criteria have been sought to identify patients who are likely to fail, so thatpremature trials of spontaneous

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breathing can be avoided. Moreover, failed trials of extubation have been associated with excess hospital mortality, prolonged ICU and hospital stays, and increased need for tracheostomy.[7,8]

The predictors of weaning that clinicians currently use, and that investigators have studied, include an assortment of demographic characteristics (*ie*, age and diagnostic categories), subjective signs (*ie*, diaphoresis and agitation), vital signs and hemodynamic variables (*ie*, heart rate and BP), lung mechanics (*ie*, tidal volume and respiratory rate [RR]), gas exchange (*ie*, $Pa{O_2}$ and $Pa{CO_2}$ levels), and severity-of-illness measures (*ie*, biochemical variables, comorbidities, levels of respiratory support, and levels of nonrespiratory support). Investigators have tested these variables individually, as composite scores or derivations, and as complex systems. Since the reasons that patients fail weaning may vary among different patient populations, the predictors of weaning also may vary. For instance, predictor variables that are useful in patients undergoing cardiac surgery may differ from those that are of value in patients with COPD, and both may differ from predictors that are useful in a general case mix of ICU patients.

In this article, we separate studies into three groups according to the following target populations: a relatively heterogeneous mix of ICU patients; patients with COPD; and patients who had undergone cardiac surgery (Table 1). One can think of three stages in the weaning process. In the first, the clinician progressively reduces, in a stepwise fashion, the level of support. In the second stage, the patient undergoes a trial of unassisted breathing. In the final stage, the clinician extubates the patient. Investigators have addressed prediction at each stage of the process. Thus, we also classified studies according to what the investigators were trying to predict in the following way: the success of stepwise reductions in mechanical support; unassisted breathing trials; extubation; and the result of trials of unassisted breathing plus extubation (Table 1). We include as trials of "unassisted" breathing those trials completed on a low level of pressure support to overcome the additional work of breathing through a ventilator circuit or those completed on a low level of continuous positive airway pressure to offset the loss of physiologic continuous positive airway pressure caused by the presence of an endotracheal tube.

Table 1—*Populations and Outcomes*

Characteristics	Description
Populations	Heterogeneous ICU patients; COPD patients; and cardiac surgery patients
Outcomes that investigators are trying to predict	Success in reducing mechanical ventilatory support; Successful trial of unassisted breathing; Success of extubation; and Successful unassisted breathing and extubation trials

Materials and Methods

Eligibility Criteria

We sought studies that included any patients receiving mechanical ventilation in an ICU setting that examined potential predictors of success in stepwise reductions in mechanical ventilation, trials of spontaneous breathing, extubation, or any combination of these outcomes.

We also included studies of the predictors of the duration of mechanical ventilation in cardiac surgery patients and COPD patients. Randomized trials and controlled clinical trials were included. We excluded predictors of self-extubation. Although they are representative of an important body of literature in this field, we excluded studies that were designed primarily to evaluate the reproducibility in the measurement of various predictors of weaning success or duration of ventilation.

Search for Relevant Studies

To identify relevant studies, we searched MEDLINE, Excerpta Medica Database, HEALTHStar, CINAHL (Cumulative Index to Nursing and Allied Health Literature), the Cochrane Controlled Trials Registry, and the Cochrane Data Base of Systematic Reviews from 1971 to September 1999, and personal files. We examined the reference lists of all included articles for other potentially relevant citations. In addition, we hand-searched the respiratory therapy journal *Respiratory Care* from 1997 to 1999. We did not explicitly search for unpublished literature. Our search strategies are available on request.

Two reviewers examined each title and abstract. Reviewers included either two of the investigators or one investigator and a senior respiratory therapist. We took a comprehensive approach and retrieved all articles that either reviewer considered to be possibly eligible. Two reviewers also examined the full text and made final decisions regarding eligibility based on the inclusion and exclusion criteria described above. These decisions were made unblinded to the source, authors, and conclusions of each study. Disagreements were resolved by consensus.

Data Abstraction

Data were abstracted and methodological quality was assessed in duplicate by two of five respiratory therapists and five intensivists. One of the senior investigators rechecked the final data abstraction.

Depending on the data available to us, we reported the results of studies of weaning predictors in a variety of ways. These include the following: the means or medians in patients who were successfully and unsuccessfully weaned; the proportions of patients with results more extreme than the specified thresholds; sensitivity, specificity, likelihood ratios (LRs), or predictive values; Pearson correlation coefficients; and χ^2 tests, Student's t tests, analysis of variance, and univariate and multivariate regressions. We implemented a process for data abstraction that allowed for the recording of all data types.

Study results may be influenced by the extent to which investigators control for important potential sources of bias in predicting weaning success and failure. Therefore, we also recorded aspects of study design, including the following: (1) whether investigators enrolled a representative sample of patients (or, alternatively, whether *selection bias* was evident); and (2) whether those making weaning decisions or assessing outcomes were aware of predictor variables (*ie*, blinding).

Finally, the applicability of study results depends on the adequate reporting of information related to patient populations and experimental methods. We recorded this information as well.

Relevant Predictors

Because of the very large number of predictor variables, our goal was a manageable presentation of the data. We present the results only for those studies in which predictors showed even a modest potential for differentiating success from failure in weaning. We developed a number of guidelines for what we considered to be a modest potential for differentiating success from failure.

1. We present all clearly specified predictors for which results could be recorded in 2 × 2 tables if there was an associated biologically sensible LR of > 2 or < 0.5.
2. When investigators presented results as means and SDs of the success and failure groups, we present predictors if the difference in means between the two groups was greater than one half of the smaller of the SDs of the two groups.
3. When there was no information about the power of the predictor in terms of either LRs or the distributions of predictor results in the success and failure groups, we included predictors with a statistically significant association with the outcome of interest (for instance, on multiple regression analysis).

In many instances, a predictor met one of these three criteria in some but not all studies. When the results differed across studies within one of the three populations, we included the predictor, unless it was not predictive in the majority of studies and in the majority of patients. For example, if only one of many studies found a predictor to be of value, we present the results with this predictor if the study sample size was > 50% of the total sample size of all studies that examined that predictor.

Table 2—*Predictors of Success in Reducing Mechanical Ventilatory Support**

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
$\dot{V}_E$, L/min	G, T	Linton et al[12]/1994	27	8.8† 8.1‡	
$\dot{V}_E$, 10 L/min	S	Rivera and Weissman[13]/1997	40	90 (78–102)§ 50 (18–82)‖	
RR	G, T	Linton et al[12]/1994	27	14† 12‡	< 0.01
	G	Stroetz and Hubmayr[14]/1995	31	14.7 (3.4)¶ 19.8 (5)#	0.39
RR, 22 breaths/min	S	Rivera and Weissman[13]/1997	40	84 (70–98)§ 76 (49–103)‖	
V_T (mL)	G, T	Linton et al[12]/1994	27	542† 602‡	
	S	Rivera and Weissman[13]/1997	40	410 (100)** 380 (90)††	0.38
VC, L	G, T	Linton et al[12]/1994	27	1.1† 0.9‡	
RSBI, 65 breaths/min/L	S	Rivera and Weissman[13]/1997	40	90 (78–102)§ 80 (55–105)‖	
P_{Imax}, cm H_2O	G	Stroetz and Hubmayr[14]/1995	31	42 (5)¶ 28 (6)#	0.08
$P_{0.1}$, cm H_2O	G, T	Linton et al[12]/1994	27	− 0.46† 2.3‡	
$P_{0.1}$, 4.5 cm H_2O	S	Rivera and Weissman[13]/1997	40	100§ 100‖	
Pressure time product, 275 cm H_2O/L/s	S	Rivera and Weissman[13]/1997	40	100§ 80 (55–105)‖	
Total PEEP, cm H_2O/L/s	S	Rivera and Weissman[13]/1997	40	6.9 (2.3)** 8.9 (2.7)††	0.02
Oxygen consumption during controlled ventilation, mL/min	G, CVS	Oh et al[15]/1991	20	233.3 (59.0)** 205.4 (44.3)††	0.29

*$\dot{V}_E$ = minute ventilation; V_T = tidal volume; VC = vital capacity; G = general medical/surgical ICU case mix; T = trauma; S = surgical ICU; CVS = cardiovascular surgery patients; PEEP = positive end-expiratory pressure.
†Median of success.
‡Median of failure.
§Sensitivity (range).
‖Specificity (range).
¶Mean (SE) of success.
#Mean (SE) of failure.
**Mean (SD) of success.
††Mean (SD) of failure.

Terminology

We use the following terminology in our interpretation and presentation of test results. We classify a test result as positive if it increases the likelihood of successful weaning (sensitivity is therefore the proportion of patients who have experienced successful weaning who have a positive test result) and as negative if it decreased the likelihood of successful weaning (specificity is then the proportion of patients whose weaning failed who had a negative test result). When using LRs, an LR of 1 means that the posttest probability is the same as the pretest probability and, thus, that the test result is unhelpful. Values of 1 to 2 (which raise probability as much as values of 1 to 0.5 lower the probability) change probability very little, values of 2 to 5 or 0.5 to 0.2 lead to small changes in probability, values of 5 to 10 or 0.2 to 0.1 lead to moderate changes in probability, and values of > 10 or < 0.1 lead to large changes in probability.

Statistical Analysis

If we identified more than one study examining a relevant predictor and presenting these data in a manner allowing the creation of a 2×2 table, we summarized data in the form of LRs.[9] The majority of studies, however, presented data only as group means and SDs. To transform these data into LRs, we tested the assumption of normality by inspecting the mean and SD for skewness. To do so, we noted the occasions on which the value obtained by adding 2 SDs to the mean and subtracting 2 SDs from the mean yielded clinically implausible values. If we could assume normality, knowing the total sample size and the number of patients in the successfully and unsuccessfully weaned groups of patients, we estimated the number of patients in each cell of a 2×2 table. We used the predictor threshold that was most often provided by the investigators to create these LRs. We calculated confidence intervals (CIs) for all summary measures.[10]

Where appropriate, we pooled data across studies to narrow the 95% CIs around estimates of accuracy in prediction. Using these data transformations, we calculated the pooled LR of a positive test result, the pooled LR of a negative test result, the pooled sensitivity and specificity of a given predictor threshold, and an associated pooled odds ratio (OR).[11] We did not pool LRs across studies in which some investigators presented their results as binary variables while others presented their results as continuous variables. Whenever we could pool three or more studies, we also constructed a summary receiver operating characteristic (ROC) curve. We tested ROC curves for the presence of a threshold effect (*ie*, the presence of a natural cutoff, or threshold, value), and for accuracy (using Q tests and area under the curves).

Definitions of Predictor Variables

Investigators defined two variables, maximal inspiratory pressure (PImax) and negative inspiratory force (NIF), in many different ways (*ie*, "PImax," "NIF," negative inspiratory pressure ["NIP"], and maximal inspiratory pressure ["MIP"]). For the purposes of this report, we refer to PImax when investigators described PImax that was measured in an occluded airway after 20 s starting from residual volume, and we refer to NIF when negative pressure was measured after at least 1 s of inspiratory effort against an occluded airway and the most negative value of three attempts was recorded.

Results

We identified 65 observational studies[12–76] of weaning predictors that were reported in 70 publications, of which 2 studies[75,76] are not included in our tables. Of these, 41 studies included heterogeneous ICU populations, 6 included only patients with COPD, and 16 studies evaluated weaning predictors in the cardiovascular ICU (CVICU). We found 462 putative weaning predictors. After grouping together predictors with similar names but different thresholds (*ie*, grouping together RR, RR < 35 breaths/min, and RR < 38 breaths/min), the following numbers of predictors met our relevance criteria in each group: heterogeneous populations, 51; COPD patients, 21; and CVICU patients, 45.

