Determinants of Weaning and Survival Among Patients with COPD Who Require Mechanical Ventilation for Acute Respiratory Failure*

Richard Menzies, M.D.;† William Gibbons, M.D.;‡ and Peter Goldberg, M.D.

The decision to institute MV in patients with COPD and ARF is difficult because the risk of complications is high and the long-term prognosis is poor. We reviewed our experience with 95 COPD patients with ARF requiring MV. Fifty-five patients required MV for more than two weeks, 72 were weaned successfully, and 59 died within one year of follow-up. Survival was associated with premorbid level of activity (p<.001), FEV₁ (p<.01), serum albumin level (p<.05), and severity of dyspnea (p<.01). Cor pulmonale on ECG, premorbid hypercarbia, and history of left ventricular failure were also more common among those who died. Weaning from MV was associated with premorbid level of activity (p<.001), FEV₁ (p<.001), albumin level (p<.05), and negative inspiratory pressure (p<.001) and respiratory rate during T-piece trial (p<.01). The duration of intubation was associated only with premorbid level of activity (p<.01). Predictive models for the weaning success and the one-year survival were developed.

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The prognosis of patients with advanced COPD is poor.¹-³ Among patients followed prospectively, survival varies from 66 to 93 percent after three years¹-⁴ and from 25 to 50 percent after ten years.⁵ In these studies the only clinical factor consistently associated with survival was the severity of airflow obstruction.¹-³⁵ Among patients with COPD who are hospitalized with ARF, mortality after one year ranges from 26 percent,⁶ if MV is not required, to 51 to 62 percent among patients who required MV.⁶,⁷,⁸,¹⁰,¹³ No clinical factors were consistently associated with survival in four studies that reported such analysis,⁶,⁷,¹⁰,¹¹ so that determinants of outcome in these patients remain unclear. To our knowledge, factors associated with difficulty in weaning from MV have been reported in only one study of post-open heart surgical patients.¹⁴ Studies of predictors of weaning among patients with COPD have focused on identifying which patients among those already receiving MV are ready to be weaned.¹⁵,¹⁶

Clinicians caring for a patient with advanced COPD and ARF must weigh the potentially lifesaving advantages of MV against its risks. The decision to institute MV in this situation is based on the physician's estimate of the outcome of the patient after MV⁹,¹²,¹³ which may be grossly inaccurate.¹¹,¹²,²² We have reviewed our experience with 95 consecutive patients with COPD and ARF who required MV over a 30-month period. The objectives of the study were to determine the outcomes of these patients; to identify the factors associated with intubation duration, weaning, and survival; and to develop predictive models for these three outcomes.

Material and Methods

Patient Selection

All patients with COPD admitted to the ICU of the Montreal Chest Hospital between July 1, 1984, and Feb 28, 1987, with ARF requiring MV were potential participants. Criteria for institution of MV were not reviewed. Patients with ARF related to musculoskeletal, neuromuscular, neurologic, or cardiac disease were excluded, as were those with diagnosed metastatic or otherwise untreatable cancer or other pulmonary disease such as cystic fibrosis or interstitial lung disease.

Data Collection

Admission records from our ICU were reviewed to identify all those who received MV during the study period. The hospital records of these patients were reviewed to determine eligibility. Records of eligible patients were reviewed by a research assistant who was unaware of the study objectives, and used a standardized data gathering form for abstracting information. The FEV₁, ECG, and ABGs were recorded if these had been measured while the patient was clinically stable within the two preceding years.

