The Effect of a Mechanical Ventilation Discontinuation Protocol in Patients with Simple and Difficult Weaning: Impact on Clinical Outcomes

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OBJECTIVE: We sought to determine whether the utilization of a respiratory therapist (RT) driven mechanical ventilation weaning protocol is associated with improvement in clinical outcomes in subjects with simple versus difficult weaning. METHODS: This was a retrospective analysis of prospectively collected data obtained during a quality improvement project. We collected data on 803 consecutive mechanically ventilated patients admitted to the ICU of an academic tertiary care hospital. We compared an RT-driven weaning protocol to a physician-driven weaning strategy. RESULTS: Of the 803 patients, 651 with simple weaning and 131 with difficult weaning were included in the analysis. In the subjects with simple weaning, 514 (79%) were weaned with the RT-driven protocol. Among the difficult weaning subjects, 101(77.1%) were liberated with the RT-driven protocol. A multivariate analysis, which included Acute Physiology and Chronic Health Evaluation II, body mass index, and type of primary ICU team under which the subjects were admitted, revealed a significant difference in ventilator-free days at 28-days, which supports the RT-driven protocol over the physician-driven strategy. Specifically, the RT-driven protocol increased ventilator-free days by 20.92% and 68.2% among subjects with simple and difficult weaning, respectively. A multivariate analysis of ICU mortality and extubation failure found no significant difference between the RT-driven protocol and the physician-driven strategy. CONCLUSIONS: The RT-driven weaning protocol increased ventilator-free days among subjects with simple and difficult weaning, with no significant differences in ICU mortality or extubation failure. *Key words: mechanical ventilation; weaning; protocols; extubation; respiratory failure; respiratory therapist.* [Respir Care 2014;59(2):170–177. © 2014 Daedalus Enterprises]

Introduction

The process of mechanical ventilation discontinuation consists of a systematic number of steps, which involve screening patients for reversal of the underlying cause of respiratory failure, spontaneous breathing trial (SBT), and assessment of airway patency. Over the last few years, guidelines on ventilator discontinuation have been published, allowing clinicians to organize their practice, but also providing them with flexibility to fill existing gaps when uncertainty remains.[1] Nevertheless, with the current

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need of standardization of best-care-practices, the evaluation and application of respiratory care protocols have dramatically expanded. Particularly, mechanical ventilation weaning protocols have been studied since 1989,[2] and the number of publications has grown ever since.[3] In fact, based on a survey of directors of respiratory therapy departments, published in 2012, 96.2% of surveyed hospitals ($n = 663$) responded that they relied on protocols for ventilator management.[4]

Recently, an international task force on ventilator discontinuation recommended categorization of weaning patients into 3 groups: simple weaning, defined as successful liberation and extubation after the first SBT; difficult weaning, defined as patients who require up to 3 SBTs or as long as 7 days after the initial SBT attempt; and prolonged weaning, defined as the need of more than 3 SBTs or more than 7 days after the first SBT.[5] Despite clear evidence supporting the utilization of mechanical ventilation weaning protocols in clinical practice, many gaps in our understanding still remain. Specifically, how do ventilator protocols perform when applied to patients with simple weaning, compared with those in whom weaning is difficult or prolonged? In order to answer the aforementioned question, we assessed a consecutive series of mechanically ventilated patients admitted to the ICU at Creighton University Medical Center. These subjects underwent the process of weaning from the ventilator, based on a respiratory therapist (RT) driven weaning protocol or a physician-driven weaning order. We aimed to compare the effect on clinical outcomes of a mechanical ventilation liberation protocol versus a physician-ordered weaning strategy, within groups of subjects with simple and difficult weaning.

QUICK LOOK

Current knowledge

Protocol-based ventilator weaning with daily spontaneous breathing trials speeds ventilator discontinuation, compared to routine physician-ordered weaning.

