WEANING READINESS AND FLUID BALANCE IN OLDER CRITICALLY ILL SURGICAL PATIENTS

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• BACKGROUND *Few studies address predictors for successful weaning of older adults from mechanical ventilation.*
• OBJECTIVE *To develop a clinical profile of older patients who are successfully weaned from long-term mechanical ventilation.*
• METHODS *Forty patients in the trauma and surgical intensive care unit who were at least 60 years old were enrolled in the study after 3 days of active weaning and were monitored daily until successfully weaned or until the end of the 14-day study. Hemodynamic and gas exchange variables, fluid balance, oxygen cost of breathing, and scores on the Burns Weaning Assessment Program were analyzed.*
• RESULTS *Compared with patients who were not weaned, successfully weaned patients required mechanical ventilation for 5.3 days, started active weaning earlier (mean 10.7 vs 14.5 days, $P = .04$), had lower mean negative daily fluid balances in the beginning (-0.394 vs 1.107 L, $P = .004$), and had lower mean net cumulative fluid balances (6.856 vs 16.212 L) at the time of enrollment. They also maintained both a lower mean net cumulative fluid balance (10.753 vs 25.049 L, $P = .02$) and a negative daily fluid balance (-0.389 vs 1.904 L, $P = .03$) throughout. Their mean central venous pressure decreased over time and was significantly lower ($P < .001$).*
• CONCLUSION *Persistent positive fluid balance in older surgical patients is associated with prolonged mechanical ventilation. Estimates of fluid balance might be useful in weaning older patients from long-term mechanical ventilation. (American Journal of Critical Care. 2005;14:54-64)*

Critical care practitioners in the surgical intensive care unit (SICU) are caring for increasing numbers of older adults admitted for postoperative management of traumatic injuries and high-risk surgical procedures. In 2000, the worldwide population of adults who are at least 65 years old increased to 420 million; in North America alone, older adults accounted for approximately 12.6% of the overall population, and by 2030 this percentage will increase to more than 20%.[1]

With greater numbers of older patients requiring intensive care, the use of mechanical ventilation in this population has increased as well.[2] The frequency of acute respiratory failure has increased exponentially with increasing age, particularly among patients older than 65 years, and 36% of patients overall with acute respiratory failure did not survive to hospital discharge.[3] Older adults treated with mechanical ventilation in general fare more poorly than younger patients because older patients are more likely to have underlying pulmonary disease, greater susceptibility to illness, and comorbid conditions.[4] Older patients also have age-related changes in pulmonary function, loss of muscle mass, and diminished physiological reserve.[4] Yet studies addressing specific strategies for improving the assessment and management of older ill patients receiving mechanical ventilation, including optimal methods of enhancing outcomes of weaning from mechanical ventilation, are scarce.[5]

The purpose of this longitudinal study was to develop a clinical profile of characteristics of older

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patients who are successfully weaned from mechanical ventilation by comparing the characteristics of older patients who are successfully weaned with the characteristics of patients who are not weaned. In this descriptive study, 40 trauma and surgical patients who were at least 60 years old were prospectively monitored during active weaning as they moved from short-term to long-term mechanical ventilation (LTMV).

More than a third of patients with acute respiratory failure do not survive to hospital discharge.

Materials and Methods

The informed consent protocol for this study was approved by the nursing research committee and the institutional review board of a 750-bed, level I trauma center. Informed consent was requested from each patient's legal next of kin; consent was refused for 1 patient. Convenience sampling was used to recruit patients who were at least 60 years old and who were admitted to the SICU for management of high-risk surgery and/or multisystem injuries. The minimum age limit of 60 years was chosen on the basis of a global analysis of the mean age of patients receiving mechanical ventilation worldwide.[6] In addition, a cutoff of 60 years was based on our observations that the frequency of patients between 60 and 65 years old who experienced difficulty being weaned from mechanical ventilation was relatively high. Included in this sample were 10 patients enrolled in a previously reported pilot study.[7] Definitions of short-term mechanical ventilation versus LTMV were based on the work of the Third National Study Group on Weaning From Mechanical Ventilation, sponsored by the American Association of Critical-Care Nurses.[8-11] The study group defined LTMV as the need for mechanical ventilation lasting 3 days or more.[11] The outcome variables included duration of mechanical ventilation and weaning outcome. Multisystem responses during active weaning, including changes in hemodynamic function, gas exchange, and metabolic status, were measured.