The following definitions were used in the data collection: (1) Survival—alive at one year or at last follow-up if less than one year, counted from date of weaning. (2) Weaning success—survival for at least 72 hours without MV. Weaning failure—death while on MV (or within 72 hours) or failure to wean after four months. (3) COPD—postbronchodilator or best recorded FEV₁ less than 70 percent predicted, with FEV₁/FVC less than 0.7 measured. Radiographic evidence of hyperinflation or typical clinical history of chronic cough and dyspnea in a smoker combined with compatible physical signs such as wheezing were accepted as supportive of the diagnosis of COPD, in the absence of lung function measurements, in 16 patients. (4) Cor pulmonale on ECG—presence of any one of the following three criteria: (i) "p pulmonale" or (ii) right ventricular hypertrophy or (iii) right axis deviation, according to the criteria of

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Weaning and Survival in COPD Patients (Menzies, Gibbons, Goldberg)
Left ventricular failure—documented history of pulmonary edema supported by radiographic and clinical evidence or compatible wedge pressure measurements with a Swan-Ganz catheter\(^*\) or a left ventricular ejection fraction on gated nuclear scan of less than 40 percent (institutional normal mean is 62 ± 10 percent [SD]). \(6\) Myocardial infarction—documented past history or unequivocal evidence on present ECG. \(7\) Hypoxemia—PaO\(_2\) less than 55 mm Hg, patient breathing room air and judged to be clinically stable. \(8\) Hypercarbia—Pco\(_2\) over 45 mm Hg, patient judged to be clinically stable. \(9\) Causes of respiratory failure—(i) exacerbation of COPD: no other cause found, (ii) pneumonia; new airspace disease on chest x-ray film and one or more of either: fever or leukocytosis or positive blood culture or unequivocal radiographic response to antibiotic therapy; (iii) pulmonary edema: typical radiographic appearance and radiographic and clinical response to diuretic therapy or compatible wedge pressure measurements with a Swan-Ganz catheter.\(^*\)

The following information was abstracted: age, sex, body height and weight, smoking history, comorbid illnesses, and medications. Premorbid dyspnea, scored according to the ATS scale,\(^*\) and activities of daily living were recorded. The latter was scored:

0 = Working
1 = Independent—fully ambulatory and living without any assistance
2 = Restricted—able to live on their own and get out of their homes to do basic necessities, but severely limited in exercise ability
3 = Housebound—cannot get out of the house unassisted or get out of the house rarely; able to perform self-care but unable to do heavy chores such as housecleaning; cannot live alone; may be institutionalized
4 = Bed- or chair-bound

The premorbid laboratory data recorded included results of ECG, lung function, and ABGs, as well as admission data such as hemoglobin and serum albumin level. The cause of ARF and the ventilator readings were noted over the first three days.

All patients received ventilation with Bypenn MA1 or MA2 + 2 volume-cycled respirators using the CMV mode. They were weaned using intermittent T-piece trials, the duration of which was increased incrementally each day. Before each T-piece trial, the maximum NIP was measured with a hand-held aneroid manometer during voluntary maximal inspiratory effort against a closed valve.\(^*\) Respiratory frequency (F) and tidal volume (Vt) were also measured over one minute using a Wright's spirometer. The best NIP, F, and Vt values recorded over the first three days of MV were used for analysis.

Information on survival and post-MV activities of daily living, scored as above, was obtained by telephone interview of all surviving patients in November 1986 and July 1987. Death was ascertained from hospital records or by telephone follow-up. Cause of death was not recorded.

### Data Analysis

Data were analyzed using SAS statistical methods (SAS Institute) and BMDP for survival analysis (BMDP Software). Using the two outcomes of survival and weaning as dichotomous dependent variables, bivariate associations were tested for significance using \(\chi^2\) on 2 x 2 contingency tables (for dichotomous), Mantel Hanszel \(\chi^2\) on 2 x 5 contingency tables (for categorical), or independent \(t\) test on the difference of means (for continuous). Life tables were computed using the Kaplan-Meier method.\(^*\) Differences in survival between groups were assessed using the log-rank test.\(^*\) The predictive models were developed using stepwise logistic regression. Variables were tested for significance in the model using the log likelihood ratio test. The hazard function was used to verify the variables used in the predictive model for survival.