What this paper contributes to our knowledge

A respiratory-therapist-driven protocol that included a weaning-readiness screening and spontaneous breathing trials increased ventilator-free days, compared to physician-directed weaning, both in simple-to-wean and difficult-to-wean patients, and with no difference in extubation-failure rate.

Methods

In September 2011, Creighton University Medical Center adopted a mechanical ventilation weaning protocol (Table 1). This protocol was approved based on prior evidence suggesting benefits of RT-driven weaning protocols, compared with physician-ordered weaning strategies. Hence, as an institutional policy, all patients in our mixed (medical, surgical, trauma, and neurologic) ICU started to be liberated from mechanical ventilation following the previously described protocol, unless the attending physician of the primary service opted out of protocol participation. The decision to opt-out was based on physician preference, physician comfort, and prior training. In order to assess the clinical effect of opting out from the protocol, we initiated a quality improvement project to assess whether this decision (opting out) was associated with worse clinical outcomes. This study was exempt from the Creighton University Medical Center institutional review board. From September 2011 to August 2012, a group of RTs initiated a prospective collection of data on every mechanically ventilated patient admitted to the ICU at Creighton University Medical Center. Demographic information, severity of disease based on the Acute Physiology and Chronic Health Evaluation II (APACHE II) score, diagnosis on ICU admission, type of primary ICU team (medical, surgical, trauma, neurologic), time on mechanical ventilation per intubation episode, weaning attempts per intubation episode, need for reintubation or noninvasive ventilation within 48 hours post-extubation, need for tracheostomy, and ICU mortality were prospectively collected on a daily basis.

In the present study we retrospectively reviewed the data to assess whether opting in versus opting out of a ventilator weaning protocol affected clinical outcomes in subjects with simple or difficult weaning. All subjects who were deemed ready for weaning underwent an SBT, after fulfilling certain parameters, as shown in Table 1. We grouped the subjects according to number of weaning attempts: simple weaning (1 attempt), difficult weaning (2 or 3 attempts or up to 7 days after initial SBT), and prolonged weaning (> 3 attempts or > 7 d after the initial SBT). Patients with prolonged weaning were not included in the analysis, as many of them were transferred to long-term acute care facilities, precluding evaluation of outcomes. Within the simple weaning and difficult weaning groups, we divided the subjects based on whether the attending physicians opted in or out of the ventilator discontinuation protocol. Clinical outcomes were compared between those groups. Of note, subjects who were reintubated after 48 hours of extubation were considered independent subjects. The primary outcome of interest was ventilator-free days at 28 days. Secondary outcomes were extubation failure, defined as the need of reintubation or noninvasive ventilation within 48 hours after extubation, and ICU mortality. Furthermore, within each group (simple or difficult weaning) we assessed the outcomes mentioned above according to the type of primary ICU team

Table 1. Assessment for Readiness for Spontaneous Breathing Trial, Spontaneous Breathing Trial Settings and Criteria, and Assessment for Extubation Readiness

Step	Criteria and Action
1	The ventilator patient in the ICU must meet all of the following criteria to enter the ventilator-weaning protocol:
	Hemodynamic stability
	Heart rate between 50 and 120 beats/min
	Blood pressure between 90 and 180 mm Hg
	No pressors
	$S_{pO_2} > 90\%$
	$F_{IO_2} < 0.50$
	PEEP < 8 cm H_2O
	Spontaneously breathing
	Tidal volume > 5 mL/kg on pressure support of zero and PEEP of zero
	Negative inspiratory force less than -20 cm H_2O on pressure support of zero and PEEP of zero
	Rapid shallow breathing index < 105 on pressure support of zero and PEEP of zero
	Minute ventilation < 15 L/min on pressure support of zero and PEEP of zero
	If *all* the above parameters are within goal, proceed to spontaneous breathing trial.
	If *any* parameter does not meet the goal, leave the patient on the prior ventilation mode and notify the physician.
2	Spontaneous Breathing Trial
	Pressure support 5 cm H_2O
	PEEP 5 cm H_2O
	60-min trial
	During the spontaneous breathing trial assess for the following signs of distress and/or failure:
	Breathing frequency > 35 breaths/min
	$S_{pO_2} < 90\%$
	Tidal volume < 5 mL/kg ideal body weight with pressure support
	Increase or decrease of heart rate or blood pressure by 20% from baseline
	Substantial agitation, anxiety, and/or diaphoresis
	If any of above signs is present, place the patient back on the previous ventilation settings and notify the physician.
3	Reevaluate in the morning. If the patient has none of the above signs of failure, proceed to assessment for extubation readiness.
4	Assessment for Extubation Readiness
	Adequate cough/gag reflex
	Minimal secretions (suctioning required no more often than every 2 hours)
	If the patient passes the assessment for extubation readiness, contact the physician on service responsible for ventilator management, to obtain the extubation order.

