Evaluation of Conventional Weaning Criteria in Patients with Acute Respiratory Failure

Kazufumi OKAMOTO, Hiroko IWAMASA*, Hiroshi DOGOMORI** and Tohru MORIOKA

We evaluated the reliability of conventional weaning criteria from a ventilator during 33 weaning trials on 25 patients with acute respiratory failure (ARF). Of 13 criteria, a ratio of maximal voluntary ventilation to minute ventilation (MV) > 2, a vital capacity $> 12\ ml \cdot kg^{-1}$, a spontaneous respiratory rate $<$ 25 breaths$\cdot min^{-1}$, and a MV $< 10\ l \cdot min^{-1}$ appeared to be useful for predicting successful weaning outcome. However, even using those criteria, there were many falsely-negative cases. The alveolar-arterial P_{O_2} gradient < 350 mmHg at an $F_{I_{O_2}}$ 1.0 was not useful as a predictor of weaning outcome. The present study demonstrates that conventional criteria are frequently inaccurate for predicting weaning outcomes and suggests that the use of some of these criteria may unnecessarily prolong the length of ventilator support. Since ventilation of most patients with poor oxygenation can be successfully discontinued by placing them on a continuous positive airway pressure system, these results suggest that the improvement of oxygenation is not an indispensable prerequisite for weaning from mechanical ventilators. (Key words: acute respiratory failure, mechanical ventilation, oxygenation, weaning, weaning criteria)

(Okamoto K, Iwamasa H, Dogomori H, et al.: Evaluation of conventional weaning criteria in patients with acute respiratory failure. J Anesth 4: 213–218, 1990)

Mechanical ventilatory support (MVS) is associated with many complications[1–3] and thus should be discontinued as soon as a patient can maintain sufficient spontaneous respiration. However, if weaning trials from mechanical ventilators are initiated too early, they may lead to severe respiratory distress or acute left ventricular dysfunction[4–6]. Thus, timing is a crucial component for successful weaning from a ventilator.

Department of Anesthesiology, Kumamoto University Medical School, Kumamoto, Japan

**Department of Anesthesiology, Kumamoto Municipal Hospital, Kumamoto, Japan*

***Department of Anesthesiology, Kagoshima University School of Medicine, Kagoshima, Japan*

Address reprint requests to Dr. Okamoto: Department of Anesthesiology, Kumamoto University Medical School, 1-1-1 Honjo, Kumamoto, 860 Japan

A number of weaning criteria have been proposed (listed in table 1[7–17]), but there exists disagreement regarding the most accurate criterion for predicting weaning outcomes. The purpose of this prospective study was to evaluate the reliability of conventional weaning criteria in patients with acute respiratory failure (ARF).

Methods

Twenty-five patients were allotted for this study. All patients were hemodynamically stable and recovering from ARF of medical and/or surgical etiology that had necessitated MVS. Ten females and 15 males had a mean age of 58 years. The duration of MVS prior to the study ranged from 1 to 12 days. No patient had chronic obstructive lung disease or evidence of diaphragmatic or

Table 1. Criteria proposed for ventilator weaning

Vital capacity (VC)	> 10 ml·kg^{-1} [7,8]
Vital capacity (VC)	> 12 ml·kg^{-1} [7]
Vital capacity (VC)	> 15 ml·kg^{-1} [9]
Vital capacity (VC)	> 1 l[10]
Tidal volume (V_T)	> 300 ml[11]
Tidal volume (V_T)	> 5 ml·kg^{-1} [8,12]
Minute ventilation (MV)	< 10 l·min^{-1} [8,13,14]
Minute ventilation (MV)	< 180 ml·kg^{-1}·min^{-1} [8,15]
Maximal voluntary ventilation to minute ventilation (MVV/MV)	> 2 times[8,13,14]
Respiratory rate (RR)	< 30 breaths·min^{-1} [16]
Respiratory rate (RR)	< 25 breaths·min^{-1} [11]
Alveolar-arterial P_{O_2} gradient with an F_{IO_2} of 1.0	< 350 mmHg[8,17]
Ratio of the arterial P_{O_2} to the F_{IO_2} (Pa_{O_2}/F_{IO_2})	> 200[16]

neurologic injury.