In general, this literature is limited by a lack of blinding; that is, caregivers making decisions about weaning were aware, to some extent (either explicitly or vaguely), of the values of the predictor variables and may have included this information in their bedside assessments. For most predictor variables, this methodological limitation was unavoidable. Only a few notable studies appeared to achieve blinding of both caregivers (*ie*, those deciding on whether or not to reduce mechanical support, to end a trial of unassisted breathing, or to extubate) and outcome assessors. Lack of blinding, which was characteristic of the remaining studies, usually results in inflated estimates of predictive accuracy.

Table 3—*Pooled Results for Predictors of Success in Reducing Mechanical Ventilatory Support**

Predictor	Study/Threshold	Study LR + (95% CI)	Summary LR +(95% CI)	Summary LR −(95% CI)	Summary Sensitivity (95% CI)	Summary Specificity (95% CI)
RR (continuous data)	Stroetz and Hubmayr[14]/38 breaths/min	1.14 (0.87–1.50)	1.10 (0.95–1.28)	0.32 (0.06–1.71)	0.97 (0.92–1.02)	0.13 (0.04–0.22)
	Rivera and Weissman[13]/38 breaths/min	1.08 (0.90–1.29)				

*LR + = LR associated with a positive test result; LR − = LR associated with a negative test result.

Table 4—*Predictors of Success in Trials of Unassisted Breathing**

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
Duration of mechanical ventilation prior to weaning					
h	G, N, T	Frutos et al[16]/1995	73	144.0 (122.4)† 273.6 (120.0)‡	0.003
	R	Del Rosario et al[17]/1997	49	163.2 (175.2)† 324.0 (506.4)‡	0.10
10 h prior to weaning	R, N, CVS	Dojat et al[18]/1996	38	71 (47–94)§ 62 (40–84)‖	
V̇E					
L/min	R	Del Rosario et al[17]/1997	49	12.8 (0.6)¶ 13.9 (1.6)#	0.44
10 L/min	R, N	Chatila et al[19]/1996	100	79 (69–89)§ 32 (16–48)‖	
12 L/min	R, N (men only)	Sassoon and Mahutte[20]/1993	45	40 (23–57)§ 50 (14–86)‖	
RR					
breaths/min	R, N	Jabour et al[21]/1991	38	26.2 (8.3)† 30.3 (7.5)‡	0.09
	G, N, T	Frutos et al[16]/1995	73	24.1 (5.3)† 30.4 (5.5)‡	< 0.001
	R, T	Saura et al[22]/1996	30	21 (1)¶ 23 (2)#	0.35
	R	Del Rosario et al[17]/1997	49	25.1 (1.1)¶ 35.2 (3.4)#	< 0.001
30 breaths/min	R, N, CVS	Dojat et al[17]/1996	38	100§ 76 (57–96)‖	
38 breaths/min	R, N (men only)	Sassoon and Mahutte[20]/1993	45	97 (91–103)§ 30 (− 3–63)‖	
VT					
mL	R, T	Saura et al[22]/1996	30	450 (20)¶ 440 (30)#	0.80
	R	Del Rosario et al[17]/1997	49	530 (28)¶ 436 (62)#	0.13
325 mL	R, N (men only)	Sassoon and Mahutte[20]/1993	45	94 (86–102)§ 40 (5–75)‖	
	R, N, CVS	Dojat et al[18]/1996	38	53 (27–79)§ 76 (57–96)‖	
Standardized to weight, mL/kg	R, N	Jabour et al[21]/1991	38	5.9 (1.7)† 4.8 (1.7)‡	0.03
	G, N, T	Frutos et al[16]/1995	73	6.8 (1.8)† 6.6 (1.9)‡	0.75
V̇E/VT, min	R, N	Jabour et al[21]/1991	38	25 (11)† 42 (16)‡	< 0.001
RSBI					
breaths/min/L	R	Del Rosario et al[17]/1997	49	54.5 (4.4)¶ 112.7 (27.3)#	< 0.001
100 breaths/min/L	R, N (men only)	Sassoon and Mahutte[20]/1993	45	97 (91–103)§ 40 (5–75)‖	
	R, N	Chatila et al[19]/1996	100	98 (94–102)§ 59 (43–75)‖	
	R, N, CVS	Dojat et al[18]/1996	38	94 (82–106)§ 81 (63–99)‖	
RSBI occlusion pressure index, 450 cm H_2O breaths/min/L	R, N (men only)	Sassoon and Mahutte[20]/1993	45	97 (91–103)§ 60 (25–95)‖	
NIF					
cm H_2O	G, N, T	Frutos et al[16]/1995	73	34.6 (13.9)† 31.7 (19.9)‡	0.62
− 25 cm H_2O	R, N, CVS	Dojat et al[18]/1996	38	94 (71–100)§ 24 (8–47)‖	
− 30 cm H_2O	R, N	Chatila et al[19]/1996	100	67 (55–79)§ 69 (54–84)‖	

(Table continues)

Table 4—*Continued*

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
Pbreath/PImax ratio	R, N	Jabour et al[21]/1991	38	0.31 (0.1)† 0.39 (0.14)‡	0.03
PImax					
cm H_2O	R, N	Jabour et al[21]/1991	38	49 (11)† 35 (15)‡	< 0.001
	R	Del Rosario et al[17]/1997	49	43.4 (3.4)¶ 33.2 (4.4)#	0.14
20 cm H_2O	R, N (men only)	Sassoon and Mahutte[20]/1993	45	91 (81–101)§ 30 (− 3–63)‖	
$P_{0.1}$					
cm H_2O	R	Del Rosario et al[17]/1997	49	3.2 (0.2)¶ 5.2 (1.3)#	0.01
5.5 cm H_2O	R, N (men only)	Sassoon and Mahutte[20]/1993	45	97 (91–103)§ 40 (5–75)‖	
$P_{0.1}$/PImax	R	Del Rosario et al[17]/1997	49	0.090 (0.015)¶ 0.165 (0.038)#	0.03
Pressure time index	R, N	Jabour et al[21]/1991	38	0.12 (0.03)† 0.17 (0.07)‡	0.004
2-h T-piece trial	R, N, CVS	Dojat et al[18]/1996	38	100§ 76 (57–95)‖	
Cardiac index, L/m^2/min	G, CVS, T	Kennedy et al[23]/1977	20	3.4 (0.4)¶ 2.5 (0.2)#	0.06
Left atrial pressure, mm Hg	G, CVS, T	Kennedy et al[23]/1977	20	9 (3)¶ 14 (2)#	0.18
Knowledge-based system	R, N, CVS	Dojat et al[18]/1996	38	100§ 91 (77–104)‖	
SBP, mm Hg	G, N, T	Frutos et al[16]/1995	73	132.6 (23.5)† 147.0 (21.0)‡	0.07
SAPS at hospital admission	R, N, CVS	Dojat et al[18]/1996	38	77 (55–98)§ 33 (12–55)‖	
APACHE at hospital admission	G, N, T	Frutos et al[16]/1995	73	19.1 (7.0)† 17.6 (7.0)‡	0.53

*N = neurology/neurosurgical; R = patients with respiratory failure, including cardiac, COPD, and acute lung injury; SBP = systolic BP; SAPS = simplified acute physiology score; Pbreath = peak airway pressure on mechanical ventilation for the corresponding ventilator VT. See Table 2 for other abbreviations not used in the text.
†Mean (SD) of success.
‡Mean (SD) of failure.
§Sensitivity (range).
‖Specificity (range).
¶Mean (SE) of success.
#Mean (SE) of failure.

The importance of selection bias in this literature was difficult to assess because the reporting of patient selection in individual studies was not detailed. For the vast majority of studies, selection bias was not evident.

Many studies omitted to report information bearing on the applicability of their results. For instance, most studies did not mention whether patients with a tracheostomy were included, how decisions to perform tracheostomy were handled in the study protocol, or whether this procedure was taken into account during the analysis. Patients with a tracheostomy might fare differently on numerous tests for weaning, and systematically excluding these patients would alter the patient population and the corresponding test properties.

Weaning Predictors in Heterogeneous Patient Populations

Tables 2 to 9 summarize the studies evaluating weaning predictors in heterogeneous populations of mechanically ventilated patients in ICUs.

For stepwise reductions in mechanical support, the most promising weaning predictors are a rapid shallow breathing index (RSBI) of < 65 breaths/min/L made using the ventilator settings that were in effect at the time the prediction is made and a pressure time product of < 275 cm H_2O/L/s (Table 2).[12–15] The small sample size of the study that reported these results (40 patients) limits the associated strength of inference.

Table 3 presents the pooled results for the only predictor (RR) for which data were amenable to pooling. The pooled LRs are 1.1 (95% CI, 0.95 to 1.28) for an RR of < 38 breaths/min and 0.32 (95% CI, 0.06 to 1.71) for an RR of > 38 breaths/min, indicating that an RR of < 38 breaths/min leaves the probability of successful weaning virtually unchanged but a value of > 38 breaths/min leads to a small reduction in the probability of success in weaning the level of mechanical support. The wide CI around the LR leaves even this estimate open to considerable uncertainty.

For trials of unassisted breathing, the most promising

Table 5—*Pooled Results for Predictors of Success in Trials of Unassisted Breathing**

Predictor	Study/Threshold	Study LR + (95% CI)	Summary LR + (95% CI)	Summary LR − (95% CI)	Summary Sensitivity (95% CI)	Summary Specificity (95% CI)
$\dot{V}_E$	Sassoon and Mahutte[20]/12 L/min	0.81 (0.40–1.64)	1.13 (0.88–1.43)	0.88 (0.48–1.61)	0.60 (0.22–0.98)	0.41 (0.24–0.57)
Binary data	Chatila et al[19]/10 L/min	1.18 (0.91–1.52)				
Continuous data	Del Rosario et al[17]/12 L/min	1.12 (0.49–2.55)	1.12 (0.49–2.55)	0.93 (0.56–1.55)	0.42 (0.28–0.55)	0.63 (0.50–0.76)
RR	Dojat et al[18]/30 breaths/min	3.89 (1.88–8.05)	2.23 (0.83–6.03)	0.09 (0.02–0.40)	0.97 (0.93–1.00)	0.53 (0.11–0.96)
Binary data	Sassoon and Mahutte[20]/38 breaths/min	1.41 (0.93–2.12)				
Continuous data	Del Rosario et al[17]/38 breaths/min	1.63 (1.01–2.62)	1.11 (0.98–1.24)	0.23 (0.08–0.63)	0.97 (0.95–1.00)	0.18 (0.06–0.30)
	Jabour et al[21]/38 breaths/min	1.08 (0.87–1.35)				
	Frutos et al[16]/38 breaths/min	1.12 (0.90–1.40)				
	Saura et al[22]/38 breaths/min	1.05 (0.86–1.27)				
V_T	Dojat et al[18]/325 mL	2.11 (0.91–4.92)	1.70 (1.10–2.61)	0.38 (0.11–1.34)	0.74 (0.34–1.13)	0.58 (0.25–0.91)
Binary data	Sassoon and Mahutte[20]/325 mL	1.57 (0.96–2.60)				
Continuous data	Del Rosario et al[17]/325 mL	1.27 (0.85–1.89)	1.10 (0.87–1.40)	0.49 (0.17–1.37)	0.88 (0.81–0.95)	0.22 (0.04–0.40)
	Saura et al[22]/325 mL	1.02 (0.75–1.37)				
RSBI	Dojat et al[18]/100 breaths/min/L	1.22 (0.93–1.61)	1.66 (1.08–2.55)	0.11 (0.03–0.37)	0.97 (0.94–0.99)	0.42 (0.21–0.63)
	Sassoon and Mahutte[20]/100 breaths/min/L	1.62 (0.99–2.66)				
Binary data	Chatila et al[19]/100 breaths/min/L	2.39 (1.63–3.52)				
Continuous data	Del Rosario et al[17]/100 breaths/min/L	2.10 (1.12–3.95)	2.10 (1.12–3.95)	0.11 (0.03–0.41)	0.94 (0.88–1.01)	0.55 (0.41–0.69)
NIF	Dojat et al[18]/25 cm H_2O	1.22 (0.93–1.61)	1.57 (0.89–2.77)	0.47 (0.32–0.70)	0.79 (0.54–1.04)	0.48 (0.04–0.91)
Binary data	Chatila et al[19]/30 cm H_2O	2.19 (1.31–3.67)				
Continuous data	Frutos et al[16]/25 cm H_2O	1.21 (0.75–1.97)	1.21 (0.75–1.97)	0.65 (0.28–1.56)	0.75 (0.65–0.85)	0.38 (0.27–0.49)
P_{Imax}						
Binary data	Sassoon and Mahutte[20]/20 cm H_2O	1.32 (0.87–2.01)	1.32 (0.87–2.01)	0.31 (0.08–1.14)	0.90 (0.82–0.99)	0.32 (0.19–0.45)
Continuous data	Del Rosario et al[17]/20 cm H_2O	1.09 (0.79–1.49)	1.15 (0.98–1.35)	0.50 (0.15–1.66)	0.92 (0.81–1.04)	0.19 (0.11–0.27)
	Jabour et al[21]/20 cm H_2O	1.18 (0.97–1.42)				

*See Tables 2 and 3 for abbreviations not used in the text.