After their admission, all eligible patients were monitored for weaning progress. Patients were considered eligible for inclusion in the study on the third day of short-term mechanical ventilation. Patients were enrolled when they were not successfully weaned from mechanical ventilation within 3 consecutive days of active weaning. Active weaning was defined as any change in ventilator settings intended to promote forward progress in weaning, consisting of spontaneous breathing trials or gradual weaning of the patient by adjusting the ventilator rate in synchronized intermittent mandatory ventilation mode. Patients who had been extubated during this 3-day period but were reintubated within 24 hours were also eligible for the study. Day 1 of the study represented the third day of active weaning in patients receiving mechanical ventilation who were not successfully weaned within 3 days.

SICU Weaning Protocol

The attending physician of the SICU initiated the orders for the weaning protocol, specified by the following parameters: spontaneous respirations (<35/min), maximal inspiratory pressure (<-25 cm H_2O), and the value on the rapid shallow breathing index developed by Yang and Tobin,[12] defined as respiratory rate divided by tidal volume, measured in breaths per liter per minute (<105). No weaning parameters were measured until the fraction of inspired oxygen was reduced to 0.50, positive end-expiratory pressure was decreased to 5 cm H_2O, and intravenous vasopressor support was no longer required.

The weaning protocol consisted of the following conditions: minute ventilation 15 L/min or less; fraction of inspired oxygen 0.50 or less; PaO_2 60 mm Hg or higher or oxygen saturation as measured by pulse oximetry 90% or higher; positive end-expiratory pressure 5 cm H_2O or less; respirations less than 35/min; heart rate less than 140/min; and absence of vasopressor support (low-dose dopamine was acceptable). The respiratory therapist performed a spontaneous breathing trial for 1 to 2 hours by way of ventilator flow-by with a transition period of pressure support, while monitoring for low tidal volumes (<3 mL/kg), tachypnea, and apnea. The weaning trial was discontinued if sustained respiratory fatigue occurred, as indicated by the following: respirations greater than 35/min; heart rate greater than 140/min or a change greater than 20% from baseline; oxygen saturation as measured by pulse oximetry less than 90%; or blood pressure (systolic) less than 80 mm Hg or greater than 200 mm Hg. Mechanical ventilation was resumed for patients who did not pass the weaning trial, and they were evaluated the next morning. Some attending physicians opted for a "slow wean," during which ventilator settings were gradually decreased. When gas exchange was adequate as indicated by arterial blood gas analysis after a spontaneous breathing trial or at a low synchronized intermittent mandatory ventilation rate, the respiratory therapist obtained clearance from the physician to extubate or, if the patient had a tracheostomy, to begin use of a tracheostomy collar.

Patients were monitored daily until they had been successfully weaned from mechanical ventilation, remaining free of mechanical ventilation for 24 hours. Patients who were not successfully weaned were monitored for 14 days.

Variables

After morning rounds, key variables were measured in real time or were collected from the medical record of the documented time when weaning attempts were made. The following variables were recorded: weaning parameters, oxygenation variables (blood gas values, hemoglobin level), hemodynamic variables (heart rate, mean arterial pressure, central venous pressure [CVP]), and systemic variables (serum albumin level, presence of heart failure).

Fluid balance was estimated by using 4 variables: daily fluid balance (DFB), net cumulative fluid balance (NCFB), body weight, and CVP. The DFB was the 24-hour net DFB as recorded on the daily ICU flow sheet at 7 AM. The DFB was calculated by subtracting the total output from the total input within a 24-hour period. The NCFB is a more global measure of the net DFB accumulated over time. The NCFB was calculated by adding and subtracting the daily 24-hour fluid balance from the day of SICU admission to the day of record. Body weight, measured in kilograms on a sling scale, was recorded from each patient's ICU flow sheet. The CVP transcribed on the SICU flow sheet at the time of active weaning was recorded. For each variable, the initial value and the final value were compared. The initial value represents the variables recorded on the day of entry into the study. The final value represents the variables recorded at the end of the study period. For patients who were successfully weaned, the final value was recorded on the day of weaning. For patients who were not weaned off mechanical ventilation, the final value was the value recorded on day 14 of the study.

As a metabolic measurement of the response to active weaning, the oxygen cost of breathing (O_2COB) was determined by using indirect calorimetry.[7] The O_2COB is an estimate of the percentage of whole-body oxygen consumption recruited for the work of breathing.[13-15] The O_2COB was calculated before and after each ventilator change by using the Puritan-Bennett 7250 Metabolic Monitor (Puritan-Bennett, Carlsbad, Calif/Mallinckrodt, St. Louis, Mo). For patients having a spontaneous breathing trial, the O_2COB was calculated before the trial began and at the end of the trial. As an estimate of the precision of measurements, the mean coefficient of variation was 4.1% (SD 1.9, range 1.3%-9.1%). Before a ventilator change, an initial measurement of oxygen consumption was recorded as the mean of 4 values taken every 30 minutes for 2 hours. After a ventilator change, a second measurement of oxygen consumption was recorded as the mean of 4 values every 30 minutes for 2 hours. The O_2COB equals the difference between the initial and final values of oxygen consumption divided by the initial oxygen consumption and is calculated as a percentage of whole-body oxygen consumption.