(medical, surgical, trauma, neurologic) the subjects were admitted to, and their severity on admission. Every subject who was opted in received sedation vacation in the morning, and the weaning protocol was initiated when the Richmond Agitation-Sedation Scale score was 0 to -2. In the opt-out group sedation vacation and weaning was per physician preference.

Statistical Methods

Within each group the subjects were stratified by whether the attending physician opted in or out of the ventilator discontinuation protocol. Continuous baseline demographic and clinical variables are presented as mean ± standard deviation, whereas categorical variables are presented as number and percent. Univariate analyses were conducted separately for subjects within the simple and difficult weaning groups, and employed independent-samples *t* tests and Fisher exact tests for continuous and categorical variables, respectively.

We evaluated for differences between subjects whose physician opted in or out of the ventilator discontinuation protocol in both ventilator-free days and the ratio of ventilator-free days to stay after adjusting for APACHE II score, body mass index (BMI), and type of ICU. For both primary outcomes, multiple regression models were estimated separately within the simple and difficult weaning groups.

Two issues were encountered when modeling the data for the 2 primary outcomes. First, for ventilator-free days, severely negatively skewed residuals were observed within the analyses in both groups. Therefore, the number of ventilator-free days was reflected, so the value of the highest number of ventilator-free days became the lowest value, and vice versa. Reflecting the data resulted in distributions of residuals with severe positive skewness, which was accounted for by using a natural log transformation of the reflected ventilator-free day values. It is important to note that both reflecting the outcome data and using a natural log transformation substantially affect how regression es-

Table 2. Univariate Analyses of Demographic and Clinical Variables for Patients Included in the Primary Analysis