Table 6—*Predictors of Successful Extubation**

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
Duration of mechanical ventilation prior to weaning, h	R, N	Tahvanainen et al[24]/1983	47	112.8 (12.0)† 144.0 (28.8)‡	0.32
	R, N	Lee et al[25]/1994	52	110.4 (93.6)§ 230.4 (163.2)‖	0.004
	General pediatric/neonatal (except N)	Khan et al[26]/1996	213	120.0 (9.6)† 124.8 (14.4)‡	0.84
	R (age > 70 yr)	Krieger et al[27]/1997	49	132 (144)§ 312 (264)‖	0.005
	R, N	Afessa et al[28]/1999	118	256.8 (153.6)§ 283.2 (187.2)‖	0.36
$\dot{V}_E$					
L/min	R, N	Tahvanainen et al[24]/1983	47	6.16 (0.55)† 5.96 (0.66)‡	0.81
	R (age > 70 yr)	Krieger et al[27]/1997	49	6.4 (2.5)§ 6.1 (2.1)‖	0.72
	R, N	Afessa et al[28]/1999	118	10.7 (3.4)§ 9.5 (4.2)‖	0.046
10 L/min	G	Leitch et al[29]/1996	163	50 (42–58)¶ 67 (− 50–184)#	
	G, N, T	Mergoni et al[30]/1996	51	60 (44–76)¶ 53 (37–69)#	
15 L/min	R, N	Yang[31]/1993	31	81 (60–102)¶ 20 (− 2–42)#	
No cut point reported	S	Gologorskii et al[32]/1997	127	66 (56–76)¶ 66 (51–81)#	
RR					
breaths/min	R, N	Tahvanainen et al[24]/1983	47	23.6 (1.2)† 19.6 (2)‡	0.14
	G, CVS	Kline et al[33]/1987	50	21.5 (4.8)§ 22.7 (5.4)‖	0.41
	Esophageal cancer only	Ochiai et al[34]/1993	38	14.4 (2.9)§ 14.5 (5.6)‖	0.95
	R (age > 70 yr)	Krieger et al[27]/1997	49	22 (7)§ 28 (5)‖	0.01
	R, N	Afessa et al[28]/1999	118	27.4 (7.8)§ 28.5 (9.5)‖	0.53
30 breaths/min	T	DeHaven et al[35]/1996	589	82 (79–85)¶ 17 (6–29)#	
	G, N, T	Mergoni et al[30]/1996	51	70 (55–85)¶ 66 (50–82)#	
38 breaths/min	R, N	Yang[31]/1993	31	88 (71–105)¶ 47 (19–75)#	
No cut point reported	S	Gologorskii et al[32]/1997	127	70 (60–80)¶ 72 (58–86)#	
V_T					
mL	R, N	Tahvanainen et al[24]/1983	47	270 (20)† 310 (30)‡	0.36
	G, CVS	Kline et al[33]/1987	50	340 (80)§ 400 (80)‖	0.01
	R (age > 70 yr)	Krieger et al[27]/1997	49	311 (137)§ 221 (76)‖	0.04
325 mL	R, N	Yang[31]/1993	31	100¶ 67 (41–93)#	
No cut point reported	S	Gologorskii et al[32]/1997	127	73 (63–83)¶ 75 (61–89)#	
Standardized to weight, mL/kg	Esophageal cancer only	Ochiai et al[34]/1993	38	9.67 (2.94)§ 10.08 (1.97)‖	0.62
4 mL/kg	General pediatric/neonatal (except N)	Khan et al[26]/1996	213	84 (78–89)¶ 28 (12–44)#	

(*Table continues*)

Table 6—*Continued*

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
VC					
L	R, N	Tahvanainen et al[24]/1983	47	0.80 (0.05)† 0.76 (0.09)‡	0.71
% predicted	Esophageal cancer only	Ochiai et al[34]/1993	38	95.9 (18.7)§ 105.7 (10.7)‖	0.05
RSBI					
Breaths/min/L	R, N	Afessa et al[28]/1999	118	79.2 (41.2)§ 103.0 (62.3)‖	0.06
100 breaths/min/L	R, N	Yang[31]/1993	31	94 (81–107)¶ 73 (48–98)#	
	R, N	Epstein[36]/1995	94	92 (86–98)¶ 22 (1–43)#	
	R, N	Epstein and Ciubotaru[37]/1996	218	89 (84–93)¶ 24 (9–38)#	
	G	Leitch et al[29]/1996	163	96 (93–99)¶ 0#	
105 breaths/min/L	R, N	Lee et al[25]/1994	52	72 (58–86)¶ 11 (− 13–35)#	
	G, N, T	Mergoni et al[30]/1996	51	65 (49–81)# 58 (42–74)#	
	R (age > 70 yr)	Krieger et al[27]/1997	49	74 (60–88)¶ 73 (43–103)#	
No cut point reported	S	Gologorskii et al[32]/1997	127	84 (76–92)¶ 83 (71–95)#	
8 mL/kg	General pediatric/neonatal (except N)	Khan et al[26]/1996	213	64 (57–71)¶ 56 (39–73)#	
11 mL/kg	General pediatric/neonatal	Baumeister et al[38]/1997	47	79 (65–92)¶ 78 (46–110)#	
RSBI 100 breaths/min and inspiratory pressure/PImax, 0.03	R, N	Yang[31]/1993	31	81 (60–102)¶ 93 (79–107)#	
NIF					
cm H_2O	R, N	Yang[31]/1993	31	11.48 (1.25)† 14.32 (2.31)‡	0.28
No cut point reported	S	Gologorskii et al[32]/1997	127	68 (58–78)¶ 62 (47–77)#	
PImax					
cm H_2O	R, N	Tahvanainen et al[24]/1983	47	35.7 (1.6)† 39 (1.4)‡	0.34
	G, CVS	Kline et al[33]/1987	50	36.1 (10.1)§ 29.0 (7.6)‖	0.009
	R (age > 70 yr)	Krieger et al[27]/1997	49	43 (11)§ 35 (11)‖	0.04
	R, N	Afessa et al[28]/1999	118	60.8 (23.7)§ 45.3 (17.2)‖	0.001
15 cm H_2O	R, N	Yang[31]/1993	31	100¶ 13 (− 6–32)#	
20 cm H_2O	G	Leitch et al[29]/1996	163	97 (94–100)¶ 0#	
30 cm H_2O	G, N, T	Mergoni et al[30]/1996	51	73 (58–88)¶ 40 (24–56)#	
$P_{0.1}$/PImax 0.14	G, N, T	Mergoni et al[30]/1996	51	85 (73–97)¶ 36 (21–53)#	
Dynamic compliance standardized to weight, mL/kg/cm H_2O	General pediatric/neonatal (except N)	Khan et al[26]/1996	213	3.3 (0.6–18.7)**	
Inspiratory pressure/PImax 0.3	General pediatric/neonatal	El Khatib et al[39]/1996	50	33 (18–49)¶ 91 (72–110)#	
	R, N	Yang[31]/1993	31	75 (52–98)¶ 67 (41–93)#	

(*Table continues*)

Table 6—*Continued*

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
Inspiratory flow rate, mL/kg/s	Esophageal cancer only	Ochiai et al[34]/1993	38	7.97 (2.69)§ 8.46 (1.47)‖	0.49
	General pediatric/neonatal (except N)	Khan et al[26]/1996	213	3.8 (1.4–10.7)††	
FEV_1, % predicted	Esophageal cancer only	Ochiai et al[34]/1993	38	76.1 (6.7)§ 71.9 (5.2)‖	0.04
FIO_2, %	General pediatric/neonatal (except N)	Khan et al[26]/1996	213	3.6 (1.2–11.1)††	
	R (age > 70 yr)	Krieger et al[27]/1997	49	40 (6)§ 38 (6)‖	0.33
CROP index standardized to weight					
0.1 mL/breaths/min/kg	General pediatric/neonatal	Baumeister et al[38]/1997	47	100¶ 100#	
0.2 mL/breaths/min/kg	General pediatric/neonatal (except N)	Khan et al[26]/1996	213	56 (48–64)¶ 47 (29–65)#	
Hemoglobin, g/dL	R, N	Tahvanainen et al[24]/1983	47	11.9 (0.2)* 11.0 (0.4)‡	0.08
Change in intrapleural pressure, cm H_2O	G, CVS	Kline et al[33]/1987	50	11.2 (2.9)§ 15.2 (4.5)‖	< 0.001
Change in intrapleural pressure/NIF	G, CVS	Kline et al[33]/1987	50	0.32 (0.07)§ 0.53 (0.1)‖	< 0.001
Cuff leak test	High-risk airways (ENT disease only)	Fisher and Raper[40]/1992	72	89 (81–97)¶ 100#	
Cuff leak test in pediatrics	Children with croup	Adderly and Mullins[41]/1987	28	75 (58–92)¶ 63 (22–103)#	
Daily screening test	R, N	Ely et al[42]/1996	300	88 (84–92)¶ 67 (57–77)#	
Physiologic shunt	S	Gologorskii et al[32]/1997	127	80 (71–89)¶ 61 (46–76)#	
APACHE score at hospital admission	R, N	Afessa et al[28]/1999	118	11.3 (5.2)§ 16.9 (5.5)‖	< 0.001

*See Tables 2 and 4 for abbreviations not used in the text.
†Mean (SE) of success.
‡Mean (SE) of failure.
§Mean (SD) of success.
‖Mean (SD) of failure.
¶Sensitivity (range).
#Specificity (range).
**Multivariate OR (95% CI).
††Univariate OR (95% CI).

weaning predictors from the review of individual studies (Table 4)[16–23] include the following: RR; RSBI; the product of RSBI and airway pressure 0.1 s after the occlusion of the inspiratory port of a unidirectional balloon occlusion valve ($P_{0.1}$) (*ie*,RSB-$P_{0.1}$ index) < 450 cm H_2O breaths/min/L; PImax < 20 cm H_2O; and a knowledge-based system for adjusting pressure support. Data allowed pooled estimates for two of these variables (RR and RSBI) (Table 5). Pooled results are consistent across studies that provided binary data and those that provided only continuous data. For both RR and RSBI, the power of a positive test result was very limited (highest LR, 2.23), while the power of a negative test result was substantial (LR, 0.09 to 0.23). Summary data suggest a similar predictive power of RR and RSBI.