The Burns Weaning Assessment Program (BWAP), a 26-item dichotomous checklist of factors known to affect weaning, was completed daily to measure patients' readiness to be weaned.[16] Systemic parameters that may affect readiness for weaning include hemodynamic stability, factors that increase metabolic rate (sepsis, fever), hematocrit, hydration status, nutritional state, serum albumin level, serum electrolyte levels, absence of bowel problems, activity level, and findings on chest radiographs. Also included in the category of general factors are items representing patients' subjective appraisals of pain control, the adequacy of sleep/rest, and level of anxiety. Patients' subjective responses were assessed by asking the patients to use 1 or 2 fingers to indicate yes or no. The BWAP subdivides respiratory factors into 5 categories:

1. gas flow and work of breathing (spontaneous respiratory rate, breath sounds, character of secretions, presence of neuromuscular disorders, size of endotracheal tube, presence of abdominal distention, obesity, or ascites),
2. airway clearance (cough and swallowing reflexes),
3. respiratory muscle strength (maximal inspiratory pressure, positive expiratory pressure),
4. endurance (spontaneous tidal volume per kilogram), and
5. arterial blood gas levels (pH, $Paco_2$, Pao_2).

The final BWAP score equals the number of positive items divided by 26; when a factor could not be assessed, it was considered a negative response. Higher scores should indicate greater readiness for weaning. Burns et al[17] reported that a score of 56% or higher indicated readiness for active weaning. In the study reported here, the interrater reliability of the BWAP was 95%.

Data Analysis

Distributions of variables were plotted and examined for outliers (S-PLUS Professional Edition, Version 6.1; 2002, Insightful Corp, Lucent Technologies Inc, Seattle, Wash) Measures of central tendency were computed, and the median, mean, and range of values are reported unless otherwise indicated. Differences between patients who were successfully weaned and those who were not were compared by using the Mann-Whitney and Wilcoxon signed-rank tests. For continuous variables, analysis of variance was used to examine whether patients who were weaned differed significantly from patients who were not weaned at the start or the end of the study. Multivariate regression analysis was not used because of the large number of variables examined and the small sample size of the study. A nondirectional α of .05 or less was considered statistically significant.

Results

The sample consisted of 40 patients whose mean age was 71.4 (SD 7.6, range 60-87) years. Table 1 gives the age, admission diagnosis, surgical procedures, complications, and weaning outcome for each patient. A total of 21 patients (53%) were admitted because of traumatic injuries, 17 patients (43%) were admitted to the surgical service, and 2 patients (5%) were managed by the cardiothoracic service.

A total of 28 patients (70%) were successfully weaned. Patients who were successfully weaned were slightly younger than those who were not weaned (70 [SD 7] years vs 74 [SD 8] years), although these differences were not significant. Of the 26 women (65%) in the sample, 17 (65%) were successfully weaned. Of the 14 men (35%) in the sample, 11 (79%) were successfully weaned. We found no significant differences between women and women who were and were not weaned from mechanical ventilation. Two of the patients who were not weaned had died by the end of the 14-day study.

Patients who were successfully weaned began the weaning process in a negative fluid balance. Those who were not successfully weaned began with a positive fluid balance.

Patients were hospitalized and received mechanical ventilation for a mean of 12 days (SD 5, range 1-29) before enrollment in the study. The prestudy period was the elapsed time to initiation of active weaning and transition to LTMV. Patients who were weaned successfully had received mechanical ventilation for 10.7 days (SD 4), compared with 14.5 days (SD 6) for those who were not weaned ($P = .04$). Once enrolled in the study, patients who were weaned successfully required mechanical ventilation for a mean of 5.3 days (SD 5).

Weaning parameters were compared between patients who were successfully weaned and those who were not (Table 2). The only significant difference was in spontaneous respirations; patients were slightly tachypneic on the successful day of their weaning. Table 3 gives the values of oxygenation variables in patients who were successfully weaned and those who were not. The mean pH differed significantly between groups; successfully weaned patients had borderline alkalotic values at the beginning of the study and on the day of extubation. The mean O_2COB decreased in the expected direction among patients who were weaned (Table 3). However, the metabolic monitor was not available during part of the study period, limiting any useful analysis of the small number of patients in this subset of the sample.