### RESULTS

#### Patient Population and Outcomes

During the study period, a total of 260 patients were admitted to our ICU, of whom 50 were admitted because of cardiac disease, including those with ARF owing to congestive heart failure without evidence of COPD. Seventeen patients had ARF related to neurologic or neuromuscular disease, and six patients were admitted because of major GI bleeding and three for miscellaneous reasons. The remaining 184 were admitted with ARF thought to be related primarily to lung disease. Ten patients were excluded, two because they had cystic fibrosis, four had interstitial fibrosis, and four had diagnoses of cancer. Eighty-three were not intubated, leaving 95 patients with ARF requiring MV who met the entry criteria for the study.

Table 1 summarizes the major premorbid characteristics of the 95 study patients. There were 50 males and 45 females, with mean age of 69.6 years. Half of the patients had FEV\(_1\) less than 30 percent of predicted, and 75 percent had FEV\(_1\) less than 45 percent of predicted. Only six patients were working before their admission to hospital, and 54 (57 percent) were confined to their homes. Causes of respiratory failure were judged to be: exacerbation of COPD, 49 percent; pneumonia, 20 percent; pulmonary edema, 7 percent; surgery, 11 percent; and other, 13 percent. There was no statistically significant relationship between cause of ARF and outcome.

Figure 1 summarizes the outcomes in the 95 patients: 72 patients were weaned; 39 in less than 15 days, 17 after 15 to 45 days, seven after 45 to 75 days, and five after 75 to 100 days. Four patients were

<table>
<thead>
<tr>
<th>Table 1—Characteristics of the 95 Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor*</td>
</tr>
<tr>
<td>Age, yr</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Smoking</td>
</tr>
<tr>
<td>% Smokers</td>
</tr>
<tr>
<td>Pack-years</td>
</tr>
<tr>
<td>Lung function</td>
</tr>
<tr>
<td>FEV(_1)</td>
</tr>
<tr>
<td>FEV(_1), % Pred</td>
</tr>
<tr>
<td>Arterial blood gases</td>
</tr>
<tr>
<td>% With Po(_2) &lt;55 mm Hg</td>
</tr>
<tr>
<td>% With Pco(_2) &gt;50 mm Hg</td>
</tr>
<tr>
<td>Cardiac history</td>
</tr>
<tr>
<td>Cor pulmonale on ECG, %</td>
</tr>
<tr>
<td>History of LVF, %</td>
</tr>
<tr>
<td>Albumin level, mg/dl</td>
</tr>
<tr>
<td>Weaning parameters</td>
</tr>
<tr>
<td>Negative inspiratory force, cm H(_2)O</td>
</tr>
<tr>
<td>Tidal volume, ml</td>
</tr>
<tr>
<td>Respiratory rate, breaths/min</td>
</tr>
</tbody>
</table>

*All factors were baseline, measured before MV, except the weaning parameters.

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weaned after more than 100 days of MV, and three remain alive but dependent on MV for over one year. Median duration of intubation was 20 days (range, 2 to 900 days). Twenty patients died while still receiving MV and another 39 died within a year after weaning. Mean follow-up of survivors was 14.3 months, and cumulative survival was 34 percent at one year (Fig 2). Despite significant early mortality, there appears to be a subgroup with prolonged survival and a reasonable quality of life. Among the patients surviving, their level of activity diminished slightly compared with their premorbid levels; lifestyle scores deteriorated by one half category on average. Currently two patients have returned to work, 13 are living independently, 12 are housebound, and only two are bed or chair-bound. Twenty-two patients are living at home, and seven are institutionalized in long-term care facilities.

Prognostic Factors

The major premorbid and postintubation data for those who were and were not weaned are given in Table 2. Significantly different premorbid characteristics between the two groups were: FEV₁, level of activity, severity of dyspnea, and serum albumin level. Cause of respiratory failure, age, sex, body weight index, comorbid illness, and premorbid Po₂, Pco₂, hemoglobin, and ECG findings were not related to weaning outcome. Premorbid level of activity was strongly associated with weaning—of the 19 who were working or independent, all but one were weaned, compared with only 37 of the 54 (68 percent) who were housebound or worse (p < .001). Figure 3, which includes only those patients who had premorbid measurement of FEV₁, shows that of the 25 with FEV₁ over 40 percent of predicted, all were weaned, compared with only 14 of the 25 (56 percent) with FEV₁ less than 25 percent predicted (p < .001).