In the prediction of successful extubation (Table 6),[24–42] an RR of < 38 breaths/min (sensitivity, 88%; 5specificity, 47%), an RSBI of < 100 breaths/min/L or 105 breaths/min/L (sensitivity, 65 to 96%; specificity, 0 to 73%), PImax, and APACHE (acute physiology and chronic health evaluation) II scores measured at hospital admission appear to be the most promising. After pooling (Table 7), two variables appeared to have some value. An RR of > 38 breaths/min and an RSBI of > 100 breaths/min/L appear to reduce the probability of successful extubation, and an inspiratory pressure/PImax

Table 7—*Pooled Results for Predictors of Successful Extubation**

Predictor	Study/Threshold	Study LR + (95% CI)	Summary LR +(95% CI)	Summary LR −(95% CI)	Summary Sensitivity (95% CI)	Summary Specificity (95% CI)
V̇E						
Binary data	Gologorskii et al[32]/not specified	1.91 (1.23–2.98)	1.31 (0.96–1.79)	0.63 (0.48–0.83)	0.63 (0.51–0.74)	0.52 (0.36–0.67)
	Mergoni et al[30]/10 L/min	1.25 (0.82–1.91)				
	Yang[31]/15 L/min	1.02 (0.71–1.45)				
	Leitch et al[29]/10 L/min	1.33 (0.37–4.77)				
Continuous data	Krieger et al[27]/12 L/min	1.02 (0.89–1.16)	0.99 (0.90–1.09)	1.23 (0.74–2.07)	0.86 (0.69–1.03)	0.12 (− 0.01–0.26)
	Tahvanainen et al[24]/12 L/min	1.00 (0.85–1.17)				
	Afessa et al[28]/12 L/min	0.90 (0.70–1.15)				
RR						
Binary data	Gologorskii et al[32]/not specified	2.54 (1.52–4.24)	1.64 (1.00–2.68)	0.52 (0.34–0.79)	0.77 (0.69–0.85)	0.51 (0.17–0.84)
	Mergoni et al[30]/30 breaths/min	2.01 (1.25–3.25)				
	DeHaven et al[35]/30 breaths/min	1.00 (0.87–1.15)				
	Yang[31]/38 breaths/min	1.61 (0.97–2.65)				
Continuous data	Krieger et al[27]/38 breaths/min	1.04 (0.89–1.21)	1.02 (0.97–1.07)	0.59 (0.25–1.36)	0.96 (0.94–0.99)	0.06 (0.02–0.11)
	Kline et al[33]/38 breaths/min	1.01 (0.93–1.09)				
	Ochiai et al[34]/38 breaths/min	1.00 (0.91–1.10)				
	Tahvanainen et al[24]/38 breaths/min	1.01 (0.87–1.19)				
	Afessa et al[28]/38 breaths/min	1.08 (0.94–1.24)				
VT						
Binary data	Gologorskii et al[32]/not specified	2.92 (1.70–5.01)	2.88 (1.89–4.40)	0.20 (0.03–1.26)	0.85 (0.62–1.09)	0.73 (0.66–0.80)
	Yang[31]/325 mL	2.82 (1.43–5.58)				
Continuous data	Krieger et al[27]/325 mL	3.83 (0.80–18.39)	0.92 (0.47–1.81)	1.07 (0.52–2.17)	0.45 (0.32–0.59)	0.54 (0.11–0.98)
	Kline et al[33]/325 mL	0.71 (0.49–1.02)				
	Tahvanainen et al[24]/325 mL	0.75 (0.33–1.73)				
RSBI	Gologorskii et al[32]/not specified	4.67 (2.42–8.99)	1.49 (1.11–1.99)	0.39 (0.25–0.62)	0.84 (0.77–0.90)	0.44 (0.24–0.65)
	Lee et al[25]/105 breaths/min/L	0.84 (0.61–1.16)				
	Mergoni et al[30]/105 breaths/min/L	1.52 (0.99–2.36)				
Binary data	Krieger et al[27]/105 breaths/min/L	2.51 (1.02–6.18)				
	Leitch et al[29]/100 breaths/min/L	1.10 (0.76–1.59)				
	Epstein[36]/100 breaths/min/L	1.17 (0.96–1.42)				
	Epstein and Ciubotaru[37]/100 breaths/min/L	1.20 (0.93–1.56)				
	Yang[31]/100 breaths/min/L	3.24 (1.46–7.19)				
Continuous data	Afessa et al[28]/100 breaths/min/L	1.43 (1.05–1.96)	1.43 (1.05–1.96)	0.60 (0.38–0.94)	0.69 (0.61–0.77)	0.52 (0.43–0.61)
RSBI standardized to weight (binary data)	Khan et al[26]/8	1.44 (0.98–2.12)	1.79 (0.90–3.53)	0.46 (0.21–1.01)	0.70 (0.56–0.84)	0.65 (0.46–0.84)
	Baumeister et al[38]/11	3.13 (1.06–9.27)				
PImax	Yang[31]/15 cm H_2O	1.15 (0.92–1.44)	1.17 (0.98–1.40)	0.60 (0.33–1.11)	0.90 (0.79–1.01)	0.27 (0.14–0.40)
Binary data	Leitch et al[29]/20 cm H_2O	1.29 (0.58–2.87)				
	Mergoni et al[30]/30 cm H_2O	1.20 (0.87–1.66)				
Continuous data	Krieger et al[27]/20 cm H_2O	1.10 (0.89–1.37)	1.03 (0.96–1.11)	0.56 (0.22–1.42)	0.95 (0.92–0.98)	0.08 (0.05–0.12)
	Kline et al[33]/20 cm H_2O	1.08 (0.89–1.30)				
	Tahvanainen et al[24]/20 cm H_2O	0.98 (0.83–1.16)				
	Afessa et al[28]/20 cm H_2O	1.03 (0.94–1.13)				
Inspiratory pressure/ PImax (binary data)	el Khatib et al[39]/0.30	2.70 (0.57–12.83)	2.23 (1.15–4.34)	0.63 (0.36–1.10)	0.53 (0.14–0.92)	0.78 (0.56–0.99)
	Yang[31]/0.30	2.14 (1.03–4.46)				
CROP index (binary data)	Baumeister et al[38]/0.1 mL/breaths/min/kg	19.7 (1.32–294.3)	3.31 (0.20–54.80)	0.14 (0.00–8.87)	0.77 (0.35–1.19)	0.71 (0.24–1.18)
	Khan et al[26]/0.2 mL/breaths/min/kg	1.05 (0.74–1.49)				

*See Tables 2 and 3 for abbreviations not used in the text.

ratio of < 0.3 (pooled LR, 2.23; 95% CI, 1.15 to 4.34) appears to marginally increase the likelihood of successful extubation.

Several studies evaluated the ability to predict the combined outcome of a successful trial of unassisted breathing followed by successful extubation. Predictor variables that showed some promise on review of the individual study results (Table 8)[43–52] include the following: duration of ventilation prior to weaning; an RR < 38 breaths/min (sensitivity, 92% [100 patients]); tidal volume,

Table 8—*Predictors of Successful Trials of Unassisted Breathing Followed by Extubation**

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
Duration of mechanical ventilation prior to weaning, h	G (age > 70 yr)	Krieger et al[43]/1989	269	62 (98)† 147 (144)‡	< 0.001
	R, N	Mohsenifar et al[44]/1993	29	148.8 (192.0)† 168.0 (96.0)‡	0.76
	G, T	Capdevila et al[45]/1995	67	353.0 (316.8)† 293.0 (151.4)‡	0.53
	Pediatric	Farias et al[46]/1998	84	192 (96–312)§ 285.6 (213.6–470.4)‖	0.03
	G, N, CVS, T	Vallverdu et al[47]/1998	217	168 (168)† 288 (288)‡	< 0.001
V̇E	G (age > 70 yr)	Krieger et al[43]/1989	269	7.9 (3.0)† 8.1 (3.2)‡	0.74
L/min	G, N	Ashutosh et al[48]/1992	30	11.33 (4.37)† 10.63 (2.40)‡	0.59
	G, T	Capdevila et al[45]/1995	67	12.61 (3.75)† 12.45 (3.90)‡	0.69
	G, N, CVS, T	Vallverdu et al[47]/1998	217	11 (10)† 10 (3)‡	0.35
10 L/min	G, N, CVS	Sahn and Lakshminarayan[49]/1973	100	96 (92–100)¶ 47 (21–73)#	
	S	Jacob et al[50]/1997	183	76 (69–83)¶ 40 (13–67)#	
12.5 L/min	R (COPD excluded), T	Gandia and Blanco[51]/1992	30	64 (45–83)¶ 75 (47–103)#	
15 L/min	R, N	Yang and Tobin[52]/1991	100	78 (64–92)¶ 18 (3–33)#	
RR					
Breaths/min	G (age > 70 yr)	Krieger et al[43]/1989	269	22 (6)† 23 (8)‡	0.42
	G, N	Ashutosh et al[48]/1992	30	22.53 (4.84)† 33.27 (7.97)‡	< 0.001
	G, T	Capdevila et al[45]/1995	67	24.16 (7.13)† 28.33 (3.98)‡	0.07
	Pediatric	Farias et al[46]/1998	84	40 (31–50)§ 46 (36–59)‖	
	G, N, CVS, T	Vallverdu et al[47]/1998	217	24 (6)†< 29 (8)‡	< 0.001
35 breaths/min	R (COPD excluded), T	Gandia and Blanco[51]/1992	30	82 (67–97)¶ 75 (47–103)#	
38 breaths/min	R, N	Yang and Tobin[52]/1991	100	92 (83–101)¶ 36 (17–55)#	
	R, N	Mohsenifar et al[44]/1993	29	100¶ 27 (− 3–57)¶	
VT					
mL	G (age > 70 yr)	Krieger et al[43]/1989	269	371 (149)† 355 (140)‡	0.59
	G, N	Ashutosh et al[48]/1992	30	552.73 (213.69)† 326.13 (99.43)‡	< 0.001

(Table continues)

> 4 mL/kg (sensitivity: in 100 adults, 94%; in 84 children, 94%); an RSBI of < 100 breaths/min/L; an NIF of < −20 cm H_2O; PImax; $P_{0.1}$ of < 5.0 cm H_2O (sensitivity, 87%; and specificity, 91% [in 67 patients]); and $P_{0.1}$/PImax ratio. Several other studies suggested potentially powerful predictors but enrolled ≤ 30 patients. In all studies, the predictors were measured immediately prior to the trial of unassisted breathing or early during the initiation of the trial. In Table 9, we present the results of pooled analyses. The RSBI yielded a statistically significant pooled LR of