Extubated patients had a negative daily fluid balance on the extubation day, while those remaining ventilator dependent had a positive daily fluid balance.

Mean BWAP scores improved from 47% to 53% among patients who were weaned, whereas scores declined from 52% to 50% in patients who were not weaned (Table 4). These changes, however, were not significant.

Patients who were successfully weaned had a mean negative DFB of -0.394 L (SD 1.387) at the time of entry into the study, a value significantly different from an initial mean DFB of 1.107 L (SD 1.532) in patients who were not weaned ($P = .004$; Table 4). Likewise, on the day of their successful extubation, patients who were weaned had a mean negative DFB of -0.389 L (SD 1.694). In contrast, patients who remained ventilator dependent at the end of the study period had a positive mean DFB of 1.904 L (SD 4.711; $P = .03$).

The mean NCFB at the time of entry into the study did not differ significantly between patients who were weaned and patients who were not weaned ($P = .08$), although the values appear to be clinically different (6.9 L vs 16.2 L). The mean NCFB in patients who were successfully weaned, however, was 10.753 L (SD 12.259) on the day of extubation, whereas the NCFB in patients who were not weaned was significantly greater at 25.049 L (SD 25.671; $P = .02$) by the end of the study period. In addition, CVPs were significantly

Table 1 Demographic and clinical description of the sample from patients' medical records

Patient No.	Age, y	Diagnosis	Procedures and surgeries	Complications	Weaning status at end of study
1	78	MVC: 6 rib fractures	Chest tube insertion	Pneumothorax	Weaned
2	73	MVC: grade IV liver laceration, hemorrhagic shock	Repair liver laceration, cholecystectomy after weaning	Acalculous cholecystitis	Weaned
3	69	MVC: flail chest, liver laceration, patellar fracture	Bilateral chest tubes	Bilateral pneumothoraces, acute tubular necrosis	Weaned
4	79	CAD and aortic valve stenosis	CABG and AVR, femoral distal bypass	Loss of circulation to affected extremity	Not weaned Tracheostomy
5	82	Fall: C5 and C6 fracture, respiratory arrest at scene	Decompression spinal fractures	ARDS	Not weaned Tracheostomy
6	60	MVC: femur fracture, splenic rupture, diaphragmatic injury with herniation of stomach to left side of chest	ORIF, splenectomy, repair of diaphragmatic injury	Pleural effusion	Weaned
7	60	Fall: intracranial hemorrhage, chronic cervical C5 and C6 spinal subluxation and dislocation	Craniotomy Tracheostomy after weaning	Pneumonia after weaning	Weaned
8	80	Infected femoral bypass graft	Removal of graft, amputation of affected extremity	Circulation loss to affected extremity	Weaned
9	84	MVC: rib, hip, and femur fractures	ORIF, tracheostomy	Pneumothorax; DVT	Not weaned
10	63	Esophageal stricture	Esophagectomy, pyloroplasty, cholecystectomy, tracheostomy	Pneumonia	Not weaned
11	63	MVC: rib, hip, and femur fractures	ORIF	None	Weaned
12	72	MVC: sternal and rib fractures	None	Pulmonary contusion	Weaned
13	65	Diverticular abscess, perforated sigmoid colon	Sigmoid colectomy with descending end colostomy, femoral bypass	Fasciotomy, subendocardial myocardial infarction, sepsis in groin	Weaned
14	80	Femoral/femoral bypass	Removal of right femoral graft, right above-the-knee amputation	Infected graft	Weaned
15	81	MVC: femur and hip fractures	ORIF	Pneumothorax, DVT	Not weaned Tracheostomy
16	66	Fall, frontal depressed skull fracture	Revision of skull fracture	None	Weaned
17	75	MVC: pelvic and rib fractures	External stabilization pelvic fracture	Hemothorax	Weaned
18	87	Fall: facial and basilar skull fractures	Repair skull fracture	Pneumocephaly	Weaned
19	76	Sigmoid colon cancer	Sigmoid colectomy, colostomy	None	Weaned
20	63	Hypotension, esophageal stricture, atrial fibrillation/flutter	Esophagectomy, pyloroplasty, cholecystectomy	None	Not weaned Tracheostomy
21	71	Pancreatic mass, jejunal leak	Exploratory laparotomy with pancreatic resection	None	Weaned Tracheostomy
22	64	GSW chest/abdomen, diaphragmatic injury, liver laceration	Ligation hepatic vessels	Pneumothorax, hemothorax	Weaned
23	68	Tractor accident: pelvic, spinal, and multiple rib fractures	Stabilization pelvic and spinal fractures	None	Weaned
24	72	Aortic aneurysm	Aortic aneurysm repair, aortic re-exploration	Renal failure	Not weaned Tracheostomy Patient died
25	68	Lung cancer	Lobectomy	Atrial fibrillation	Weaned
26	61	Paravaginal defect, respiratory distress	Abdominal/sacral colpapexy, cystoscopy	Respiratory failure	Weaned Tracheostomy
27	64	Pancreatitis, cholelithiasis	None	Hepatic coma	Not weaned No tracheostomy