	Simple Weaning			Difficult Weaning		
	Opt-In $n = 470$	Opt-Out $n = 120$	P	Opt-In $n = 99$	Opt-Out $n = 30$	P
Age, mean ± SD y	57.95 ± 18.21	54.61 ± 18.97	.06	61.16 ± 15.07	54.50 ± 18.29	< .001
Weight, mean ± SD kg	84.65 ± 24.69	84.11 ± 24.68	.82	87.48 ± 33.22	87.02 ± 22.06	.94
Height, mean ± SD cm	172 ± 10	172 ± 11	.94	171 ± 10	172 ± 11	.54
Body mass index, mean ± SD kg/m^2	28.49 ± 8.40	28.15 ± 7.77	.68	29.44 ± 11.90	30.86 ± 11.38	.57
Acute Physiology and Chronic Health Evaluation score, mean ± SD	19.23 ± 6.17	19.91 ± 6.58	.27	19.74 ± 5.52	20.20 ± 7.25	.75
Ventilator-free days, mean ± SD d	24.39 ± 7.08	22.53 ± 8.47	< .001	23.26 ± 5.54	20.68 ± 6.66	< .001
Stay, mean ± SD d	12.44 ± 17.22	17.96 ± 23.67	< .001	18.84 ± 14.97	26.10 ± 23.33	< .001
Ventilator-free days/stay	0.23 ± 0.30	0.26 ± 0.31	.47	0.24 ± 0.20	0.35 ± 0.25	< .001
Male, no. (%)	321 (64.1)	92 (68.7)	.36	56 (56.0)	16 (53.3)	.84
ICU type, no. (%)						
Medical	208 (45.5)	43 (35.8)	.050	47 (47.0)	9 (30.0)	.14
Surgical	171 (34.9)	36 (28.4)	.18	34 (34.0)	13 (43.3)	.39
Trauma	91 (19.6)	41 (35.8)	< .001	18 (19.0)	8 (26.7)	.44
ICU deaths, no. (%)	31 (6.2)	14 (10.4)	.09	1 (1.0)	0 (0)	> .99
Surgery ICU, no. (%)*						
Cardiac	104 (60.6)	5 (15.8)	< .001	26 (76.5)	1 (7.7)	< .001
Abdominal	47 (28.0)	25 (68.4)	< .001	4 (11.8)	6 (46.2)	< .001
Thoracic	17 (9.7)	3 (7.9)	> .99	3 (8.8)	2 (15.4)	.61
Trauma ICU, no. (%)†						
Cardiac	3 (3.1)	1 (2.1)	> .99	1 (5.3)	0 (0)	> .99
Abdominal	15 (15.3)	6 (12.5)	.80	2 (10.5)	0 (0)	> .99
Thoracic	14 (14.3)	7 (14.6)	> .99	2 (10.5)	0 (0)	> .99

* Simple opt-in $n = 175$, simple opt-out $n = 38$, difficult opt-in $n = 34$, difficult opt-out $n = 13$.
† Simple opt-in $n = 98$, simple opt-out $n = 48$, difficult opt-in $n = 18$, difficult opt-out $n = 8$.

timates are interpreted. Specifically, using reflected data results in positive regression estimates being associated with decreases in ventilator-free days. Further, a natural log transformation produced regression estimates that are associated with changes in the natural log of ventilator-free days. For example, using reflected and natural log transformed ventilator-free days, a regression estimate of +2.0 would indicate that for every one-unit increase in the independent variable the natural log of ventilator-free days decreases by 2.0.

Second, for the ratio of ventilator-free days to stay there was severe positive skewness, which was remedied by using a natural log transformation. This transformation also affected the interpretation: an increase in an independent variable resulted in an increase in the natural log of the ratio of ventilator-free days to stay. For all primary analyses, non-constant variance was indicated in residual values, which was accounted for using a technique described by MacKinnon and White.[6]

For the secondary outcomes, multiple logistic regression analyses were employed to evaluate differences in both the probability of ICU death and extubation failure between subjects whose physicians opted in or out of the ventilator discontinuation protocol, after adjusting for APACHE II score, BMI, and type of ICU. No differences in ICU death could be evaluated within the difficult weaning group, as only one subject died.

For all the regression-type models, continuous predictors were centered near their mean. All analyses were conducted with statistics software (SAS 9.3, SAS Institute, Cary, North Carolina). $P < .05$ was considered statistically significant.

Results

Over the year post-implementation of the RT-driven ventilator weaning protocol, 803 patients were admitted and mechanically ventilated in our ICU. Of those patients, 651 (81.1%) required simple weaning, whereas 131 (16.3%) and 1 (0.1%) were difficult and prolonged weaning cases, respectively. Demographic information, APACHE II scores, and ICU type are shown in Table 1. Among subjects who required simple weaning, 514 (79.0%) were weaned with the RT-driven protocol, whereas 137 (21.0%) were liberated from the ventilator by physician orders. In the group of subjects with difficult weaning, 101 (77.1%)