Table 8—*Continued*

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
	G, T	Capdevila et al[45]/1995	67	527 (161)† 458 (188)‡	0.07
	G, N, CVS, T	Vallverdu et al[47]/1998	217	432 (143)† 378 (134)‡	0.005
325 mL	R, N	Yang and Tobin[52]/1991	100	97 (91–103)¶ 54 (35–73)#	
	R, N	Mohsenifar et al[44]/1993	29	100¶ 18 (− 8–44)#	
360 mL	R (COPD excluded), T	Gandia and Blanco[51]/1992	30	75 (58–92)¶ 58 (27–89)#	
4 mL/kg	R, N	Yang and Tobin[52]/1991	100	94 (86–102)¶ 39 (20–58)#	
	Pediatric	Farias et al[46]/1998	84	94 (88–100)¶ 43 (20–66)#	
VC, L	G, T	Capdevila et al[45]/1995	67	1.21 (0.68)† 0.8 (0.35)‡	0.03
	G, N, CVS, T	Vallverdu et al[47]/1998	217	1.63 (0.64)† 1.30 (0.51)‡	< 0.001
RSBI					
60 breaths/min/L	G, T	Capdevila et al[45]/1995	67	73 (61–85)¶ 75 (47–103)#	
96 breaths/min/L	R (COPD excluded), T	Gandia and Blanco[51]/1992	30	82 (67–97)¶ 83 (59–107)#	
100 breaths/min/L	S	Jacob et al[50]/1997	183	97 (94–100)¶ 33 (7–59)#	
	G, N, CVS, T	Vallverdu et al[47]/1998	217	90 (85–95)¶ 36 (26–46)#	
105 breaths/min/L	R, N	Yang and Tobin[52]/1991	100	97 (91–103)¶ 64 (45–83)#	
	R, N	Mohsenifar et al[44]/1993	29	100¶ 27 (− 3–57)#	
11 mL/kg	Pediatric	Farias et al[46]/1998	84	86 (77–95)¶ 48 (25–71)#	
RSBI occlusion pressure index, cm H_2O breaths/min/L	G, N, CVS, T	Vallverdu et al[47]/1998	217	241 (177)† 452 (363)‡	< 0.001
NIF					
cm H_2O	G, N	Ashutosh et al[48]/1992	30	38.8 (10.40)† 21.0 (6.07)‡	< 0.001
− 20 cm H_2O	R, N	Mohsenifar et al[44]/1993	29	100¶ 9 (− 10–28)#	
	S	Jacob et al[50]/1997	183	96 (93–99)¶ 7 (− 7–21)#	
− 25 cm H_2O	G, N, CVS	Sahn and Lakshminarayan[49]/1973	100	100¶ 100#	
PImax					
cm H_2O	G (age > 70 yr)	Krieger et al[43]/1989	269	38 (14)† 32 (14)‡	0.02
	Pediatric	Farias et al[46]/1998	84	45 (36–60)§ 37 (33–54)‖	
	G, N, CVS, T	Vallverdu et al[47]/1998	217	65 (21)† 53 (17)‡	< 0.001
15 cm H_2O	R, N	Yang and Tobin[52]/1991	100	100¶ 11 (− 1–23)#	
23 cm H_2O	R (COPD excluded), T	Gandia and Blanco[51]/1992	30	82 (67–97)¶ 75 (47–103)#	
50 cm H_2O	G, T	Capdevila et al[45]/1995	67	80 (69–91)¶ 41 (10–72)#	
Inspiratory effort quotient 0.19	R (COPD excluded), T	Gandia and Blanco[51]/1992	30	82 (67–97)¶ 100#	

(Table continues)

Table 8—*Continued*

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
$P_{0.1}$					
3.4 cm H_2O	R (COPD excluded), T	Gandia and Blanco[51]/1992	30	61 (42–80)¶ 75 (47–103)#	
4.5 cm H_2O	G, N, CVS, T	Vallverdu et al[47]/1998	217	75 (67–83)¶ 55 (45–65)#	
5.0 cm H_2O	G, T	Capdevila et al[45]/1995	67	87 (78–96)¶ 91 (73–109)#	
$P_{0.1}$/PImax	G, N, CVS, T	Vallverdu et al[47]/1998	217	0.063 (0.032)† 0.103 (0.056)‡	< 0.001
$P_{0.1}$/PImax 0.09	G, T	Capdevila et al[45]/1995	67	98 (94–102)¶ 100#	
$P_{0.1}$/PImax 0.14	R (COPD excluded), T	Gandia and Blanco[51]/1992	30	82 (67–97)¶ 100#	
Maximum expiratory pressure, cm H_2O	G, N, CVS, T	Vallverdu et al[47]/1998	217	53 (25)† 37 (17)‡	< 0.001
Gastric intramural pH	R, N	Mohsenifar et al[44]/1993	29	7.45 (0.13)† 7.36 (0.20)‡	0.15
Gastric intramural pH change	R, N	Mohsenifar et al[44]/1993	29	0.01 (0.01)** − 0.27 (0.08)††	0.001
Gastric Pco_2					
mm Hg	R, N	Mohsenifar et al[44]/1993	29	37 (12)† 49 (23)‡	0.08
Change, mm Hg	R, N	Mohsenifar et al[44]/1993	29	− 1 (1.5)** 62 (20.4)††	< 0.001
Gastric intramural pH change > 7.3/or < 0.09	R, N	Mohsenifar et al[44]/1993	29	100¶ 100#	
F_{IO_2}, %	R, N	Mohsenifar et al[44]/1993	29	35 (8)† 40 (7)‡	0.10
SBP, mm Hg	R, N	Mohsenifar et al[44]/1993	29	128 (24)† 140 (22)‡	0.21
Statistical prediction model	G, N	Ashutosh et al[48]/1992	30	93 (79–107)¶ 93 (79–107)#	
Neural network analysis	G, N	Ashutosh et al[48]/1992	30	100¶ 93 (79–107)#	
SAPS at hospital admission	G, T	Capdevila et al[45]/1995	67	11.1 (4.3)† 13.3 (3.8)‡	0.11

*See Tables 2 and 4 for abbreviations not used in the text.
†Mean (SD) of success.
‡Mean (SD) of failure.
§Median (interquartile range) of success.
||Median (interquartile range) of failure.
¶Sensitivity (range).
#Specificity (range).
**Mean (SE) of success.
††Mean (SE) of failure.

1.58 (95% CI, 1.30 to 1.90), indicating that it remains a very weak predictor. $P_{0.1}$/PImax ratio yielded a much more clinically useful pooled LR of 16.3 (95% CI, 2.35 to 113).

Summary ROC curves deal with the problem of different thresholds among studies. We show the summary ROC curves for several predictors of successful extubation (Figs 1-3) and of successful trials of unassisted breathing and extubation (Figs 4-7). Testing for the presence of a threshold effect indicated that none of these variables were associated with an ideal cut point or threshold level for weaning. Moreover, judging by the modest areas under the curve for all variables, none of these variables demonstrate more than modest accuracy in predicting weaning outcome, and none appear to perform any better than the others.

Weaning Predictors for Patients With COPD

Hilbert et al[53] evaluated a number of variables, including RR, RSBI, $P_{0.1}$, effective inspiratory impedance, and Pa_{O_2}/fraction of inspired oxygen (F_{IO_2}) ratio, for the ability to predict success on a trial of extubation in 40 patients with COPD but found none to be of any value (Table 10).

Two groups of investigators evaluated predictors of success in trials of unassisted breathing followed by extubation in two relatively small studies (N = 26 and N = 31) (Table 11).[54,55] A gastric intramucosal pH > 7.3 and a gastric intramucosal Pa_{CO_2} < 60 mm Hg showed some promise as weaning predictors in a study of 26 patients.

Table 9—*Pooled Results for Predictors of Trials of Unassisted Breathing Followed by Extubation**

Predictor	Study/Threshold	Study LR + (95% CI)	Summary LR +(95% CI)	Summary LR −(95% CI)	Summary Sensitivity (95% CI)	Summary Specificity (95% CI)
V̇E	Sahn and Lakshminarayan[49]/10 L/min	1.82 (1.17–2.82)	1.36 (0.93–1.98)	0.45 (0.20–1.01)	0.79 (0.65–0.93)	0.44 (0.26–0.63)
Binary data	Yang and Tobin[52]/15 L/min	0.95 (0.74–1.22)				
	Gandia and Blanco[51]/12.5 L/min	2.37 (0.93–6.05)				
	Jacob et al[50]/10 L/min	1.28 (0.85–1.94)				
Continuous data	Capdevila et al[45]/12 L/min	0.95 (0.49–1.85)	0.87 (0.68–1.12)	1.33 (0.90–1.96)	0.61 (0.35–0.88)	0.30 (0.14–0.45)
	Vallverdu et al[47]/12 L/min	0.72 (0.59–0.89)				
	Krieger et al[43]/12 L/min	1.04 (0.90–1.20)				
	Ashutosh et al[48]/12 L/min	0.79 (0.46–1.36)				
RR	Ashutosh et al[48]/38 breaths/min	1.63 (1.08–2.47)	1.50 (1.23–1.83)	0.23 (0.12–0.44)	0.93 (0.87–0.99)	0.45 (0.25–0.65)
Binary data	Yang and Tobin[52]/38 breaths/min	1.42 (1.06–1.90)				
	Mohsenifar et al[44]/38 breaths/min	1.37 (0.95–1.99)				
	Gandia and Blanco[51]/35 breaths/min	3.01 (1.21–7.50)				
Continuous data	Capdevila et al[45]/38 breaths/min	1.01 (0.89–1.15)	1.07 (1.00–1.15)	0.15 (0.05–0.50)	0.99 (0.98–1.00)	0.07 (0.02–0.13)
	Vallverdu et al[47]/38 breaths/min	1.14 (1.05–1.24)				
	Krieger et al[43]/38 breaths/min	1.04 (0.96–1.13)				
VT	Ashutosh et al[48]/325 mL	1.67 (0.93–2.98)	1.58 (1.20–2.08)	0.29 (0.14–0.63)	0.89 (0.80–0.98)	0.46 (0.29–0.63)
Binary data	Yang and Tobin[52]/325 mL	2.06 (1.39–3.06)				
	Mohsenifar et al[44]/325 mL	1.23 (0.91–1.66)				
	Gandia and Blanco[51]/360 mL	1.75 (0.90–3.43)				
Continuous data	Capdevila et al[45]/325 mL	1.20 (0.86–1.68)	1.16 (1.01–1.34)	0.74 (0.54–0.99)	0.76 (0.61–0.90)	0.35 (0.27–0.43)
	Vallverdu et al[47]/325 mL	1.18 (0.99–1.41)				
	Krieger et al[43]/325 mL	1.07 (0.77–1.47)				
VT standardized to weight	Farias et al[46]/4 mL/kg	1.64 (1.13–2.37)	1.58 (1.25–2.00)	0.17 (0.07–0.37)	0.93 (0.89–0.97)	0.42 (0.34–0.49)
(binary data)	Yang and Tobin[52]/4 mL/kg	1.55 (1.14–2.10)				
RSBI (binary data)	Gandia and Blanco[51]/105 breaths/min/L	1.52 (0.94–2.47)	1.58 (1.30–1.90)	0.22 (0.13–0.37)	0.92 (0.87–0.97)	0.47 (0.33–0.60)
	Jacob et al[50]/100 breaths/min/L	1.47 (1.03–2.10)				
	Vallverdu et al[47]/100 breaths/min/L	1.41 (1.20–1.66)				
	Yang and Tobin[52]/105 breaths/min/L	2.65 (1.63–4.32)				
	Mohsenifar et al[44]/105 breaths/min/L	1.37 (0.95–1.99)				
	Capdevila et al[45]/60 breaths/min/L	2.69 (1.08–6.67)				
NIF (binary data)	Jacob et al[50]/20 cm H_2O	1.05 (0.90–1.24)	1.32 (0.92–1.90)	0.14 (0.03–0.68)	0.97 (0.93–1.00)	0.46 (− 0.11–1.03)
	Ashutosh et al[48]/25 cm H_2O	2.45 (1.21–4.99)				
	Sahn and Lakshminarayan[49]/25 cm H_2O	35.8 (2.33–550)				
	Mohsenifar et al[44]/20 cm H_2O	1.11 (0.89–1.40)				
PImax	Gandia and Blanco[51]/23 cm H_2O	3.01 (1.21–7.50)	1.38 (0.92–2.08)	0.34 (0.19–0.60)	0.87 (0.72–1.02)	0.42 (0.07–0.77)
Binary data	Yang and Tobin[52]/15 cm H_2O	1.12 (0.98–1.29)				
	Capdevila et al[45]/50 cm H_2O	1.38 (0.85–2.24)				
	Vallverdu et al[47]/20 cm H_2O	1.01 (0.97–1.06)	1.03 (0.95–1.11)	0.51 (0.25–1.06)	0.94 (0.86–1.02)	0.12 (− 0.05–0.29)
Continuous data	Krieger et al[43]/20 cm H_2O	1.13 (0.94–1.37)				
$P_{0.1}$ (binary data)	Gandia and Blanco[51]/3.4 cm H_2O	2.24 (0.87–5.75)	2.25 (1.18–4.32)	0.35 (0.18–0.67)	0.75 (0.64–0.87)	0.72 (0.49–0.95)
	Vallverdu et al[47]/4.5 cm H_2O	1.68 (1.31–2.15)				
	Capdevila et al[45]/5.0 cm H_2O	7.51 (1.66–33.9)				
$P_{0.1}$/PImax	Gandia and Blanco[51]/0.09	10.3 (0.66–162)	16.3 (2.35–113)	0.15 (0.01–3.08)	0.69 (0.12–1.25)	0.96 (0.93–1.00)
(binary data)	Capdevila et al[45]/0.09	25.3 (1.67–383)				

*See Tables 2 and 3 for abbreviations not used in the text.