Each patient was evaluated at our routine morning conference with regard to undergoing a weaning trial. The decision whether to try weaning or not was primarily based on clinical assessment and the patient's ability to generate a vital capacity (VC) of at least 10 ml·kg^{-1} body weight or greater. In some of the patients, VC was a little bit lower than 10 ml·kg^{-1} body weight, but a weaning trial was still judged clinically appropriate if a patient's general physical condition was good. All patients consented to this study.

The study was conducted in a semirecumbent position. The lead II of ECG and arterial blood pressure were monitored continuously. The radial or dorsalis pedis artery was cannulated to obtain arterial blood samples and all blood gas tensions and pH were measured with a Corning 168 pH/blood gas analyzer. Prior to each weaning trial, arterial blood gases under MVS with an ordinary F_{IO_2} were measured for calculating the ratio of arterial oxygen tension to the fraction of inspired oxygen (Pa_{O_2}/F_{IO_2}). Subsequently, the patients were mechanically ventilated with pure oxygen to calculate the alveolar-arterial oxygen tension difference (A-aD_{O_2} with an F_{IO_2} of 1.0). Minute ventilation (MV), VC and maximal voluntary ventilation (MVV) were measured using a Wright respirometer (Medishield, U.K.) during a brief interruption of the ventilator therapy. A spontaneous respiratory rate (RR) was measured concomitantly with MV. Tidal volume (V_T) was calculated from MV and RR. The MVV to MV ratio (MVV/MV) was obtained by calculation.

After all measurements were made, it was attempted to wean the patients from MVS. Of the 25 patients studied, 4 failed to wean. In these 4 patients, another weaning trial was repeated on a different day. Consequently, a total of 33 weaning trials were attempted. Of 33 weaning trials, 18 were made by using T-piece breathing circuit with a large 20 l balloon reservoir[18]. Three to 5 cmH_2O of continuous positive airway pressure (CPAP) were applied if it seemed to be clinically preferable. In the remaining 15 trials, intermittent mandatory ventilation (IMV) or pressure support ventilation (PSV) was used as a weaning process. However, IMV or PSV was not used longer than 4 hr. These patients were also placed on the T-piece breathing circuit for the final process of weaning. The weaning process was considered to be completed when endotracheal tube was extubated or when CPAP was discontinued in tracheostomized patients.

The weaning was judged a "failure" if the patient complained of severe dyspnea and/or

Table 2. The predictive ability of weaning outcome by simple measurement of the conventional weaning criteria

	false positive		false negative		P
MVV/MV > 2 times	4.8%	(1/21)	33.3%	(4/12)	< 0.01
VC > 12 ml·kg^{-1}	9.1%	(2/22)	36.4%	(4/11)	< 0.01
RR < 25 breaths·min^{-1}	12.5%	(3/24)	33.3%	(3/9)	< 0.01
RR < 30 breaths·min^{-1}	18.5%	(5/27)	33.3%	(2/6)	< 0.05
MV < 10 l·min^{-1}	13.6%	(3/22)	45.5%	(5/11)	< 0.05
VC > 15 ml·kg^{-1}	11.1%	(2/18)	53.3%	(8/15)	< 0.05
MV < 180 ml·kg^{-1}·min^{-1}	21.4%	(6/28)	40.0%	(2/5)	N.S.
VC > 10 ml·kg^{-1}	21.4%	(6/28)	40.0%	(2/5)	N.S.
VC > 1 l	7.7%	(1/13)	60.0%	(12/20)	N.S.
$V_T > 300$ ml	30.8%	(8/26)	14.3%	(1/7)	N.S.
$V_T > 5$ ml·kg^{-1}	26.1%	(6/23)	70.0%	(7/10)	N.S.
A-aDo$_2$ < 350 mmHg	33.3%	(6/18)	80.0%	(12/15)	N.S.
$Pa_{O_2}/FI_{O_2} > 200$	32.0%	(8/25)	87.5%	(7/8)	N.S.

false positive: predicted success but actual failure
false negative: predicted failure but actual success
P values were by two-tailed Fisher's exact test

developed anxiety, agitation or diaphoresis, and was placed back on MVS within 24 hr. Statistical analysis of the data was performed using two-tailed Fisher's exact test or chi-square analysis. A $P < 0.05$ was considered significant.