The NIP, tidal volume, and frequency while on T-piece were strongly associated with weaning outcome. The measures recorded were those from the first three days of MV, even if weaning from MV occurred many days later. Impedance and compliance, calculated using ventilator readings such as peak pressure, flow rate, and tidal volume, were not significantly associated with outcome.

Table 3 summarizes the major premorbid characteristics among the 59 who died compared with the 36...
survivors. Factors significantly different between these two groups were lifestyle score, FEV₁, and serum albumin level. Cause of respiratory failure, age, sex, body weight index, comorbid illness, and history of MI or premorbid hypoxemia were not significantly different between the two groups. There were differences between the two groups with respect to cor pulmonale and history of LVF, which did not quite achieve statistical significance.

Lifestyle score was strongly associated with survival. Figure 4 shows survival curves for patients, grouped by their premorbid levels of activity, which are significantly different (p<.01). Figure 5 shows that of 19 patients who were working or fully independent and ambulatory before MV, only five (26 percent) died, compared with a mortality of 42 of 54 patients (78 percent) who were housebound or worse (p<.001).

The FEV₁ was also highly predictive of survival. Of 25 patients with FEV₁ > 40 percent, 15 survived (60 percent), compared with seven of 25 patients (28 percent) with FEV₁ less than 25 percent of predicted. The effect of FEV₁ on survival can be seen from the life tables for the patients grouped according to their values of FEV₁ (Fig 6).

There was little correlation between premorbid data or postintubation measurements and intubation duration. The only factor that achieved significance was lifestyle score; among the 19 working or fully ambulatory patients, only six required MV for two weeks or more, compared with 35 of the 54 (65 percent) who were housebound or worse (p<.01). Figure 1 shows that prognosis, once weaned, was not affected by the duration of intubation. Of the 39 patients weaned in less than 15 days, 49 percent remain alive, compared with 43 percent of those who required MV for over two weeks.

Premorbid level of activity was the most important determinant of all three outcomes assessed. Table 4 summarizes the relationships of lifestyle category to outcome and several clinical characteristics that were all highly significant.

Predictive Models

Using stepwise logistic regression, we developed

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Table 3—Factors Associated with Survival

<table>
<thead>
<tr>
<th>Factor</th>
<th>Survived (n = 36)</th>
<th>Died (n = 59)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>67</td>
<td>71</td>
</tr>
<tr>
<td>Sex, % M</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>FEV₁, % pred</td>
<td>40</td>
<td>31†</td>
</tr>
<tr>
<td>Albumin, mg/dl</td>
<td>3.2</td>
<td>2.9‡</td>
</tr>
<tr>
<td>Hypoxemia, %</td>
<td>50</td>
<td>49</td>
</tr>
<tr>
<td>Hypercarbia, %</td>
<td>39</td>
<td>56‡</td>
</tr>
<tr>
<td>Cor pulmonale on ECG, %</td>
<td>31</td>
<td>47‡</td>
</tr>
<tr>
<td>History of LVF, %</td>
<td>11</td>
<td>24‡</td>
</tr>
<tr>
<td>Lifestyle score</td>
<td>1.9</td>
<td>2.8§</td>
</tr>
<tr>
<td>Dyspnea severity, ATS index</td>
<td>3.1</td>
<td>3.8†</td>
</tr>
</tbody>
</table>

*All factors are premorbid, measured at baseline before ARF, except the weaning parameters, which were recorded after institution of MV. Differences between groups assessed using independent T tests, χ², and analysis of variance (ANOVA).