continued

Table 1 *continued*

Patient No.	Age, y	Diagnosis	Procedures and surgeries	Complications	Weaning status at end of study
28	77	Abdominal aortic aneurysm, iliac artery aneurysm	Repair of abdominal aortic and iliac arterial aneurysms	Respiratory distress	Weaned
29	63	MVC: Closed head injury, flail chest	Repair of dissecting aortic aneurysm	Hemothoraces/ pneumothoraces	Weaned
30	73	Colon cancer	Hemicolectomy, re-exploration for mesenteric ischemia	Mesenteric ischemia	Not weaned
31	67	Abdominal aortic aneurysm rupture	Repair of abdominal aortic aneurysm, colectomy	Ischemia of colon	Weaned
32	81	Anastomotic leak with peritonitis	Colon resection with ileostomy	CVA, hypotension, sepsis	Not weaned Tracheostomy
33	68	Necrotizing abdominal wound infection	Small-bowel resection, exploratory laparotomy with debridement of wound infection, repair ventral hernia	Metabolic acidosis, hypotension, sepsis	Weaned
34	60	MVC: renal/hepatic lacerations, flail chest, gallbladder avulsion; internal carotid artery dissection	Exploratory laparotomy with repair of lacerations, cholecystectomy, IVC filter	CVA, DVT	Weaned Tracheostomy
35	78	Acute myocardial infarction	CABG x 4, intra-aortic balloon pump, placement of CVVH catheters	Atrial fibrillation, hypotension/ bradycardia, with external atrial pacemaker support, CVVH and hemodialysis	Weaned Tracheostomy
36	87	Self-inflicted GSW to abdomen with injuries to distal pancreas/transverse colon, diaphragmatic injury	Exploratory laparotomy with segmental resection of colon, repair of diaphragm, exploratory laparotomy with pancreatic debridement, colon resection, and ileostomy; exploratory laparotomy with distal pancreatectomy, splenectomy	Atrial fibrillation, supraventricular tachycardia, intraoperative liver laceration in second surgery, biliary obstruction, pleural effusion, hepatic abscess	Not weaned Tracheostomy
37	67	MVC: multiple extremity fractures pneumothorax, pulmonary contusion	ORIF bilateral ulna/radius	None	Weaned Tracheostomy
38	71	Colonic rupture with peritonitis	Partial colectomy with ileostomy	VRE infection, respiratory failure	Not weaned No tracheostomy Patient died after being in study 6 days
39	70	MVC: femur and ankle fractures, closed head injury	ORIF femur/ankle	Respiratory acidosis	Weaned Tracheostomy
40	72	Fall	Hemiarthroplasty	Postoperative respiratory distress	Not weaned Tracheostomy

Abbreviations: ARDS, acute respiratory distress syndrome; AVR, aortic valve replacement; CABG, coronary artery bypass graft; CAD, coronary artery disease; CVA, cerebrovascular accident; CVVH, continuous venovenous hemofiltration; DVT, deep vein thrombosis; GSW, gunshot wound; IVC, inferior vena cava; MVC, motor vehicle crash; ORIF, open reduction and internal fixation; VRE, vancomycin-resistant enterococcus.

lower in patients who were weaned off mechanical ventilation than they were in patients who were not weaned ($P<.001$).

Discussion

A systematic international review of the demographic characteristics of ICU patients indicated that the average patient receiving mechanical ventilation is 60 years old.[6] According to estimates, 42% to 48% of beds in ICUs in the United States are occupied by patients who are at least 65 years old.[18]

However, the potential interactions of age with severity of illness and prehospital morbid conditions preclude a uniform reliance on chronological age alone to predict patients' outcome after mechanical ventilation.[5] Study findings on the effect of chronolog-

Table 2 Initial and final weaning parameters of patients who were and were not weaned from mechanical ventilation

Parameter	Initial values*						Final values†					
	Weaned (n = 28)			Not weaned (n = 12)			Weaned (n = 28)			Not weaned (n = 12)		
	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD
Respiratory rate, breaths per minute‡	24	24	9	20	23	8	28	27	6	22	19	6§
Minute ventilation, L/min	9.75	9.6	2.6	9	8.1	2.2	8.8	9	2	9	10	3
Maximal inspiratory pressure, cm H_2O	-30	-32	12	-30	-28	5.5	-40	-36	32	-25	-15	42
Rapid shallow breathing index‖	92	74.5	52	64	47.3	39	87	70	41	94	51	36