Results

Of 33 weaning trials, 24 were successful and 9 failures. In the latter group, all patients required reinstitution of MVS within 9 hr due to progressive respiratory distress. No complications occurred from these trials.

Table 2 shows the predictive ability of each criterion for weaning outcome. Of the 13 criteria, a MVV/MV > 2, a VC > 12 ml·kg^{-1} and a RR < 25 breaths·min^{-1} were most consistent with a successful weaning outcome ($P < 0.01$). However, these were also associated with a significant number of false-negatives (predicted failure but actual success). A RR < 30 breaths·min^{-1}, a MV < 10 l·min^{-1} and a VC > 15 ml·kg^{-1} also had predictive value for weaning outcome ($P < 0.05$). However, a MV < 10 l·min^{-1} and a VC > 15 ml·kg^{-1} were associated with many more cases of false-negatives than the 3 above mentioned criteria. A MV $<$ 180 ml·kg^{-1}·min^{-1}, a VC > 10 ml·kg^{-1}, a VC $> 1l$, a $V_T > 300$ ml and a $V_T > 5$ ml·kg^{-1} were inconsistent with weaning outcome and surprisingly, A-aDO$_2$ < 350 mmHg and $Pa_{O_2}/FI_{O_2} > 200$ were also unreliable in predicting weaning outcomes. For example, among the 15 patients receiving MVS for poor oxygenation (A-aDo$_2$ > 350 mmHg), 12 (80%) were successfully discontinued from MVS and were able to sustain spontaneous respiration on a CPAP system with a large balloon reservoir. All these patients placed on a CPAP system were successfully extubated within 2 to 52 hr.

Table 3 and 4 show the predictive value of weaning outcome through combinations of the 3 or 4 criteria. All 17 patients who satisfied 3 or 4 of the criteria were successfully weaned. The less the criteria were satisfied, the smaller the success rate was ($P < 0.01$). However, it should be noted that one patient who failed to satisfy all of these 4 criteria was also successfully weaned.

Discussion

MVS is associated with numerous complications, including pneumonia, pneumothorax, depression of cardiac output, fluid retention, gastric bleeding due to stress ulcer, etc[1–3]. Therefore, weaning from MVS should

Table 3. The predictive ability of weaning outcome by the combination of a MVV/MV > 2 times, a RR < 25 breaths·min^{-1}, a MV < 10 l·min^{-1} and a VC > 12 ml·kg^{-1}

No. of the criteria satisfied	No. of weaning success	No. of weaning failure	Success rate
4	17	0	100.0%
3	2	1	66.7%
2	2	1	66.7%
1	2	3	40.0%
0	1	4	20.0%

$P < 0.01$ by using chi-square analysis

Table 4. The predictive ability of weaning outcome by the combination of a RR < 25 breaths·min^{-1}, a MV < 10 l·min^{-1} and a VC > 12 ml·kg^{-1}

No. of the criteria satisfied	No. of weaning success	No. of weaning failure	Success rate
3	17	0	100.0%
2	3	2	60.0%
1	3	3	50.0%
0	1	4	20.0%

$P < 0.01$ by using chi-square analysis

be undertaken as soon as any illness requiring MVS is resolved. If MVS can be discontinued earlier, its complications may be lessened, length of ICU stay decreased, medication requirements diminished, and patient comfort improved. However, it is often difficult to determine when weaning trials should be initiated. Premature discontinuation of MVS may lead to severe respiratory distress and left ventricular dysfunction[4–6]. Therefore, it is imperative to have reliable predictors for weaning outcome.

A MVV/MV > 2 has been recommended as a specific predictor of a successful weaning outcome[8,13,14]. However, Tahvanainen et al.[4] have recently questioned its predictive ability. In the present study, the MVV/MV > 2 criterion would have resulted in a significant number of false-negatives (33.3%) suggesting that this criterion may unnecessarily prolong the length of MVS. The drawback of MVV/MV as a criteria is its dependence on patient's effort and good cooperation. Furthermore, the MVV maneuver is an exhausting test and must be avoided in patients with coronary artery disease. This criterion will not be appropriate as a routine test in patients of advanced age.