Finally, Table 12[56–58] summarizes studies evaluating the prediction of successful extubation at 4 months in patients with COPD. Menzies et al[56] examined the predictive power of a number of variables that were recorded in COPD patients in the first 3 days after their admission to an ICU. The investigators recorded variables immediately before a trial of unassisted breathing through a ventilator circuit. Nava et al[57] enrolled only COPD patients who resided in a rehabilitation unit and who had received mechanical ventilation for at least 21 days. They examined the predictive power of variables recorded between 5 and 10 days after hospital admission during a period of clinical stability. The investigators almost invariably presented their results as differences in means and SDs between groups that did or did not wean from mechanical ventilation, a format that is not easily applied to patient-care decisions.

Weaning Predictors in the CVICU

Two groups of investigators[59,60] have studied predictors for trials of unassisted breathing in the CVICU (Table 13). Neither report included threshold values that could be applied in the clinical arena, rather, all results were

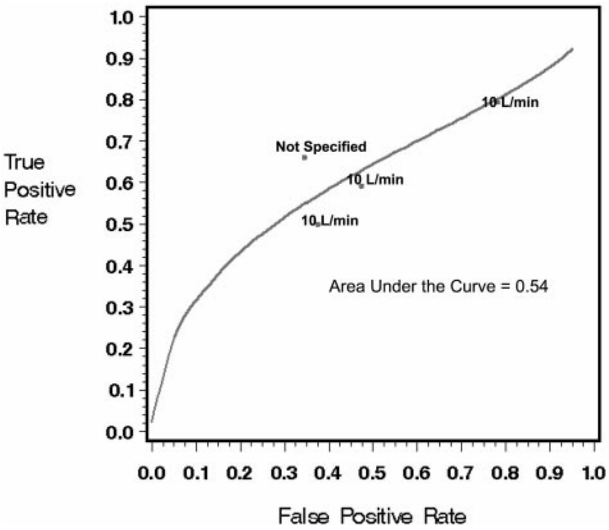

FIGURE 1. Summary ROC curve for minute ventilation predicting successful extubation.

presented as means and SDs among patients who passed and failed trials of unassisted breathing. The investigators found a large number of predictor variables that were associated with successful trials.

Table 14[61,62] presents predictors of successful extubation, which also have been studied by two separate groups of investigators. Once again, there appears to be a large number of variables that are associated with successful extubation, although the investigators do not provide any threshold values.

In a single study of 23 CVICU patients, Saito et al[63] evaluated $P_{0.1} < 4.0$ cm H_2O as a predictor of success on a trial of unassisted breathing followed by successful extubation. Their measure had a sensitivity of 100% and a specificity of 56% (LR for a positive result, 2.3; and LR for a negative result, 0).

Another single study[64] of 230 patients evaluated predictors for successful extubation within 24 h of the patient undergoing cardiovascular surgery. The authors presented their results as differences in means and SDs in those patients who successfully underwent extubation by 24 h after surgery and those who did not. Successfully extubated patients had a statistically significant larger vital capacity, a shorter operating room time, and a higher Pa_{CO_2} level, but the differences between groups were small. Patients who were successfully extubated had a mean American Society of Anesthesia

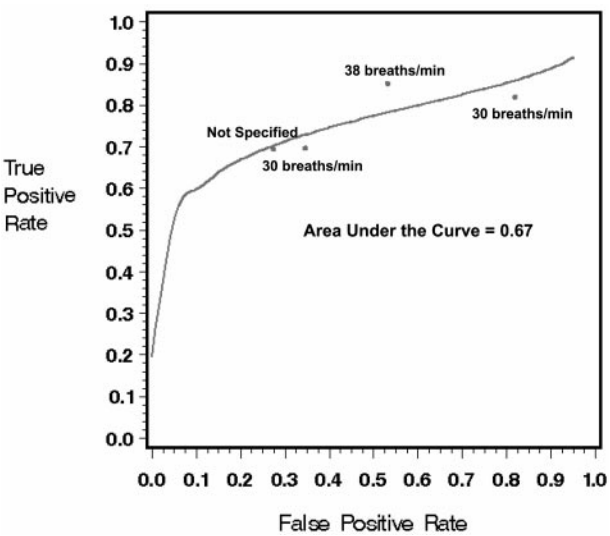

FIGURE 2. Summary ROC curve for RR predicting successful extubation.

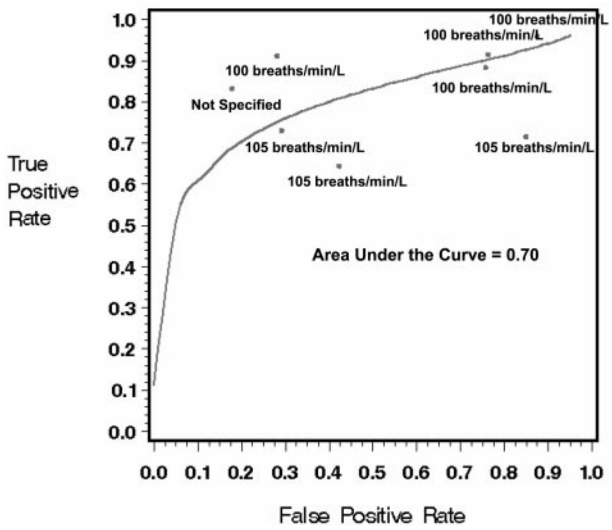

FIGURE 3. Summary ROC curve for RSBI predicting successful extubation.

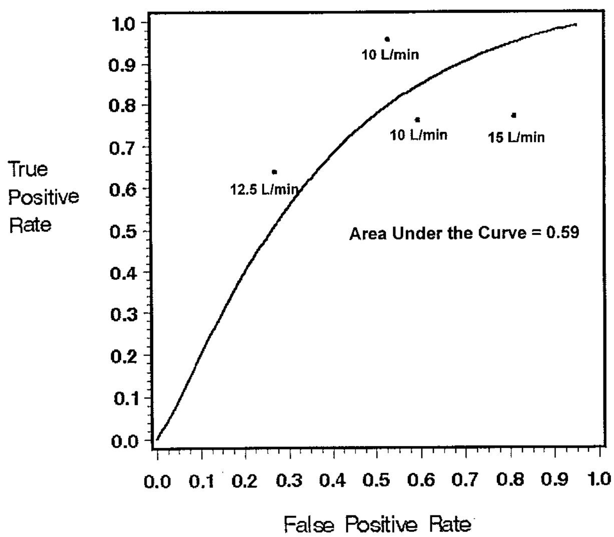

FIGURE 4. Summary ROC curve for minute ventilation predicting successful trials of unassisted breathing.

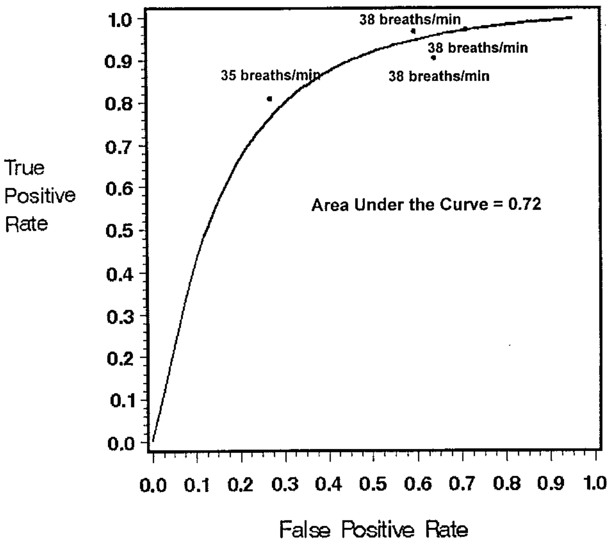

FIGURE 5. Summary ROC curve for RR predicting successful trials of unassisted breathing and extubation.

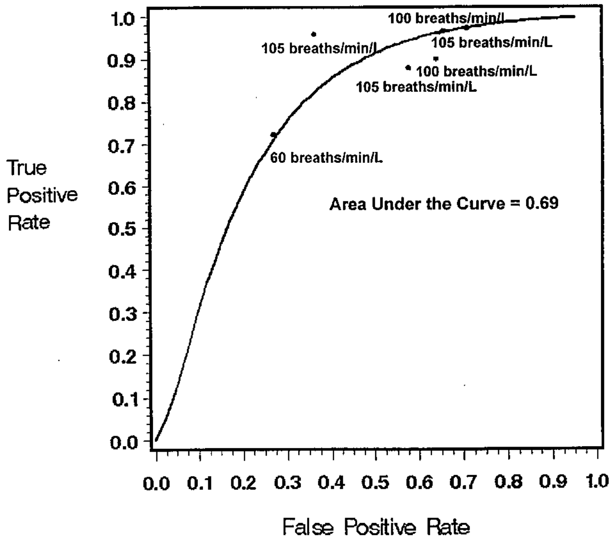

FIGURE 7. Summary ROC curve for RSBI predicting successful trials of unassisted breathing and extubation.

surgical risk score of 1.5, while those patients who were not extubated successfully by 24 h after surgery had a surgical risk score of 3.3.

A separate group of 10 studies (Table 15)[65–74] evaluated the ability of variables to predict the duration of mechanical ventilation following cardiac surgery. The predictor variables considered included those related to preoperative morbidity (*eg*, prior myocardial infarction), pre-ICU respiratory mechanics (*eg*, FEV_1 percent predicted), surgical issues (*eg*, second cardiac surgery procedures), and postoperative events (*eg*, new Q waves on ECG). In general, this table provides information about which variables might be the most important to consider, although the relative importance of each variable, and the threshold values of importance for each variable, were not available. The variables with the greatest potential include just one preoperative variable (preoperative length of stay), one intraoperative variable (fentanyl dose), and a number of postoperative variables (duration of mechanical ventilation prior to weaning, maximum expiratory pressure, presence of new Q waves, degree of bleeding and RBC transfusion, and decreased cardiac output). The only variable that was examined in more than one study was whether patients had undergone coronary artery bypass surgery. The results suggest only a small decrease in the probability of successful extubation (LR, 0.42; 95% CI, 0.24 to 0.75) for patients who had undergone a procedure other than coronary artery bypass grafting (CABG).

