Comparison Between Automatic Tube Compensation and Continuous Positive Airway Pressure During Spontaneous Breathing Trials

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BACKGROUND: Various methods to perform spontaneous breathing trials (SBTs) exist, but no one method has been shown to be superior. Automatic tube compensation (ATC) is a new and potentially advantageous ventilation mode to use during SBT. We compared ATC to continuous positive airway pressure (CPAP) during SBTs, to determine their efficacy in identifying patients ready to be liberated from mechanical ventilation. METHODS: We randomized 118 adults in a general intensive care unit on mechanical ventilation for ≥ 24 h who were about to undergo an SBT as part of an established respiratory-therapist-driven weaning protocol to undergo 30 min SBT with ATC or CPAP with no pressure support. We predefined the SBT-failure criteria. The primary outcome was duration of weaning (days from first SBT to extubation). Other outcomes included unsuccessful extubation within 48 h, first-SBT-pass rate, and total duration of mechanical ventilation. RESULTS: We found a trend toward less failure of first SBT with ATC, compared to CPAP (3% vs 13% respectively, $P = .09$), but no difference in duration of weaning, rate of unsuccessful extubation, or duration of mechanical ventilation. CONCLUSIONS: When applied as part of a respiratory-therapist-driven weaning protocol in a general intensive-care population, SBTs with ATC were safe but did not hasten liberation from mechanical ventilation, when compared to CPAP. *Key words: spontaneous breathing trial; automatic tube compensation; ventilator weaning; weaning predictors; mechanical ventilation.* [Respir Care 2010;55(5):549–554. © 2010 Daedalus Enterprises]

Introduction

A spontaneous breathing trial (SBT) is the recommended[1,2] and widely used[3] final test for assessment of readiness for discontinuation of mechanical ventilation in patients recovering from respiratory failure. Passing the SBT is interpreted as readiness for discontinuation of ventilatory support, whereas failing the SBT indicates non-readiness. The diagnostic accuracy of SBT is, however, limited. By failing to identify a patient who is ready for discontinuation of ventilatory support, a failed SBT could unnecessarily prolong duration of mechanical ventilation.[4] On the other hand, passing an SBT can be associated with a re-intubation rate of up to 20%,[5-8] with the associated risks of worse outcomes.[9,10] Ventilator-weaning guidelines imply that the SBT method (T-piece, low-level continuous positive airway pressure [CPAP], or a low level of pressure support) has little effect on outcome.[1,2] However, to

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our knowledge, only T-piece and pressure support have been compared for clinical outcomes.[5,11]

Patients who fail an SBT develop increasing mechanical load on the respiratory muscles during the SBT.[12] We reasoned that methods that offer more support during SBT could improve the SBT-pass rates but also could mask

some patients' inability to overcome the ventilatory load once extubated, resulting in a higher risk of unsuccessful extubation. On the contrary, low or no support during SBT could impair the patient's ability to demonstrate his readiness and increase the risk of unnecessary prolongation of mechanical ventilation, but those able to tolerate the SBT would be less likely to fail extubation. The optimal method to perform SBTs would have the best balance between those risks.

Automatic tube compensation (ATC) is a relatively new ventilation mode that supports the patient with an automatically calculated magnitude of inspiratory pressure that is continuously adjusted during inspiration, to compensate for the flow-dependent resistance added by the artificial airway.[13] This ventilatory-support concept makes ATC an attractive mode for use during SBT. Haberthür et al reported that more patients passed an SBT with ATC than with T-piece or pressure support.[4] More recently, Cohen et al found a similar trend for better SBT tolerance with ATC than with CPAP,[14] but also reported a higher rate of successful extubation in the ATC group, which seems difficult to explain in the context of our reasoning above. Further evaluation of ATC during SBT is therefore needed.

We compared ATC to CPAP during SBTs, within the context of a respiratory-therapist (RT) driven weaning protocol, in their efficacy to identify patients ready to be liberated from mechanical ventilation. We previously presented part of these results in abstract form.[15]

Methods

Study Design

This prospective randomized controlled study was conducted in a general intensive care unit (ICU) that includes medical, surgical, and trauma patients, in a university teaching hospital, from March 2007 to September 2008. The ICU operates with a closed model in which intensivists have primary responsibility for the care of all patients. The study was approved by the local institutional review board, and written informed consent was obtained from the patient or next of kin.