*First set of values recorded upon entry into the study.
†For patients who were successfully weaned, last set of values recorded before successful weaning; for patients who were not weaned successfully, last set of values recorded on day 14 of the study.
‡While receiving mechanical ventilation.
§F = 12.6, $P < .001$.
‖ Calculated as respiratory rate measured in breaths per minute divided by tidal volume measured in breaths per liter per minute.

ical age on patients' outcomes have been inconsistent. In a study[19] of 4315 older patients who were 67 years old (SD 9) and who underwent nonemergent, noncardiac surgery, older age was associated with a significantly higher risk for bacterial pneumonia, respiratory failure requiring mechanical ventilation, longer hospital length of stay, and in-hospital mortality. In contrast, when the outcomes of patients older and younger than 75 years were compared by using a standardized weaning protocol in a prospective cohort study[20] of 63 patients receiving mechanical ventilation, the 2 groups did not differ significantly in duration of mechanical ventilation, lengths of ICU and hospital stay, or mortality rates; findings were similar when outcomes were compared by using a cutoff age of either 65 or 80 years. Yet in a more recent multisite, randomized, controlled study[21] of 902 patients with acute lung injury and acute respiratory distress syndrome who were receiving mechanical ventilation, patients 70 years and older spent significantly longer periods receiving mechanical ventilation and in the ICU than did younger patients, and they were less likely to survive.

In our study, patients who were successfully weaned within 14 days had significantly higher respiratory rates and pH than did patients who were not weaned. We found no clinically significant differences between the 2 groups in respiratory status, weaning parameters, calculation of BWAP factors, or oxygen cost of breathing. A shorter length of time to the initiation of weaning was associated with successful weaning from LTMV.

Our findings on initial values of arterial pH and respiratory rate among patients who were successfully weaned are similar to those reported by Goodnough Hanneman[22] in a study of 162 cardiac surgical patients during short-term mechanical ventilation. In that study, arterial pH during mechanical ventilation and spontaneous respirations were higher in patients who were successfully weaned. Goodnough Hanneman[22] proposed that arterial pH reflects not only the dimension of gas exchange but also hemodynamic status, because patients who cannot be weaned quickly may have impaired myocardial reserves that would otherwise enable the patients to respond with greater respiratory effort to the demands of the postoperative hypermetabolic process.

In our study, BWAP scores increased in patients who were successfully weaned and decreased in patients who were not, although these differences were not significant. Perhaps the poor differential performance of the BWAP was due to the population of patients and the small sample size. Previous studies with the BWAP involved patients in medical ICUs. In one study,[23] compared with 4 other weaning indices, the BWAP had the strongest negative predictive power. On the basis of these findings, Burns et al[23] suggested that scores of 65% or less may indicate that weaning should be delayed for the next 48 hours. More recently, Burns et al[17] reported that a score of 56% or higher may indicate readiness for active weaning in medical, critically ill patients. Future studies of the BWAP in older surgical patients with an adequately powered sample size might assist in testing the predictive power of the BWAP.

Our results did indicate significant differences in fluid balance between patients who were and were not

Table 3 Initial and final oxygenation variables for patients who and were not weaned from mechanical ventilation

Variable	Initial values*						Final values†					
	Weaned (n = 28)			Not weaned (n = 12)			Weaned (n = 28)			Not weaned (n = 12)		
	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD
Oxygen cost of breathing, % ‡	6	8.2 (n = 5)	3-15	6	6.7 (n = 4)	2-12	7	7.0 (n = 7)	1-17	4	4.0 (n = 3)	1-7
pH	7.44	7.44	0.04	7.40	7.40	0.12§	7.43	7.44	0.05	7.43	7.38	0.12‖
$Paco_2$, mm Hg	39	39	6	43	43	6	41	41	6	43	42	9
Pao_2, mm Hg	87	98	30	99	102	30	91	99	25	91	102	35
Base excess	2.45	2	4	2.45	1	4	2.45	3	4	1.7	0.4	9

*First set of values recorded upon entry into the study.
†For patients who were successfully weaned, last set of values recorded before successful weaning; for patients who were not weaned successfully, last set of values recorded on day 14 of the study.
‡For this variable, the range of values is provided rather than the SD. The number of patients in each cell differs from the total number of patients in each group and is indicated in parentheses in each cell.
§F = 9.4, *P* = .004.
‖F = 4.9, *P* = .03.