†p<.01.
‡p<.05.
§.05<p<.1.
¶p<.001.
predictive models for the outcomes of survival and weaning. The models and their factors, with coefficients and standard errors, are given in the Appendix, as well as examples using two hypothetical patients. The best fitting model for survival employed five factors: lifestyle score, FEV1, albumin level, cor pulmonale, and history of LVF. Two models were developed for weaning. The first, employing premorbid data only, included lifestyle score, FEV1, and albumin level. The second employed all data and included lifestyle score, FEV1, albumin level, and the weaning parameters, NIP and tidal volume. Factors such as age, body weight index, premorbid hypercarbia or hypoxemia, or severity of dyspnea could not be entered into any of these models. As we had found using bivariate analyses, intubation duration could not be predicted using the factors measured, so that no model could be developed for this outcome.

DISCUSSION

The patients in the study population had severe underlying obstructive lung disease and serious impairment before their hospitalization for ARF. Intubation was prolonged in many patients, but 76 percent were weaned successfully. However, only 42 percent of those weaned were alive at one year, so that overall one-year survival was only 32 percent. In studies of initially stable patients with COPD, survival ranged from 88 to 94 percent after one year, and 65 to 80 percent at three years.1-4 In studies restricted to patients with COPD and ARF, success in weaning ranged from 60 to 74 percent and one-year survival from 32 to 49 percent,7-13 figures similar to those reported here.

Burrows and Earle1 studied a population of stable COPD patients and found that resting heart rate, lung function, PaCO2, and cor pulmonale on ECG were associated with long-term survival. In several similar studies reported since, the only consistent finding has been the importance of lung function.5-6 However, these studies were based on a patient population that was more heterogeneous,1,3,4 younger,1-6 and less severely impaired.1-4-6 Our findings are best compared with those from the four studies that were restricted to patients with COPD and ARF.8-11 Among our patients, survival was associated with better lung function, as was found in two studies,10,11 less severe dyspnea, reported by one group,9 and higher serum albumin levels, not reported previously among patients with COPD and ARF.8-11 In two studies cor pulmonale on ECG was associated with prognosis,8,11 but in no study was hypercarbia related to outcome.8-11 Some of the differences in findings could be explained by chance variation, but might also be due to differences in the underlying study populations. There is only a limited description of the study population in three of these studies,8,9,11 and not all patients had undergone MV in two.5,10 The strength of the present study is that the patients provide a homogeneous representation of COPD patients who require MV. Furthermore, all were weaned at one center using a standardized protocol.

The determinants of weaning have not been as thoroughly studied as those for survival in patients with COPD. In 1973 Sahn and Lakshminarayan15 proposed that NIP and MVV measured at the bedside could be used to identify those who would wean successfully. Our findings support these criteria, in that NIP was strongly associated with weaning among our patients. Our patients did not perform an MVV maneuver, but tidal volume and respiratory rate (F), recorded during the first minute on T-piece, were also strongly associated with weaning outcome. Recently, the pattern of breathing while on T-piece,16 airway occlusion pressure,17 response to hypercapnic challenge,18 and transdiaphragmatic pressures19 have been proposed as weaning criteria. In two of these studies, NIP and F on T-piece were also strongly associated with weaning outcome but were not directly compared with the proposed new criteria.16,18 In the other two studies NIP and F were not reported19 or were not significantly associated with weaning.17

Although these findings are of interest, it would be more relevant to be able to predict difficulty in

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**Figure 5.** Cross-tabulation demonstrating the combined influence of premorbid lung function and level of activity on survival after institution of MV.

**Figure 6.** Survival after weaning among patients grouped by their premorbid lung function.
weaning before instituting MV. We could find no report associating premorbid clinical characteristics with weaning outcome in patients with COPD. None of the studies cited above reported premorbid data.10-19 Hilbermann et al11 prospectively studied 124 patients undergoing cardiac surgery to determine premorbid factors associated with difficulty of weaning in the immediate postoperative period. Preoperative lung function and severity of symptoms (NYHA classification) and preweaning with family were the most important determinants.12 Despite the obvious differences between patient populations and outcomes assessed, the similarity with our findings is striking.