Patients

The study population comprised adult patients endotracheally intubated, undergoing mechanical ventilation for at least 24 h, about to undergo SBT, with the intention of discontinuing mechanical ventilation on the same day, per our ICU's ventilator weaning protocol (described below). Exclusion criteria were: age < 18 years, pregnant, tracheostomy, inability to obtain consent, decision not to reintubate, and SBT or extubation performed not in compliance with our ventilator weaning protocol. All patients

were ventilated with a mechanical ventilator (840, Nellcor Puritan Bennett, Pleasanton, California).

Weaning Protocol

Our ICU ventilator-weaning protocol is modified from protocols in published studies[16,17] and was in place during the whole study period. All adult patients who undergo mechanical ventilation for ≥ 24 h are screened daily by an RT, for the following criteria: fraction of inspired oxygen (F_{IO_2}) < 0.5, positive end-expiratory pressure ≤ 5 cm H_2O, and minute volume < 15 L/min. Upon meeting those criteria, a second set of screening criteria are considered: $P_{aO_2}/F_{IO_2} \geq 175$ mm Hg, ratio of frequency to tidal volume ≤ 105 breaths/min/L (while on CPAP of 5 cm H_2O, without mandatory breaths or pressure support for 1 min, which is a modification from the original method[18]), cough and gag reflex during endotracheal suctioning and stimulation of oropharynx, respectively, absence of sedative or vasopressor infusions (except dopamine ≤ 5 μg/kg/min), and (for trauma patients only) Glasgow coma score ≥ 10. Upon meeting the screening criteria, the ICU treating physicians are notified and they decide whether to order an SBT.

SBTs are performed and supervised by RTs, for a maximum duration of 30 min. SBT failure is defined as meeting any one of the following criteria: respiratory rate > 35 breaths/min, oxygen saturation (via pulse oximetry) < 90%, change in heart rate > 20%, increase in systolic blood pressure > 25%, or presence of agitation, diaphoresis, or visible use of accessory respiratory muscles. SBT failure ends the SBT and ventilatory support is resumed. SBT success is defined as ability to complete the SBT without meeting any of the SBT-failure criteria. SBTs are performed only once a day. Patients who fail an SBT are re-assessed the following morning, with the same screening and SBT process. If the patient succeeds an SBT, that information is communicated to the ICU treating physicians to decide about extubation.