weaned. This finding is important for older surgical or trauma patients who require aggressive replacement of fluids early in the course of resuscitation. Underlying hypovolemia is common in older patients, because of poor oral intake and the use of diuretics. Hemorrhage, extracellular accumulation of fluid after surgery, systemic inflammatory response syndrome, and sepsis all require different combinations of crystalloids, colloids, and blood products. Mechanical ventilation itself induces a gradual fluid retention after 48 to 72 hours of positive-pressure ventilatory support.[24] With the onset of positive pressure ventilation, a decrease in venous return is thought to inhibit the release of atrial natriuretic peptide from cells embedded in the walls of the right atrium. Atrial stretch is normally the catalyst for the renal excretion of sodium and water mediated by atrial natriuretic peptide.[25] In addition, decreased venous return is sensed by the vagal stretch receptors positioned in the right atrium, which in turn stimulate the release of antidiuretic hormone from the posterior lobe of the pituitary gland and further contribute to fluid retention.[26] In the context of unstable hemodynamic status, hypovolemia, and mechanical ventilation, the decreased renal perfusion adds another trigger to fluid retention, through the activation of the renin-angiotensin-aldosterone system.

Mechanical ventilation induces a gradual fluid retention after 48 to 72 hours of positive-pressure ventilatory support.

In contrast, by increasing intrathoracic pressure, positive-pressure ventilation may also decrease left ventricular afterload,[27] thereby enhancing cardiac output, renal blood flow, and diuresis. However, this beneficial effect on cardiac output occurs in patients who have normal myocardial and respiratory function, including a normal cardiac output during mechanical ventilation and a normal left ventricular end-diastolic pressure.[28-30] The presence of left ventricular dysfunction during weaning in cardiac surgery patients is associated with unfavorable patterns of hemodynamic responses, including increases in CVP and pulmonary artery occlusion pressure, decreases in mean arterial pressure, acute decreases in cardiac output, and a failure to increase cardiac index.[28-30]

Resuscitation of older patients is complicated by known changes that occur with age, including increased hypertrophy and thickness of the left ventricular wall, decreased myocardial contractility, and decreased responsiveness to endogenous or exogenously administered catecholamines.[5,31] These patients often have diastolic dysfunction and thus require more fluids than younger patients do. Younger patients, and those with normal cardiovascular function, often begin to mobilize resuscitation fluid 48 to 72 hours after surgery or injury. Yet mobilization of fluids is often delayed in older patients, partly because of cardiac dysfunction and partly because of overexpansion of extracellular water.[32]

We measured fluid balance by calculating DFB on the day weaning started and on the day weaning ended, by calculating NCFB at the beginning and the end of the study, by comparing initial and final body weight, and by comparing CVP measurements. Although

Table 4 Comparison of initial and final systemic variables between patients who were and were not weaned from mechanical ventilation

	Initial values*						Final values[†]					
	Weaned (n = 28)			Not weaned (n = 12)			Weaned (n = 28)			Not weaned (n = 12)		
Variable	**Median**	**Mean**	**SD**	**Median**	**Mean**	**SD**	**Median**	**Mean**	**SD**	**Median**	**Mean**	**SD**
Hemoglobin level, g/L	102	102 (76-136)	11.4	99.5	102 (82-135)	14	99.5	101 (87-119)	9.3	102.5	100 (78-127)	15
Albumin level, g/L	21	25.6 (19-43)	10	21	21 (15-28)	6.5	23	23 (18-28)	3.2	23.5	25 (15-38)	8.6
Heart rate, beats per minute	99	92 (54-128)	19	95	94 (74-118)	13	95	94 (60-127)	15	96	90 (64-116)	15
Mean arterial pressure, mm Hg	88	89 (54-125)	18	88	86 (61-108)	15	94	91 (60-113)	15	77	84 (84-110)	16
Central venous pressure,[‡] mm Hg	10	9 (4-17) (n = 22)	3.18	12	12 (4-20) (n = 10)	4.5	8	8 (4-15) (n = 22)	3.14	12	15 (7-27) (n = 10)	6.4[§]
Daily net fluid balance, L	-0.268	-0.394 (-3.210 to 2.530)	1.387	0.521	1.107 (-0.212 to 4.727)	1.532[‖]	-0.556	-0.389 (-3.210 to 3.913)	1.694	0.422	1.904 (-2.485 to 12.458)	4.711[¶]
Net cumulative fluid balance, L	3.246	6.856 (-6.736 to 41.087)	11.579	13.011	16.212 (-14.507 to 63.848)	22.222	8.240	10.753 (-2.107 to 46.923)	12.259	16.182	25.049 (-3.781 to 72.753)	25.671[#]
Body weight, kg	84	84 (54-107)	14.5	79	91 (54-187)	37.9	81	81 (49-101)	13	82	92 (48-179)	37
Change in body weight, kg		NA			NA			3.2 (-6.7 to 16.4)	6		-0.9 (-19.7 to 13.0)	11
Burns Weaning Assessment Program score, %	46	47 (26-73)	11	54	52 (38-62)	8	54	53 (19-80)	12	50	50 (34-77)	11