Serum albumin level was associated with both weaning and survival. An association between albumin and survival has been noted previously among stable COPD patients,1 and the importance of nutrition in weaning is well recognized.16,20 We did not do systematic nutritional assessments, but none of our patients had serious renal or hepatic disease. We think that the association of serum albumin with outcome underscores the importance of nutritional factors in these patients.

Premorbid level of activity was the most important determinant of outcome among our patients. This association has been examined once previously, by Jessen et al,8 among 111 COPD patients who underwent MV. Of 56 patients who had been able to work to some extent, 68 percent survived one year, compared with 37 percent of the 46 who could not work but had been able to get out of their homes, and only 8 percent of those confined to their homes.6 Unfortunately, lung function and arterial blood gas measurements were not reported8 but the survival of our patients was strikingly similar (Fig 6).

As seen in Table 4, premorbid level of activity was highly correlated with several clinical and physiologic measurements. It was also more strongly associated with outcome than any other single measure. This may reflect either the limitations of current physiologic measures in assessing the impact of disease, or simply that premorbid level of activity is a good summary measure influenced by many clinical factors. We think that this finding may also reflect the importance of certain unmeasurable factors, such as motivation and family support, or other psychosocial factors in determining both weaning success and long-term survival.

Treatment decisions by physicians are based on the patient's anticipated outcome.30-33 For a particular intervention the potential benefit must be weighed against the risks. Institution of MV for ARF in patients with COPD is potentially lifesaving yet carries considerable risk of complications and the specter of long-term dependence on MV. The major factors influencing physicians' decisions in this situation are their estimates of the patients' longevity, functional status, and quality of life after weaning from MV.30,32 However, the accuracy of physicians' estimates is poor and does not correlate with their level of training or experience.31,32 The need for better prediction of likely outcome has been emphasized recently.33

Prediction of outcome based on consideration of only one clinical factor such as lifestyle score is conceptually very easy but, as Figures 3 and 5 show, is much less accurate than consideration of both lifestyle and FEV1 together. Even after consideration of these two factors, the likely outcome would still be unclear in many patients. Consideration of four or five factors is conceptually and practically impossible without some sort of predictive model, but it is clearly important to consider all relevant factors.

Prediction of survival in patients in the ICU setting has been tried with several models, of which the APACHE score30 has been the best accepted. When used in a general ICU, this score predicted death in only 48 percent of those who died.30 The APACHE score was derived from inclusion and weighting of several clinical factors by an expert panel and was designed for use in a general ICU with a heterogeneous patient population. It has not been evaluated in a group of COPD patients, who usually constitute a distinct and different subgroup. Kaelin et al31 attempted unsuccessfully to develop a predictive model for six-month survival in a group of COPD patients undergoing MV. None of the acute physiologic or nutritional factors measured was related to survival. However, this was a retrospective analysis of only 35 patients in whom important clinical data such as premorbid level of activity, ABGs, and ECG findings were not recorded, and, in contrast to the findings of many others,1,6,10,11 lung function was not associated with prognosis.31