VC is one of the most commonly-used predictors[7–10] and among the 4 criteria related to VC, a VC > 12 ml·kg^{-1} appeared to be most useful. However, a VC > 12 ml·kg^{-1} was also associated with a significant number of false-negatives (36.4%). This disappointing results, as with MVV/MV, may be partly due to its dependence on patient cooperation. Moreover, VC is associated with respiratory muscle strength rather than endurance[19]. Respiratory muscle fatigue, an important cause of weaning failure, is associated with endurance rather than strength[19].

Sahn et al.[8,14] have recommended using peak negative pressure (PNP) < −30 cmH_2O to determine weaning outcome and in a series of 100 patients found that all generated values less than −30 cmH_2O were successfully weaned, while none with values more than −20 cmH_2O could sustain spontaneous respiration. In contrast, Tahvanainen et al.[4] recently reported that a value of −30 cmH_2O was falsely negative in 100% of patients and falsely positive in 26%. We did not measure PNP in this study due to several of its significant drawbacks. Similar to VC, PNP requires the patient's cooperation and provides limited information about respiratory muscle endurance[19]. In addition, PNP does not take into account thoracic compliance[19]. In ARF patients with low lung compliance, high PNP values may be produced by relatively small increases in lung volume and the associated increase in the work of breathing to sustain spontaneous respiration may induce respiratory muscle fatigue.

Measurement of RR is the simplest and most non-invasive technique[20]. In a series of patients with chronic obstructive lung disease, Tobin et al.[11] suggested that

RR and V_T may be useful in distinguishing ventilator-dependent patients from those who can be weaned easily. They found that patients who exhibited rapid and shallow-breathing patterns immediately following discontinuation of MVS failed the weaning trial. We also observed similar phenomena in RR in most of the present patients who failed to wean. However, unlike the study of Tobin et al.[11], we were unable to find any predictive value in V_T, though this discrepancy may be due to the differences of underlying diseases in the patients. In the present study, a RR < 25 breaths$\cdot$min^{-1} was more reliable than a RR < 30 breaths$\cdot$min^{-1} in distinguishing patients who could and could not be successfully weaned. The results were consistent with those of Gravelyn et al.[20]

A high MV often implies the presence of increased dead space related to residual pulmonary disease and/or increased CO_2 production[19]. If a high MV is required to maintain adequate ventilation, the associated increase in the work of breathing may lead to respiratory muscle fatigue and consequent weaning failure. In the present study, a MV < 10 $l\cdot$min^{-1} was significant in predicting weaning outcomes while a MV < 180 ml$\cdot$kg$^{-1}\cdot$min^{-1} was not, and therefore, we recommend using the former as opposed to the latter criteria. Unlike MVV/MV, VC and PNP, MV is independent of the patient's effort: a distinct advantage.

In a 1970 paper, Pontoppidan et al. recommended an A-a$DO_2 < 350$ mmHg as an additional useful predictor of weaning outcomes. However, we could not find any predictive value for an A-a$DO_2 < 350$ mmHg and $Pa_{O_2}/FI_{O_2} > 200$. Eighty percent of patients with poor oxygenation were successfully discontinued from MVS. They sustained spontaneous respiration on a CPAP system with a large balloon reservoir[18] and were extubated within 2 to 52 hours without problems. Thus, improvements in oxygenation in patients with ARF is not a prerequisite for ventilator weaning. A patient with poor oxygenation may be placed on a CPAP system with a large balloon reservoir[18] if the patient's ventilation appears to be sufficient. The use of this CPAP system may facilitate weaning.

Finally, we examined the predictive ability of weaning outcome by combination of the 3 or 4 criteria (tables 3 and 4). The predictive ability of the combinations of the 3 or 4 criteria was almost similar. The results suggest that if a patient at least satisfies RR < 25 breaths$\cdot$min^{-1}, MV < 10 $l\cdot$min^{-1} and VC > 12 ml$\cdot$kg^{-1} he or she will successfully wean. Still, patients not satisfying some or all of the 3 criteria may also be successfully weaned.

In conclusion, among the 13 conventional criteria, a MVV/MV > 2 times, a RR < 25 breaths$\cdot$min^{-1}, a MV < 10 $l\cdot$min^{-1} and a VC > 12 ml$\cdot$kg^{-1} appeared to be most useful as predictors of weaning outcome in patients with ARF. However, these were also highly falsely-negative as predictors of weaning outcome. Therefore, these criteria may prolong the length of ventilator support. Since most of the patients with poor oxygenation were able to be discontinued from ventilators by placing them on a CPAP system with a large balloon reservoir, the improvement of oxygenation is not prerequisite for ventilator weaning in patients with ARF.