Study Intervention

At the point of first SBT order by the ICU treating physicians, each patient was randomized, with a randomization table, to undergo the SBT with CPAP (per our ICU weaning protocol usual method) or with ATC. The patients were blinded to their group allocation, but the RTs supervising the SBTs were not. The CPAP group underwent the SBT on spontaneous mode, with positive end-expiratory pressure of 5 cm H_2O and no pressure support, resulting in a continuous positive airway pressure of 5 cm H_2O. The ATC group underwent the SBT on 100% ATC mode and positive end-expiratory pressure of 5 cm H_2O without other support. In both groups the F_{IO_2}
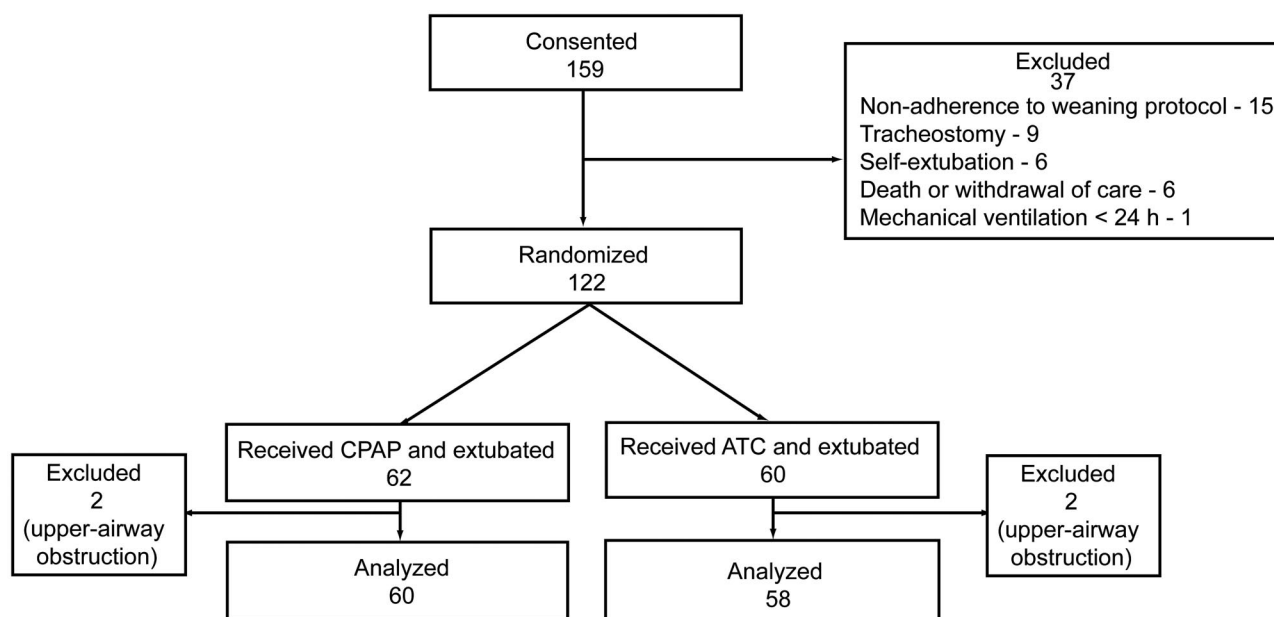
Fig. 1. Flow diagram of the study.

was kept at the level set prior to SBT. Patients who failed the first SBT underwent all subsequent SBTs with the same SBT method to which they had been randomized.

Data Collection

Baseline data on the date the first SBT was ordered included age, sex, primary service, main cause of respiratory failure (as determined by the investigators upon clinical data review), duration of mechanical ventilation, Acute Physiology and Chronic Health Evaluation II score, P_{aO_2}/F_{IO_2}, ratio of frequency to tidal volume, endotracheal tube diameter, and variables monitored during SBT. Patients were followed daily until extubation, for the duration of weaning, and until 48 h after extubation, for unsuccessful extubation (both described below).

Outcome Measures

The primary outcome measure was duration of weaning, defined as the number of days from first SBT to extubation (zero days for patients extubated on the day of the first SBT). Additional outcome measures were rate of unsuccessful extubation within 48 h, failure of first SBT, and total duration of mechanical ventilation. Unsuccessful extubation was predefined as the need for re-intubation or initiation of noninvasive ventilation to treat any of: hypoxemia despite supplemental oxygen, respiratory acidosis, worsening mental status, or severe respiratory distress. The ICU treating physicians were responsible for deciding on re-intubation or initiation of noninvasive ventilation.

Patients re-intubated because of upper-airway obstruction (defined as respiratory distress and audible stridor after extubation) were excluded from the analysis.

Statistical Analysis

Assuming a standard deviation for duration of weaning of 1.5 days, we estimated that 50 patients in each group would be needed to detect a 1-day mean difference in weaning duration, with 90% power and a 2-sided significance level of .05. Differences between the groups were analyzed with the independent 2-sample t test for means, the Wilcoxon 2-sample test for medians, and the chi-square or Fisher's exact test for proportions.

Results

Of a total of 159 patients who consented, 37 were excluded due to noncompliance with the weaning protocol (15 patients), tracheostomy without prior SBT (9 patients), self-extubation (6 patients), death or withdrawal of care without prior SBT (6 patients), and < 24 h on mechanical ventilation (1 patient) (Fig. 1). Four additional patients, 2 in the CPAP group and 2 in the ATC group, were excluded from the analysis because of re-intubation due to upper-airway obstruction.