In the current study, both short- and long-term

<table>
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<th>Characteristic (Means)</th>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>(6)</td>
<td>(14)</td>
<td>(22)</td>
<td>(41)</td>
<td>(12)</td>
</tr>
<tr>
<td>% Weaned</td>
<td>100</td>
<td>79</td>
<td>86</td>
<td>78</td>
<td>33†</td>
</tr>
<tr>
<td>% Surviving</td>
<td>53</td>
<td>79</td>
<td>50</td>
<td>29</td>
<td>25†</td>
</tr>
<tr>
<td>Intubation duration, days</td>
<td>37</td>
<td>25</td>
<td>40</td>
<td>33</td>
<td>93†</td>
</tr>
<tr>
<td>Age, yr</td>
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<td>73</td>
<td>69</td>
<td>71</td>
<td>76†</td>
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<tr>
<td>FEV1, L</td>
<td>1.16</td>
<td>1.03</td>
<td>0.83</td>
<td>0.68</td>
<td>0.57‡</td>
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<td>45</td>
<td>37</td>
<td>32</td>
<td>28†</td>
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<tr>
<td>Premorbid hypoxemia, %</td>
<td>33</td>
<td>15</td>
<td>73</td>
<td>33</td>
<td>92§</td>
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<td>Premorbid hypercarbia, %</td>
<td>50</td>
<td>8</td>
<td>55</td>
<td>52</td>
<td>75‡</td>
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<tr>
<td>NIP, cm H2O</td>
<td>46</td>
<td>37</td>
<td>34</td>
<td>32</td>
<td>26§</td>
</tr>
<tr>
<td>Tidal volume, ml</td>
<td>356</td>
<td>410</td>
<td>354</td>
<td>300</td>
<td>264§</td>
</tr>
</tbody>
</table>

*Differences between means of lifestyle categories tested using analysis of variance (ANOVA).

†p<.05
‡p<.01
§p<.001
clinical factors were recorded. Using both bivariate and multivariate analyses, we found, in agreement with others, that the major determinants of prognosis were not the acute problems but the chronic underlying disease. Based on this, we developed predictive models for weaning, which have not been reported previously, and for survival. The strength of our findings are that they are derived from analysis of a large series of patients, all of whom had COPD with ARF requiring MV. In contrast to other predictive models developed on the basis of arbitrary decisions about inclusion and relative importance of factors, both the factors and their coefficients in our models are derived from this analysis. These models also utilize clinical data that are available to physicians practicing in almost all settings. Therefore, we think that these predictive models should be readily applicable to similar patients with COPD and ARF in other centers.

These predictive models have several limitations. First, they are derived from a retrospective analysis. As a result, some data are missing, and in some cases premorbid characteristics might have been misclassified, although efforts were made to minimize this. The process of patient care was not assessed, so it is conceivable that differences in outcome were due to differences in care, or perhaps other important differences in patient characteristics were not measured or recorded. We did not systematically measure other potential predictors, such as pulmonary hemodynamics, pattern of breathing, occlusion, or diaphragmatic pressures, so no comparison can be made with these measures. Finally, any predictive model is likely to fit the body of data from which it is derived and must be validated by prospective application to a second group of patients.

In patients with COPD and ARF the decision to institute MV is difficult because of the high rate of complications, the risk of long-term dependence on MV, and uncertainty about the long-term prognosis. We found that there was a subgroup with prolonged survival with a reasonable quality of life. Consideration of all significant factors through use of predictive models with a programmable pocket calculator or a simple software program (available from the authors) would allow physicians to identify patients most likely to benefit from MV. It is unlikely that treatment decisions will be based entirely on this information, particularly until these models have been validated. We think that knowledge of likely outcome would be useful in making these difficult decisions and in discussing them with patients and their families.

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APPENDIX: Predictive Models

General Model:

Probability (outcome) =

\[
\text{Exp} \left[ \frac{-3.52 - .74 \text{(Lifestyle)} + 2.8 \text{(FEV)} + 1.5 \text{(Albumin)} - 1 \text{(Cor P)} - 1.5 \text{(LVF)}}{1 + \text{Exp} \left[ -3.52 - .74 \text{(Lifestyle)} + 2.8 \text{(FEV)} + 1.5 \text{(Albumin)} - 1 \text{(Cor P)} - 1.5 \text{(LVF)}} \right] \right]
\]

Specific Models

Probability (Survival) =

\[
\text{Exp} \left[ -7.94 - .48 \text{(Lifestyle)} + 7.73 \text{(FEV)} + 1.4 \text{(Alb)} + .06 \text{(NIP)} + .006 \text{(Vr)} \right]
\]

Examples

Patient 1

Lifestyle (working) = 0, FEV, = 50% of predicted, albumin = 4.5 mg/dl, no cor pulmonale = 1, and no LVF = 0, NIF = 40 cm H₂O, tidal volume = 350 ml.