(Received Sep. 20, 1989, accepted for publication Nov. 15, 1989)

References

1. Grum CM, Morganroth ML: Initiating mechanical ventilation. J Intensive Care Med 3:6–20, 1988
2. Craven DE, Kunches LM, Kilinsky V, Lichtenberg DA, Make BJ, Mccabe WR: Risk factors for pneumonia and fatality in patients receiving continuous mechanical ventilation. Am Rev Respir Dis 133:792–796, 1986
3. Tsuno K, Sakanashi Y, Kishi Y, Urata K, Tanoue T, Higashi K, Yano T, Terasaki H, Morioka T: Acute respiratory failure induced by mechanical pulmonary ventilation at a peak inspiratory pressure of 40 cmH_2O. J Anesth 2:176–183, 1988
4. Tahvanainen J, Salmenpera M, Nikki P: Extubation criteria after weaning from intermittent mandatory ventilation and continuous positive airway pressure. Crit Care Med 11:702–707, 1983

5. Demling RH, Read T, Lind LJ, Flanagan HL: Incidence and morbidity of extubation failure in surgical intensive care patients. Crit Care Med 16:573–577, 1988
6. Lemaire F, Teboul J-L, Cinotti L, Giotto G, Abrouk F, Steg G, Macquin-Mavier I, Zapol WN: Acute left ventricular dysfunction during unsuccessful weaning from mechanical ventilation. Anesthesiology 69:171–179, 1988
7. Bendixen HH, Egbert LD, Hedley-Whyte J, Laver MB, Pontoppidan H: Management of patients undergoing prolonged artificial ventilation. Respiratory Care. St. Louis: C.V. Mosby Co., 1965, pp 149–150
8. Sahn SA, Lakshminarayan S, Petty TL: Weaning from mechanical ventilation. JAMA 235:2208–2212, 1976.
9. Feeley TW, Hedley-Whyte J: Weaning from controlled ventilation and supplemental oxygen. N Engl J Med 292:903–906, 1975
10. Safar P, Kunkel HG: Prolonged artificial ventilation. Respiratory Therapy. Edited by Safar, P. Philadelphia, F.A. Davis Co., 1969, pp 126–128
11. Tobin MJ, Perez W, Guenther SM, Semmes BJ, Mador MJ, Allen SJ, Lodato RF, Dantzker DR: The pattern of breathing during successful and unsuccessful trials of weaning from mechanical ventilation. Am Rev Respir Dis 134:1111–1118, 1986
12. Radford EP, Ferris BG, Kriete BC: Clinical use of a nomogram to estimate proper ventilation during artificial respiration. N Engl J Med 251:877–884, 1954
13. Stetson JB: Prolonged Tracheal Intubation. Boston, Little Brown & Co Inc., 1970, vol. 8, pp 767–779
14. Sahn SA, Lakshminarayan S: Bedside criteria for discontinuation of mechanical ventilation. Chest 63:1002–1005, 1973
15. Lecky JH, Ominsky AJ: Postoperative respiratory management. Chest 62:50S–57S, 1972
16. Kubota T, Ohtake K: Weaning from mechanical ventilator. Criteria, method and respiratory monitor for weaning (Japanese). Acute Medicine 11:341–351, 1987
17. Pontoppidan H, Laver MB, Geffin B: Acute respiratory failure in the surgical patient. Advances in Surgery. Edited by Welch, C.E., Chicago, Year Book Medical Publishers, 1970, vol. 4, pp 163–254
18. Bshouty ZH, Roeseler J, Reynaert MS, Rodenstein D: The importance of the balloon reservoir volume of a CPAP system in reducing the work of breathing. Intensive Care Med 12:153–156, 1986
19. Tobin MJ: Respiratory monitoring in the intensive care unit. Am Rev Respir Dis 138:1625–1642, 1988
20. Gravelyn TR, Weg JG: Respiratory rate as an indicator of acute respiratory dysfunction. JAMA 244:1123–1125, 1980