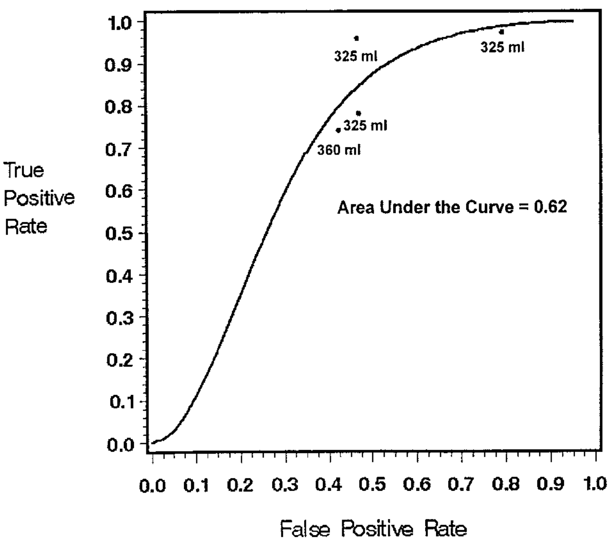

FIGURE 6. Summary ROC curve for tidal volume predicting successful trials of unassisted breathing and extubation.

CONCLUSION

Studies have evaluated an extraordinarily diverse collection of variables for their ability to predict successful weaning and/or duration of mechanical ventilation. Many of these physiologic predictors already have provided great insights into the mechanisms of the failure of liberation. However, from a clinical point of view, the results are disappointing. First, a large number of predictors were found to be of no use in predicting the results of weaning. We found few predictors (1) that had been studied in > 50 patients and (2) for which investigators presented data that allowed estimates of the predictive power, and (3) had, at least in some studies, appreciable predictive power. Of these predictors, none are extremely powerful, and their results are not consistent across studies.

Only twice, after pooling, did we observe an LR of > 10 or < 0.1. The $P_{0.1}$/PImax ratio was highly predictive of trials of unassisted breathing and extubation in two studies, with a pooled LR of 16.3 (95% CI, 2.35 to 113). Most

Table 10—*Predictors of Successful Extubation in Patients With COPD*

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
RR, breaths/min	General COPD	Hilbert et al[53]/1998	40	24 ± 5* 25 ± 5	0.56
RSBI, breaths/min/L	General COPD	Hilbert et al[53]/1998	40	60 ± 2* 66 ± 28†	0.27
$P_{0.1}$, cm H_2O	General COPD	Hilbert et al[53]/1998	40	2.4 ± 0.9* 2.9 ± 0.7†	0.09
Effective inspiratory impedance	General COPD	Hilbert et al[53]/1998	40	5.2 ± 1.2* 6.1 ± 1.3†	0.04
PaO_2/FIO_2	General COPD	Hilbert et al[53]/1998	40	248 ± 62* 241 ± 56†	0.73

*Mean ± SD of success.
†Mean ± SD of failure.

of the remaining tests did not bear results that are very helpful in increasing or decreasing the probability of success. We did not observe any pooled LRs between 5 and 10, although we did observe five variables with LRs < 0.2, indicating that a negative test result is associated with a moderate reduction in the probability of weaning. These variables for the combined end point of a successful trial of unassisted breathing followed by successful extubation included the following: an RSBI < 100 breaths/min/L for trials of unassisted breathing; the compliance/

Table 11—*Predictors of Successful Trials of Unassisted Breathing and Extubation in Patients With COPD**

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
Duration of mechanical ventilation prior to weaning, h	Infectious COPD exacerbation	Bouachour et al[54]/1996	26	8 ± 4† 11 ± 7‡	0.19
	General COPD	Jubran and Tobin[55]/1997	31	10.79 ± 3.26§ 25.12 ± 9.49‖	0.20
RR, breaths/min	General COPD	Jubran and Tobin[55]/1997	31	22.7 ± 1.6§ 34.5 ± 2.6‖	< 0.001
RSBI, breaths/min/L	General COPD	Jubran and Tobin[55]/1997	31	75 ± 11§ 158 ± 20‖	0.001
Intrinsic PEEP, cm H_2O	General COPD	Jubran and Tobin[55]/1997	31	0.7 ± 0.1§ 2.0 ± 0.5‖	0.03
Gastric intramucosal pH > 7.3	Infectious COPD exacerbation	Bouachour et al[54]/1996	26	100¶ 100#	
Gastric intramucosal $PCO_2 < 60$ mm Hg	Infectious COPD exacerbation	Bouachour et al[54]/1996	26	95 (85–105)¶ 100#	
Heart rate, beats/min	Infectious COPD exacerbation	Bouachour et al[54]/1996	26	85 ± 13† 103 ± 22‡	0.02
SBP, mm Hg	Infectious COPD exacerbation	Bouachour et al[54]/1996	26	134 ± 15† 115 ± 17‡	0.01
Pressure time product, cm H_2O/s/min	General COPD	Jubran and Tobin[55]/1997	31	158 ± 23§ 255 ± 59‖	0.17
Inspiratory resistance, cm H_2O/L/s	General COPD	Jubran and Tobin[55]/1997	31	5.3 ± 1.1§ 9.0 ± 1.7‖	0.11
Inspiratory time, s	General COPD	Jubran and Tobin[55]/1997	31	1.16 ± 0.09§ 0.71 ± 0.04‖	< 0.001
Dynamic elastance, cm H_2O/L	General COPD	Jubran and Tobin[55]/1997	31	9.9 ± 1.7§ 21.2 ± 3.4‖	< 0.01
SaO_2, %	Infectious COPD exacerbation	Bouachour et al[54]/1996	26	96 ± 2† 97 ± 1‡	0.25

*SaO_2 = pulse oximetry arterial oxygen saturation. See Tables 2 and 4 for abbreviations not used in the text.
†Mean ± SD of success.
‡Mean ± SD of failure.
§Mean ± SE of success.
‖Mean ± SE of failure.
¶Sensitivity (range).
#Specificity.

Table 12—*Predictors of Extubation Within 4 Months for Patients With COPD*

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
RR, breaths/min	General COPD	Menzies et al[56]/1989	95	26.0*	0.01
				30.7†	
	Tracheostomy; difficult to wean	Nava et al[57]/1994	42	23.5 ± 5.9‡	0.07
				26.4 ± 3.8§	
RSBI, breaths/min/L	Tracheostomy; difficult to wean	Nava et al[57]/1994	42	55.2 ± 16.6‡	0.01
				69.9 ± 20.8§	
NIF, cm H_2O	Tracheostomy; difficult to wean	Nava et al[57]/1994	42	44.0 ± 16.4‡	0.003
				31.3 ± 6.1§	
$P_{0.1}$, cm H_2O	Tracheostomy; difficult to wean	Nava et al[57]/1994	42	3.5 ± 1.3‡	< 0.001
				5.2 ± 0.5§	
FEV_1/FVC, %	Tracheostomy; difficult to wean	Nava et al[57]/1994	42	45 ± 12‡	0.14
				40 ± 9§	
FEV_1, % predicted	General COPD	Menzies et al[56]/1989	95	7.73‖	
	Tracheostomy; difficult to wean	Nava et al[57]/1994	42	25 ± 14‡	0.27
				21 ± 7§	
Dyspnea	Long-term respiratory-care center	Moody et al[58]/1997	27	35.00 ± 16.52‡	0.05
				49.23 ± 20.19§	
$Pa O_2/F I O_2$	Tracheostomy; difficult to wean	Nava et al[57]/1994	42	231.1 ± 53.3‡	0.08
				201.8 ± 52.5§	
Discriminant function model	Tracheostomy; difficult to wean	Nava et al[57]/1994	42	84 (69–99)¶	
				82 (63–101)#	

*Mean of success.
†Mean of failure.
‡Mean ± SD of success.
§Mean ± SD of failure.
‖β-coefficient.
¶Sensitivity (range).
#Specificity (range).

rate/oxygenation/pressure (CROP) index for trials of extubation and an RR of > 38 breaths/min; tidal volume standardized to body weight; and NIF of < 20 to 25 cm H_2O. Therefore, on balance, the best results achieved with any of these tests were moderate reductions in the probability of successful weaning in association with a negative test result.

The virtual absence of any tests with high LRs (thereby markedly increasing the probability of successful weaning) and the less infrequent occurrence of tests with LRs substantially < 1 (thereby appreciably decreasing the likelihood of successful weaning) corresponds to tests with high sensitivity (*ie*, > 90%) but unimpressive specificity. Again, this corresponds to positive test results that do not increase the likelihood of success substantially and to negative test results that sometimes decrease the probability of success appreciably. For example, assuming a pretest probability of success of 50%, a high RR (*ie*, > 38 breaths/min; LR, 0.32) will decrease the probability of success in reducing mechanical ventilation support from 50% to approximately 25%, the probability of success in a trial of unassisted breathing (LR, approximately 0.2) to approximately 20%, and the probability of success in a trial of extubation (LR, approximately 0.55) to approximately 33%.

The most frequently studied test, and one of the most powerful, is the RSBI. Pooled results for this test consistently show that a positive result (*ie*, a breathing pattern that is neither rapid nor shallow) is minimally helpful in increasing the probability of successful weaning. LRs from individual studies are usually < 2, meaning that the pretest probability of 50% will rise no higher than 66%. Considering the pooled data, the LR for the RSBI at predicting successful trials of unassisted breathing was 1.7, the LR for predicting successful extubation was between 1.3 and 1.8 (the latter value occurs when the variable is indexed to body weight), and the LR for predicting successful trials of unassisted breathing and extubation was as high as 2.8.

LRs associated with a negative result (*ie*, breathing that tends to be rapid and shallow) were 0.11 for predicting unassisted breathing, 0.39 for successful extubation, and 0.22 for the combined end point of unassisted breathing and extubation. These LRs correspond to decreases in the probability of success from 50% to 10%, 28%, and 18%, respectively.

Another observation about these studies is that measurement techniques often have differed across studies; large coefficients of variations have been demonstrated when different investigators make these measurements.[77] An additional challenge is the absence of

Table 13—*Predictors of Successful Trials of Unassisted Breathing in the CVICU**

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
Duration of mechanical ventilation prior to weaning, h	Mixed CVS	Hilberman et al[59]/1976	124	13.4 (11.5)† 23.7 (26.9)‡	0.004
Gross alveolar ventilation, mL	Pediatric and adult CVS	Delooz[60]/1976	41	229.0 (61.1)† 160.8 (42.7)‡	< 0.001
VT, mL	Pediatric and adult CVS	Delooz[60]/1976	41	469 (151)† 371 (111)‡	0.03
VC					
L	Mixed CVS	Hilberman et al[59]/1976	124	1.30 (0.63)† 0.79 (0.30)‡	< 0.001
mL/kg	Mixed CVS	Hilberman et al[59]/1976	124	18.3 (7.2)† 11.9 (4.0)‡	< 0.001
% predicted preoperatively	Mixed CVS	Hilberman et al[59]/1976	124	90.7 (13.7)† 71.3 (21.9)‡	< 0.001
NIF, cm H_2O	Mixed CVS	Hilberman et al[59]/1976	124	30.7 (8.8)† 24.3 (9.4)‡	0.001
Inspiratory resistance, cm H_2O/L/s	Mixed CVS	Hilberman et al[59]/1976	124	7.2 (2.7)† 9.1 (2.6)‡	0.001
Compliance, L/cm H_2O	Mixed CVS	Hilberman et al[59]/1976	124	0.05 (0.01)† 0.04 (0.02)‡	< 0.001
DLCO, % predicted	Mixed CVS	Hilberman et al[59]/1976	124	98.9 (1.7)† 104.6 (21.3)‡	0.01
pH	Pediatric and adult CVS	Delooz[60]/1976	41	7.41 (0.04)† 7.38 (0.05)‡	0.04
	Mixed CVS	Hilberman et al[59]/1976	124	7.47 (0.06)† 7.46 (0.07)‡	0.46
Pa_{CO_2}, mm Hg	Pediatric and adult CVS	Delooz[60]/1976	41	38.0 (3.4)† 41.7 (6.9)‡	0.03
	Mixed CVS	Hilberman et al[59]/1976	124	35.2 (4.9)† 36.6 (7.6)‡	0.25
Pulmonary arterial pressure, mm Hg	Pediatric and adult CVS	Delooz[60]/1976	41	24.0 (11.6)† 31.1 (13.8)‡	0.08
Pulmonary vascular resistance index, dynes·s·cm^{-5}	Pediatric and adult CVS	Delooz[60]/1976	41	507 (287)† 810 (648)‡	0.05

*DLCO = diffusing capacity of the lung for carbon monoxide. See Table 2 for abbreviations not used in the text.
†Mean (SD) of success.
‡Mean (SD) of failure.

objective criteria to determine the tolerance for a trial of discontinuation or extubation, and the variation across studies.