We analyzed the data from 118 patients. Of all the RT screenings that met all the passing criteria, a first SBT was ordered by physicians 68% of the time. Seventy-five percent of the patients underwent the SBT upon passing the

Table 1. Characteristics of Study Patients at Randomization

	ATC Group (n = 58)	CPAP Group (n = 60)	P
Age (mean ± SD y)	51.7 ± 20.2	50.8 ± 18.6	.78*
Male (n, %)	42 (72)	37 (62)	.21†
Time From Intubation to Randomization			
Mean ± SD d	5.1 ± 4.2	4.7 ± 3.2	.58*
Median and IQR d	4 (2–6)	4 (2–7)	.88‡
APACHE II score (mean ± SD)	13.9 ± 4.5	13.6 ± 5.7	.80*
ETT inner diameter (mean ± SD mm)	7.52 ± 0.4	7.51 ± 0.4	.90*
P_{aO_2}/F_{IO_2} (mean ± SD mm Hg)	246.8 ± 61.3	241.1 ± 62.8	.62*
f/V_T (mean ± SD breaths/min/L)	57.3 ± 19.0	59.1 ± 22.5	.64*
Cause of respiratory failure (n, %)			.10†
Multiple trauma	14 (24)	17 (28)	
Postoperative	16 (28)	12 (20)	
Neurologic emergency	16 (28)	9 (15)	
ALI or ARDS	7 (12)	7 (12)	
Other	5 (9)	15 (25)	

* Independent 2-sample t test.
† Via chi-square test.
‡ Wilcoxon 2-sample test.
ATC = automatic tube compensation
CPAP = continuous positive airway pressure
IQR = interquartile range
APACHE = Acute Physiology and Chronic Health Evaluation
F_{IO_2} = fraction of inspired oxygen
ETT = endotracheal tube
f/V_T = ratio of frequency (respiratory rate) to tidal volume
ALI = acute lung injury
NA = not applicable
ARDS = acute respiratory distress syndrome

Table 2. Outcomes

	ATC Group (n = 58)	CPAP Group (n = 60)	P
Days From First SBT to extubation (n, %)			.10*
0 d	56 (97)	52 (87)	
1 d	1 (2)	6 (10)	
2 d	1 (2)	1 (2)	
3 d	0 (0)	1 (2)	
Mean ± SD d	0.05 ± 0.3	0.18 ± 0.5	.10†
Median and IQR d	0 (0–0)	0 (0–0)	.06‡
Unsuccessful extubation by 48 h (n, %)	3 (5)	4 (7)	> .99*
Patients who failed first SBT (n, %)	2 (3)	8 (13)	.09*
Total Duration of Mechanical Ventilation			
Mean ± SD d	5.1 ± 4.2	4.9 ± 3.4	.74†
Median and IQR d	4 (2–6)	4 (2–7)	> .99‡

* Via Fisher's exact test.
† Via Independent 2-sample t-test.
‡ Via Wilcoxon 2-sample test.
ATC = automatic tube compensation
CPAP = continuous positive airway pressure
IQR = interquartile range
SBT = spontaneous breathing trial

Discussion

When SBTs were performed with ATC versus CPAP in a sample of a general ICU population, we found no significant difference in the duration of weaning or the rate of unsuccessful extubation.

Although T-piece would have been the truly unsupported SBT method to compare to ATC, we chose CPAP as the control because (1) CPAP is our current SBT method, with which our RTs are familiar in our weaning protocol, and which was modeled after landmark studies on weaning-protocol implementation,[16,19] and (2) CPAP yields more clinically applicable results, because T-piece SBT seems to be infrequently done in the United States.[20]

We found a trend toward more failure of the first SBT in the CPAP group; this same finding was also reported in a similar study of ATC versus CPAP,[14] and in a study of ATC versus T-piece versus low-level pressure support.[4] Esteban et al found a significantly lower percentage of failed first SBTs with low-level pressure support than with T-piece.[5] All those reports support the concept that inspiratory support improves SBT tolerance. In addition, a recently published study of SBT with a fixed pressure support of 7 cm H_2O versus pressure support set by ATC also found a trend of better SBT tolerance with ATC.[21] Our study is the largest to date to compare ATC to an unsupported SBT method, and is unique in that we fol-

screen for the first time. All patients were included only once, extubated, and followed for 48 h after extubation. Table 1 shows the baseline characteristics at time of first SBT, which were not significantly different between the groups. The most frequent causes of respiratory failure were multiple trauma; postoperative state (hemodynamic and/or respiratory instability after surgery); and neurologic emergencies (includes stroke, traumatic brain injury without other trauma, and encephalopathy). Other causes of respiratory failure included obstructive lung disease, congestive heart failure, lobar pneumonia, neuromuscular weakness, and shock.