Table 3. Multiple Regression Results for Number of Ventilator-Free Days*

	Simple Weaning			Difficult Weaning		
	Estimate	Standard Error	95% CI	Estimate	Standard Error	95% CI
Intercept	1.13	0.07		2.03	0.16	
Acute Physiology and Chronic Health Evaluation II score (0 = 20)	0.03*	0.01	0.02 to 0.04	0.02	0.01	0 to 0.04
Body mass index (0 = 30)	0	0	−0.01 to 0.01	0	0.01	−0.01 to 0.01
ICU type						
Surgery vs medical	−0.37*	0.06	−0.49 to −0.25	−0.68*	0.15	−0.97 to −0.38
Trauma vs medical	0.09	0.08	−0.08 to 0.25	0.35	0.18	0 to 0.70
Surgery vs trauma	−0.46*	0.08	−0.62 to −0.29	−1.03*	0.18	−1.38 to −0.68
Opt-out vs opt-in	−0.19*	0.07	−0.33 to −0.04	−0.52*	0.15	−0.82 to −0.21

* $P < .05$. Because we natural log transformed ventilator-free days, a 1-unit increase in any predictor variable is associated with a change in the natural log of ventilator-free days. Because the number of ventilator-free days was reflected prior to analysis, a positive regression estimate (ie, estimate) is associated with a decrease in ventilator-free days.

Table 4. Multiple Regression Results for Ratio of Ventilator-Free Days to Stay*

	Simple Weaning			Difficult Weaning		
	Estimate	Standard Error	95% CI	Estimate	Standard Error	95% CI
Intercept	−1.79	0.12		−0.93		
Acute Physiology and Chronic Health Evaluation II score (0 = 20)	0.03*	0.01	0.02 to 0.05	0.02	0.02	−0.01 to 0.05
Body mass index (0 = 30)	−0.01	0.01	−0.02 to 0.01	0	0.01	−0.01 to 0.02
ICU type						
Surgery vs medical	−1.17*	0.11	−1.39 to −0.96	−1.13*	0.20	−1.53 to −0.73
Trauma vs medical	0.13	0.13	−0.12 to 0.39	0.12	0.24	−0.35 to 0.59
Surgery vs trauma	−1.31*	0.12	−1.56 to −1.05	−1.25*	0.24	−1.72 to −0.78
Opt-out vs opt-in	−0.01	0.13	−0.24 to 0.22	−0.62*	0.21	−1.03 to −0.22

* $P < .05$. Because we natural log transformed the ratio, a 1-unit increase in any predictor variable is associated with a change in the natural log of the ratio.

used the weaning protocol, whereas only 30 (22.9%) were weaned based on physician orders. Of these subjects, 49 (simple $n = 48$, difficult $n = 1$) died in the ICU, and an additional 14 were missing predictor variables (simple $n = 13$, difficult $n = 1$). Because the regression-type models used in this study consider only subjects with complete data, the sample sizes differed between the analyses. That is, a subject with missing data on any variable was excluded from analysis. Therefore, given the missing data, the primary analyses included 590 subjects in the simple weaning group and 129 subjects in the difficult weaning group, ICU death included 638 subjects (simple weaning group only), and extubation failure included 638 and 130 subjects for the simple and difficult weaning groups, respectively.

The results for number of ventilator-free days are presented in Table 3. In the simple weaning group there was a statistically significant difference in the number of ventilator-free days between the opt-in and opt-out subjects. After adjusting for APACHE II score, BMI, and ICU type, opting in was associated with a 20.9% increase in ventilator-free days, compared to the opt-out group (ie, $((1/\exp(-0.19)) - 1) \times 100$). As explained in the statistical methods section, the increase in ventilator-free days associated with a negative regression coefficient is a direct result of reflecting the ventilator-free days prior to analysis. A similar pattern of results was observed for the difficult weaning group: after adjusting for APACHE II score, BMI, and ICU type, opting-in was associated with a 68.2% increase in ventilator-free days, compared to opting out.