*First set of values recorded upon entry into the study. Values in parentheses are ranges.
[†] For patients who were successfully weaned, last set of values recorded before successful weaning; for patients who were not weaned successfully, last set of values recorded on day 14 of the study. Values in parentheses are ranges.
[‡] The number of patients in each cell differs from the total number of patients in each group and is indicated in parentheses in each cell.
[§] F = 16.4, $P < .001$.
[‖] F = 9.24, $P = .004$.
[¶] F = 5.22, $P = .03$.
[#] F = 5.79, $P = .02$.
Abbreviation: NA, not applicable.

change in body weight was not significantly associated with successful weaning, patients who were weaned had a decrease in body weight over time, whereas patients who were not weaned had an increase in body weight throughout the study period.

Patients who were weaned successfully during the 14-day period had a negative mean DFB both initially and at the end of successful weaning, whereas patients who remained ventilator dependent had a positive mean DFB. Most significantly, though, NCFB on the day of successful weaning was comparatively negative in patients who were weaned successfully and comparatively positive in patients who remained ventilator dependent. CVP was significantly lower in patients who were weaned successfully.

Mobilization of fluids is often delayed in older patients, partly because of cardiac dysfunction.

Little information is available on the effects of volume replacement and fluid management on weaning from mechanical ventilation. In a retrospective study[33] of 119 critically injured patients, fluid retention of more than 2000 mL in the first 48 hours was a factor indicating the need for prolonged mechanical ventilation. A prospective study[34] of fluid balance and weaning from mechanical ventilation in 87 patients indicated that fluid balance was significantly more negative in patients who were successfully weaned than in patients who were not weaned. In an observational, prospective study[35] of postoperative ICU patients, patients who were not weaned had a significantly greater weight gain than did patients who were successfully weaned off mechanical ventilation.

The value of aggressive diuresis in older critically ill patients is unclear, and we did not evaluate this intervention. It is unclear whether induced negative fluid balance contributed to more rapid weaning or whether the ability to achieve spontaneous negative fluid balance was a predictor of weaning success. Despite the observation of a relationship between fluid balance and weaning from mechanical ventilation, no studies have indicated a role for diuretics in facilitating weaning from mechanical ventilation. In a study[36] of patients with acute lung injury and hypoproteinemia, compared with a control group, patients given albumin and furosemide had improvements in oxygenation, but weaning from mechanical ventilation did not differ between the 2 groups.

Clinicians should have an ongoing knowledge of NCFB and the potential indications for active diuresis to facilitate resolution of peripheral and pulmonary edema and to decrease CVP. Ongoing fluid retention, or the inability to respond to active diuresis, may indicate that a patient will most likely require LTMV.

Ongoing fluid retention, or the inability to respond to active diuresis, may indicate that a patient will most likely require long-term mechanical ventilation.

Limitations

In this study, we monitored patients for a maximum of 14 days and thus could not evaluate the effects of weaning variables on patients who required ventilatory support after the study period. In addition, many of the patients were transferred to long-term acute care facilities for completion of weaning, so the actual length of weaning could not be determined.

The potential for inaccuracy and lack of precision of clinical data retrieved from daily flow sheets is another limitation of the study. The investigators and research assistants could not be present consistently at the bedside when a weaning trial was initiated by the respiratory therapist.

Finally, many of the patients in the study underwent tracheostomy, increasingly so at the end of the study. The association of tracheostomy with weaning from LTMV could not be addressed. Tracheostomy and its influence on duration of mechanical ventilation, occurrence of pneumonia, ICU length of stay, and mortality remain controversial.[37-39]

Conclusion

In a study of older surgical and trauma patients, parameters associated with fluid balance were associated with the ability to be weaned from mechanical ventilation. Previous predictors such as weaning parameters, BWAP scores, and O_2COB were not useful as predictors in these patients. Surgical patients who require large volumes of fluids and have persistently positive NCFB may benefit from active diuresis to facilitate weaning from mechanical ventilation. Further prospective studies, including potential interventions to normalize fluid balance during weaning, will be most useful in the assessment and management of older trauma and surgical patients.

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Commentary by Mary Jo Grap (see shaded boxes).

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