Within 48 h of extubation, 3 patients in the ATC group and 2 in the CPAP group were re-intubated, and 2 other patients in the CPAP group were started on noninvasive ventilation. All 7 of those patients met the predefined criteria for extubation failure. None of the other extubated patients failed extubation. Table 2 shows the outcomes data.

lowed patients who failed the first SBT with subsequent daily SBTs with the same SBT method allocated at randomization, to assess a more clinically important outcome measure: duration of weaning. Despite the trend of better first-SBT tolerance in the ATC group, the duration of weaning was not significantly different between the groups.

We did not find a difference in extubation outcome between ATC and CPAP. Although it should be noted that with a control-group unsuccessful-extubation rate of 7% our study is not powered to exclude a statistical difference in this outcome, a clinically important difference in this context seems unlikely and would require a very large number of subjects to be detected. This apparent discrepancy with a similar study by Cohen et al,[14] which claimed a superior extubation outcome with ATC, merits further consideration. That study found no difference in re-intubation rates between the groups (ATC 14% vs CPAP 24%, $P = .28$), albeit with higher re-intubation rates, possibly due in part to relatively conservative criteria to reintroduce ventilatory support, and higher Acute Physiology and Chronic Health Evaluation II scores. This finding, especially considering the high control-group re-intubation rate (24%), is in line with the lack of difference in extubation failure in the present study and in the study by Esteban et al, which compared T-piece and pressure support.[5] Cohen et al,[14] however, reported a significant difference in favor of ATC in "successful extubation," calculated as a rate of successfully extubated patients over the total of patients randomized to a given group (some of them not extubated). This variable compounds tolerance of SBT and extubation outcome, and has been found not different between groups in studies that compared T-piece and pressure support.[5,11] We chose outcome measures that address the individual components of the SBT test: duration of weaning (primarily), and unsuccessful extubation.

Some considerations on patient selection should be mentioned to help interpret our findings. First, our control-group rate of passing the first SBT (88%) is within the range (76–96%) reported by other investigators with various SBT methods.[5,6,14,21-23] Second, our relatively low unsuccessful-extubation rate can in part be explained by excluding from the analysis unsuccessful extubations caused by upper-airway obstruction, as SBT is not able to assess this complication and we did not evaluate the risk for it in our subjects. Compared to studies that reported higher unsuccessful-extubation rates,[5-8,14,22,24] our sample has similar duration of mechanical ventilation prior to SBT and SBT eligibility criteria, but a lower percentage of patients with a primary pulmonary cause of respiratory failure. Although patients with a primary pulmonary cause of respiratory failure might be at higher risk for weaning failure, this concept has not been uniformly confirmed in studies.[6,8,25] Finally, although our unsuccessful-extubation rate is lower than the rates (12–24%) in some studies of

SBTs,[5-8,14,21,22,24] it is within the 3–7% range reported by others in a similar context of a systematic weaning protocol with medical and surgical populations.[16,20,26,27] These considerations suggest that our findings are representative of protocol weaning in a general ICU population.

SBTs are an integral part of the weaning assessment, so the accuracy of different SBT methods will depend on the patient's "weaning condition" upon entry to SBT. It remains then possible that a particular method to perform SBT is superior to others in selected patients at higher risk for prolonged weaning or unsuccessful extubation than the sample in this study. Our study was aimed at the use of SBT in the context of a systematic RT-driven weaning protocol applied uniformly to all patients on mechanical ventilation, and its findings cannot be extrapolated to specific populations with difficult weaning.

Conclusions

When applied as part of an RT-driven weaning protocol in a general ICU population, performing SBTs with ATC was safe but did not hasten liberation from mechanical ventilation, when compared to CPAP.

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