The results for the ratio of ventilator-free days to stay are presented in Table 4. For the difficult weaning group there was a statistically significant difference in the ratio of ventilator-free days to stay between the opt-in and opt-out subjects. After adjusting for APACHE II score, BMI, and ICU type, opting in was associated with a 32.2% increase in this ratio, compared to opting out (ie, $(1 - \exp(-0.39)) \times 100$). For the simple weaning group,

Table 5. Multiple Logistic Regression Results for ICU Death in the Simple Weaning Group

	Estimate	Standard Error	Odds Ratio	95% CI for Odds Ratio
Intercept	−1.78	0.39		
Acute Physiology and Chronic Health Evaluation II score (0 = 20)	0.12*	0.02	1.13	1.07–1.18
Body mass index (0 = 30)	0	0.02	1.00	0.96–1.04
ICU type				
Surgery vs medical	−0.81	0.47	0.45	0.17–1.16
Trauma vs medical	−0.66	0.40	1.93	0.88–4.27
Surgery vs trauma	−1.47	0.52	0.23	0.08–0.63
Opt-out vs opt-in	−0.39	0.36	0.68	0.34–1.36

* $P = < .001$.

Table 6. Multiple Logistic Regression Results for Extubation Failure

	Simple Weaning				Difficult Weaning			
	Estimate	Standard Error	Odds Ratio	95% CI for Odds Ratio	Estimate	Standard Error	Odds Ratio	95% CI for Odds Ratio
Intercept	−2.37	0.42			−1.75	0.71		
Acute Physiology and Chronic Health Evaluation II score (0 = 20)	−0.02	0.03	0.98	0.93–1.04	0.03	0.05	1.03	0.93–1.14
Body mass index (0 = 30)	−0.04	0.03	0.96	0.91–1.01	0.06*	0.02	1.06	1.02–1.11
ICU type								
Surgery vs medical	−0.84	0.45	0.43	0.18–1.05	0.11	0.70	1.11	0.28–4.42
Trauma vs medical	−0.98	0.53	0.37	0.13–1.06	−0.60	0.97	0.55	0.08–3.66
Surgery vs trauma	0.14	0.61	1.15	0.35–3.80	0.71	0.97	2.02	0.30–13.64
Opt-out vs opt-in	−0.30	0.43	0.74	0.32–1.72	−0.62	0.65	0.54	0.15–1.92

* $P = < .001$.

opt-in or opt-out was not associated with a difference in the ratio.

The results for ICU death and extubation failure are presented in Tables 5 and 6. There were no statistically significant differences between the opt-in and opt-out subjects in the probability of death or extubation failure.

Discussion

The main findings of this study are:

- The ventilation liberation protocol increased ventilator-free days, compared with the physician-driven strategy, in both the simple and difficult weaning groups, and after adjustment for severity of disease, BMI, and type of ICU.
- When the number of ventilator-free days was adjusted for the total number of hospital days, opting-out decreased the ventilator-free days in the difficult-to-wean subjects.
- There were no differences in ICU mortality or extubation failure between the opt-in and opt-out groups, in both the simple and difficult weaning groups.

To the best of our knowledge, this is the first study to compare an RT-driven weaning protocol to a physician-driven strategy within groups of patients with different weaning complexity (simple and difficult). Prior studies on RT-driven weaning protocols did not specify whether the subjects were classified as simple, difficult, or prolonged weaning. Specifically, Ely and colleagues[7] studied 300 mechanically ventilated subjects in medical and coronary ICUs. After a daily screening by RTs and nurses, the intervention group underwent a 2-hour SBT with CPAP of 5 cm H_2O, whereas the control group was liberated based on standard practice. Notably, the study revealed a reduction of duration of mechanical ventilation, reintubation rate, and costs with the SBT strategy. The following year, Kollef and colleagues[8] published a study comparing protocol-directed to physician-directed weaning. Three hundred fifty-seven subjects admitted to the medical and surgical ICUs were included. Subjects randomized to the protocol-directed strategy had a median ventilation dura-