Probability of survival =

\[
\text{Exp} \left[ -3.52 - .74(0) - 2.8(1.5) + 1.55(4.5) - 1.04(0) - 1.50 \right]
\]

Probability of survival = 99.3%, or 99.9%.

Probability of weaning (premorbid data) =

\[
\text{Exp} \left[ -7.94 - .48(0) + 7.73(5.5) + 1.42(4.5) + .059(0) + .0062(350) \right]
\]

Probability of weaning = 999, or 99.9%.

Probability of weaning (all data) =

\[
\text{Exp} \left[ -7.94 - .48(0) + 7.73(5.5) + 1.42(4.5) + .059(0) + .0062(350) \right]
\]

Probability of weaning = .999, or 99.9%.

Patient 2

Lifestyle (housebound) = 3, FEV, = 30% predicted, albu-

Table A1—Survival

<table>
<thead>
<tr>
<th>No.</th>
<th>Factor</th>
<th>Coefficient (b)</th>
<th>SE</th>
<th>STD Coefficient*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lifestyle</td>
<td>- .74</td>
<td>2.7</td>
<td>.78</td>
</tr>
<tr>
<td>2</td>
<td>FEV,</td>
<td>+ 2.81</td>
<td>1.7</td>
<td>.51</td>
</tr>
<tr>
<td>3</td>
<td>Albumin</td>
<td>+ 1.54</td>
<td>5.2</td>
<td>.80</td>
</tr>
<tr>
<td>4</td>
<td>Cor pulmonale</td>
<td>- 1.04</td>
<td>.58</td>
<td>.52</td>
</tr>
<tr>
<td>5</td>
<td>LVF</td>
<td>- 1.53</td>
<td>.73</td>
<td>.60</td>
</tr>
</tbody>
</table>
Table A3 — Weaning: Premorbid Data Only

<table>
<thead>
<tr>
<th>No.</th>
<th>Factor</th>
<th>Coefficient (b)</th>
<th>SE</th>
<th>STD Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lifestyle</td>
<td>−.88</td>
<td>.35</td>
<td>.92</td>
</tr>
<tr>
<td>2</td>
<td>FEV₁</td>
<td>+5.63</td>
<td>2.43</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>Albumin</td>
<td>+1.33</td>
<td>.53</td>
<td>.77</td>
</tr>
</tbody>
</table>

Table A3 — Weaning: All Data

<table>
<thead>
<tr>
<th>No.</th>
<th>Factor</th>
<th>Coefficient (b)</th>
<th>SE</th>
<th>STD Coefficient*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lifestyle</td>
<td>−.48</td>
<td>.37</td>
<td>.50</td>
</tr>
<tr>
<td>2</td>
<td>FEV₁</td>
<td>+7.73</td>
<td>3.04</td>
<td>1.39</td>
</tr>
<tr>
<td>3</td>
<td>Albumin</td>
<td>+1.42</td>
<td>.54</td>
<td>.82</td>
</tr>
<tr>
<td>4</td>
<td>NIP</td>
<td>+.058</td>
<td>.036</td>
<td>.42</td>
</tr>
<tr>
<td>5</td>
<td>Tidal volume</td>
<td>+.0062</td>
<td>.0037</td>
<td>.45</td>
</tr>
</tbody>
</table>

*STD Coefficient: The standardized coefficient is derived by multiplying the coefficient of a factor times the SD of that factor (given in Table 1). This gives an idea of the relative importance of the factors in the model, by reflecting the relative change in the logit probability for each change of that factor equal to its SD. *

min = 3.0, cor pulmonale present = 1, LVF = absent = 0, NIF = 25, tidal volume = 260 ml.

Probability survival = .22 or 22%.

Probability of weaning (premorbid data) = .681, or 68.1%.

Probability of weaning (all data) = .565, or 56.5%.

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