Why do most of these tests perform so poorly, and why do so few provide helpful information? The likely explanation is that clinicians already have considered the results when they choose patients for trials of weaning. For instance, clinicians may seldom test patients who have very high RRs, who are capable of generating only very low pressures, or patients whose tidal volumes are very low for their ability to wean. Similarly, clinicians may not wait until the RR, tidal volume, or pressure generation is normal before they undertake weaning, for this would lead to excessive time spent receiving mechanical ventilation. Thus, the range of results is relatively narrow. The more narrow the range of results, the less likely that a test can discriminate between patients destined to fail a weaning trial and those destined to succeed.

Furthermore, when results of a single test are more extreme, it is likely that physicians are attempting to wean the patient only because other observations suggest the limited impact of an isolated aberrant finding. For instance, adequate tidal volume and pressure generation may indicate to a clinician that an elevated RR is due largely to patient anxiety and does not indicate that the patient will be unable to be weaned from mechanical ventilation.

In essence, this means that the predictive power of the tests is "used up" by the time that investigators formally test their properties in patients that clinicians already have decided are candidates for weaning. Thus, it is unrealistic

Table 14—*Predictors of Successful Extubation in the CVICU**

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
Duration of mechanical ventilation prior to weaning, h	Mixed CVS	Engoren et al[61]/1999	82	6.0 (4.7–12.7)† 15.5 (8.2–19.5)‡	< 0.05
$\dot{V}_E$, mL/min/kg	Mixed CVS	Engoren et al[61]/1999	82	105 ± 28§ 91 ± 27‖	0.003
V_T, mL	Mixed CVS	Engoren et al[61]/1999	82	533 ± 173§ 457 ± 131‖	0.03
VC					
L	Mixed CVS	Engoren et al[61]/1999	82	0.12¶	0.01
mL/kg	Mixed CVS	Engoren et al[61]/1999	82	15.6 ± 6.2§ 11.5 ± 3.9‖	< 0.001
NIF, cm H_2O	Mixed CVS	Engoren et al[61]/1999	82	42 ± 8§ 38 ± 10‖	0.05
F_{IO_2}	Mixed CVS	Engoren et al[61]/1999	82	0.53 ± 0.08§ 0.61 ± 0.19‖	0.02
Total operating room time, h	Mixed CVS	Engoren et al[61]/1999	82	6.79¶	0.02
	Mixed CVS	Rady and Ryan[62]/1999	11,330	5.2 ± 1.5§ 6.5 ± 3.1‖	< 0.001
Total bypass time, min	Mixed CVS	Rady and Ryan[62]/1999	11,330	108 ± 46§ 136 ± 75‖	< 0.001
Arterial grafts	Mixed CVS	Engoren et al[61]/1999	82	3 (2–4)† 3 (2–4)‡	1.00
CABG	Mixed CVS	Rady and Ryan[62]/1999	11,330	42 (41–42)# 41 (37–44)**	

*See Table 2 for abbreviations not used in the text.
†Median (interquartile range) of success.
‡Median (interquartile range) of failure.
§Mean ± SD of success.
‖Mean ± SD of failure.
¶Multivariate OR.
#Sensitivity (range).
**Specificity (range).

to expect physiologic tests to be highly predictive in patients in whom clinicians judge to have an intermediate probability of weaning success.

Future Research

LRs provide the best format for presenting the results of weaning predictors, and future research should consider this presentation metric. Sensitivity and specificity provide common, but less easily applied, measures of predictive power. Reporting only means and measures of variance for groups that have undergone successful and unsuccessful weaning, or reporting regression coefficients and p values, is far less useful in terms of clinical application.

The results of these studies would be more helpful to clinicians if data were reported related to multiple cut points for a given variable, rather than a single cut point. For instance, rather than reporting success rates in patients with RRs of > 36 breaths/min and < 36 breaths/min, investigators should report success rates in patients with RRs of < 20, 21 to 28, 29 to 36, 36 to 44, and > 44 breaths/min. These cut points are obviously somewhat arbitrary. The point is that since extreme results may be highly predictive, intermediate results may be somewhat predictive, and results at the margin may not be predictive at all. The use of a single cut point or threshold obscures this important information.

Having said this, investigators and clinicians should not expect any test to be particularly powerful. The findings to date validate the clinical intuition. Once clinicians have decided that a patient is likely but not certain to be weaned from mechanical ventilation, a formal examination of physiologic tests that the clinician has in some way considered in making the decision about pretest probability is unlikely to be very helpful.

As we point out elsewhere in this supplement, formal weaning protocols may perform better than usual clinical care. When the predictors of weaning are incorporated in such protocols, they retain their full predictive power, because clinicians have not already used them to select a subgroup of patients whom they are considering for weaning. We believe that, at least in clinical research, further testing of formal weaning protocols represents the

Table 15—*Predictors of Duration of Mechanical Ventilation Following Cardiac Surgery**

Predictor	Population	Study/yr	Patients, No.	Predictive Power	Reported p Value
Duration of mechanical ventilation prior to weaning, h	Mixed CVS	Hanneman[65]/1994	162	11 ± 5† 88 ± 9‡	< 0.001
Failed extubation	Pediatric CVS	Kanter et al[66]/1986	140	§	< 0.005
VC					
L	Elective CVS	Peters et al[67]/1979	49	3.2 ± 1.1† 2.4 ± 0.9‡	0.02
	Mixed CVS	Bando et al[68]/1997	586	‖	0.36
ml/kg	Mixed CVS	Hanneman[65]/1994	162	14.2 ± 5† 11 ± 4‡	0.001
% predicted preoperatively	Elective CVS	Ingersoll and Grippi[69]/1991	47	59.6 ± 15.3† 71.9 ± 13.9‡	0.02
	Mixed CVS	Bando et al[68]/1997	586	‖	0.41
Maximum expiratory pressure, cm H_2O	Elective CVS	Peters et al[67]/1979	49	68 ± 24† 47 ± 26‡	0.01
F_{IO_2}	Mixed CVS	Hanneman[65]/1994	162	0.61 ± 0.09† 0.72 ± 0.17‡	< 0.001
$MMEF_{50-75}$, L/min	Elective CVS	Peters et al[67]/1979	49	1.8 ± 1.0† 1.1 ± 0.6‡	0.02
$MMEF_{75-85}$, L/min	Elective CVS	Peters et al[67]/1979	49	0.9 ± 0.5† 0.5 ± 0.2‡	0.006
Preoperative length of hospital stay, d	Elective CVS	Ingersoll and Grippi[69]/1991	47	6.3 ± 6.7† 12.2 ± 10.8‡	0.03
Preoperative mechanical ventilation	Pediatric CVS	Kanter et al[66]/1986	140	§	< 0.05
Preoperative diuretics	CABG	Arom et al[70]/1995	645	0.68¶	0.001
Perioperative intra-aortic balloon pump	CABG	Habib et al[71]/1996	507	2.55 (1.10–5.92)#	0.03
Total operating room time, h	Elective, fast-track CVS	London et al[72]/1998	299	4.9 ± 1.0† 5.4 ± 1.3‡	0.001
Total bypass time, min	CABG	Doering et al[73]/1998	116	0.01**	
	Elective, fast-track CVS	London et al[72]/1998	299	115 ± 28† 134 ± 39‡	0.001
Arterial grafts	Elective, fast-track CVS	London et al[72]/1998	299	0.32 (0.14–0.72)#	0.006
Second surgical procedure	Pediatric CVS	Kanter et al[66]/1986	140	0.005††	0.005
Priority operation	Mixed CVS	Bando et al[68]/1997	586	0.005††	0.005
CABG	Elective CVS	Peters et al[67]/1979	49	71 (56–87)‡‡ 71 (45–97)§§	
	CABG	Doering[74]/1997	62	91 (72–110)‡‡ 26 (13–38)§§	
	Elective, fast-track CVS	London et al[72]/1998	299	0.5 (0.24–1.06)#	0.07
Core intraoperative temperature, °C	CABG	Arom et al[70]/1995	645	32.7 ± 1.7† 30.6 ± 2.8‡	< 0.001
	CABG	Habib et al[71]/1996	507	35.3 ± 2.8† 34.8 ± 2.2‡	0.03
DLCO, % predicted	Mixed CVS	Bando et al[68]/1997	586	0.68††	0.68
New Q waves	Mixed CVS	Bando et al[68]/1997	586	27 ± 38† 75 ± 150‡	< 0.001
Bleeding	Mixed CVS	Bando et al[68]/1997	586	28 ± 44† 86 ± 171‡	< 0.001
Homologous RBCs administered	CABG	Habib et al[71]/1996	507	2.41 (1.48–3.94)#	< 0.001
	Elective, fast-track CVS	London et al[72]/1998	299	16.4‖‖ 45.5¶¶	< 0.001
Platelets administered	Elective, fast-track CVS	London et al[72]/1998	299	10.03 (2.01–50.20)#	0.005
Decreased cardiac output	Mixed CVS	Bando et al[68]/1997	586	26 ± 30† 81 ± 151‡	< 0.001
Unstable angina	CABG	Arom et al[70]/1995	645	0.43##	0.03
Fentanyl use	Elective, fast-track CVS	London et al[72]/1998	299	3.41 (0.69–16.88)#	0.13
Fentanyl dose, μg/kg	Elective, fast-track CVS	London et al[72]/1998	299	35.6 ± 12.4† 45.5 ± 22‡	0.002

(*Table continues*)

Table 15—*Continued*

Predictor	Population	Study/Year	Patients, No.	Predictive Power	Reported p Value
Inotropes	Elective, fast-track CVS	London et al[72]/1998	299	5.73 (1.76–18.66)#	0.004
pH	Mixed CVS	Hanneman[65]/1994	162	7.41 ± 0.06†	< 0.001
				7.35 ± 0.08‡	
Study-derived predictive index	Pediatric CVS	Kanter et al[66]/1986	140	57 (48–66)‡‡	
				95 (84–105)§§	
CHF/pulmonary edema	Mixed CVS	Bando et al[68]/1997	586	0.105##	0.01
Coma	Mixed CVS	Bando et al[68]/1997	586	0.296##	< 0.001

*$MMEF_{50-75}$ = maximal midexpiratory flow measured between 50% and 75% of expired volume; $MMEF_{75-85}$ = maximal midexpiratory flow between 75% and 85% of expired volume; CHF = congestive heart failure. See Tables 2 and 13 for abbreviations not used in the text.
†Mean ± SD of success.
‡Mean ± SD of failure.
§Multivariate β-p value.
‖Univariate β-p value.
¶β-value.
#Multivariate OR (95% CI).
**Univariate β-coefficient.
††β-p value.
‡‡Sensitivity (range).
§§Specificity (range).
‖‖Mean of success.
¶¶Mean of failure.
##Multivariate β-coefficient.

best step forward, rather than focusing exclusively on testing physiologically predictive information to optimize the weaning process.

The data included in this systematic review and a more comprehensive discussion of the original articles are included in an Evidence Report of the Agency for Healthcare Research and Quality.[78]

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