tion of 35 hours, compared with 44 hours among the subjects in the physician-directed strategy ($P = .02$). Differences in hospital mortality and costs were not statistically significant between the groups. It is noteworthy that the studies by Ely,[7] and Kollef[8] and our study included subjects with similar severity of disease (average APACHE II scores of 18.85, 17.05, and 19.75, respectively), but ICU mortality differed substantially, with ranges of 22–23%, 38–40%, and 1–13%, respectively. These differences may be related to improvement in overall ICU care over the last 16 years, and further application of evidence-based bundles (eg, sepsis, low-tidal volume). Marelich and colleagues[9] randomized 335 subjects from medical and surgical ICUs to a 30-min SBT performed with either pressure support or T-piece, versus standard ICU care. The SBT subjects had shorter ventilation duration and a trend toward a reduced rate of ventilator-associated pneumonia. Interestingly, that study applied different weaning strategies, depending on whether the subject had been ventilated for more or less than 72 hours. Subjects ventilated less than 72 hours were liberated after an SBT, whereas those ventilated for $>$ 72 hours were gradually weaned to specific goals and then underwent SBT.

A more recent study by Krishnan and colleagues[10] found no differences in clinical outcomes between an RT-driven weaning protocol and a physician-driven strategy. Interestingly, the staffing model applied in their closed ICU might explain the lack of differences in outcomes. Particularly, the usual group had a staffing model with a physician-hour/bed/day of 9.5, compared with Ely[7] (3.5 h), Kollef[8] (4.0 h), Marelich[9] (4.7 h), and ours ($\cong$ 4.5 h), which had a lower physician-hour/bed ratio. Therefore, it is likely that the control group in the Krishnan study received higher intensity care than at most institutions.

Among studies that addressed weaning in organ-specific ICUs, Navalesi and colleagues[11] randomized 318 subjects from a neurologic ICU to a liberation protocol consisting of a 1-hour SBT, versus usual care (physician-driven strategy). There was a lower incidence of extubation failure (5% vs 12%, $P = .047$) in the intervention group. Secondary outcomes, such as ventilation duration, ICU stay, rate of tracheostomy, and ICU mortality, were not different between groups.

Finally, a recent meta-analysis by Blackwood and colleagues,[12] which included 11 randomized-control trials (1,971 subjects), found weaning protocols were associated with a 25% reduction in the mean duration of mechanical ventilation ($P = .006$), with the highest impact in surgical ICU subjects.

Our work adds to the current knowledge, as this is the first study that addresses the effect of a weaning protocol on subjects with different weaning classifications. We studied a large number of subjects (782), which is the largest number of weaning subjects considered in a weaning study. Also, all subjects were admitted to one mixed ICU that uses the same protocols in all patients for all aspects of ICU care (eg, sepsis bundle, low-tidal volumes, glucose control). Therefore, it is unlikely that our results are due to heterogeneity in patient care. Despite the aforementioned strength, our study has several limitations. First, as we analyzed our data retrospectively, it is likely that we incurred selection and information biases. We did not collect the reasons why providers opted out of the protocol. It is possible that some of the opt-out subjects had contraindications to an RT-driven protocol (ie, need for deep sedation due to airway instability). Also there were imbalances in the distribution of subjects within the groups. For example, more post-cardiac-surgery subjects were included in the opt-in group, whereas post-abdominal-surgery subjects were most frequently opted out. These imbalances may have impacted our results, as post-cardiac-surgery subjects are on mechanical ventilation only briefly.[13,14] Conversely, post-abdominal-surgery subjects are more likely to have complications[15] (eg, abdominal compartment syndrome, atelectasis) that prolong ventilation. By performing multivariate analysis we attempted to adjust based on type of ICU, but our analysis did not include adjustments within surgical ICU subjects. Finally, the approach to weaning in the physician-driven group may have been affected by behavioral factors. Providers within certain ICUs may have decided to wean subjects in a more conservative fashion, based on, for instance, their prior experiences or training.

Conclusions

In summary, our study demonstrated that an RT-driven weaning protocol increased ventilator-free days in both the simple and difficult weaning groups, and when adjusted for severity of disease, BMI, and type of ICU. The rate of extubation failure and ICU mortality were not affected by the weaning strategies within the groups.

REFERENCES

1. MacIntyre NR, Cook DJ, Ely EW Jr, Epstein SK, Fink JB, Heffner JE, et al. Evidence-based guidelines for weaning and discontinuing ventilatory support: a collective task force facilitated by the American College of Chest Physicians; the American Association for Respiratory Care; and the American College of Critical Care Medicine. Chest. 2001;120(6 Suppl):375S-395S.
2. Tomlinson JR, Miller KS, Lorch DG, Smith L, Reines HD, Sahn SA. A prospective comparison of IMV and T-piece weaning from mechanical ventilation. Chest 1989;96(2):348-352.
3. Haas CF, Loik PS. Ventilator discontinuation protocols. Respir Care 2012;57(10):1649-1662.
4. Kacmarek RM, Barnes TA, Durbin CG Jr. Survey of directors of respiratory therapy departments regarding the future education and credentialing of respiratory care students and staff. Respir Care 2012; 57(5):710-720.

5. Boles JM, Bion J, Connors A, Herridge M, Marsh B, Melot C, et al. Weaning from mechanical ventilation. Eur Respir J 2007;29(5): 1033-1056.
6. MacKinnon JG, White H. Some heteroscedasticity-consistent covariance matrix estimators with improved finite sample properties. J Econometrics 1985;29:305-325.
7. Ely EW, Baker AM, Dunagan DP, Burke HL, Smith AC, Kelly PT, et al. Effect on the duration of mechanical ventilation of identifying patients capable of breathing spontaneously. N Engl J Med 1996; 335(25):1864-1869.
8. Kollef MH, Shapiro SD, Silver P, St John RE, Prentice D, Sauer S, et al. A randomized, controlled trial of protocol-directed versus physician-directed weaning from mechanical ventilation. Crit Care Med 1997;25(4):567-574.
9. Marelich GP, Murin S, Battistella F, Inciardi J, Vierra T, Roby M. Protocol weaning of mechanical ventilation in medical and surgical patients by respiratory care practitioners and nurses: effect on weaning time and incidence of ventilator-associated pneumonia. Chest 2000;118(2):459-467.
10. Krishnan JA, Moore D, Robeson C, Rand CS, Fessler HE. A prospective, controlled trial of a protocol-based strategy to discontinue mechanical ventilation. Am J Respir Crit Care Med 2004;169(6): 673-678.
11. Navalesi P, Frigerio P, Moretti MP, Sommariva M, Vesconi S, Baiardi P, et al. Rate of reintubation in mechanically ventilated neurosurgical and neurologic patients: evaluation of a systematic approach to weaning and extubation. Crit Care Med 2008;36(11):2986-2992.
12. Blackwood B, Alderdice F, Burns K, Cardwell C, Lavery G, O'Halloran P. Use of weaning protocols for reducing duration of mechanical ventilation in critically ill adult patients: Cochrane systematic review and meta-analysis. BMJ 2011;342:c7237.
13. Gruber PC, Gomersall CD, Leung P, Joynt GM, Ng SK, Ho KM, et al. Randomized controlled trial comparing adaptive-support ventilation with pressure-regulated volume-controlled ventilation with automode in weaning patients after cardiac surgery. Anesthesiology 2008;109(1):81-87.
14. Dongelmans DA, Veelo DP, Paulus F, de Mol BA, Korevaar JC, Kudoga A, et al. Weaning automation with adaptive support ventilation: a randomized controlled trial in cardiothoracic surgery patients. Anesth Analg 2009;108(2):565-571.
15. Sachdev G, Napolitano LM. Postoperative pulmonary complications: pneumonia and acute respiratory failure. Surg Clin North Am. 2012;92(2):321-344.

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