Correlation Between the %MinVol Setting and Work of Breathing During Adaptive Support Ventilation in Patients with Respiratory Failure

Chin-Pyng Wu MD PhD, Hen-I Lin MD, Wann-Chern Perng MD, Shih-Hsing Yang MSc, Chien-Wen Chen MD, Yuh-Chin T Huang MD MHS, and Kun-Lun Huang MD PhD

BACKGROUND: Adaptive support ventilation (ASV) is a new mode of mechanical ventilation that seeks an optimal breathing pattern based on the minimum work of breathing (WOB) principle. The operator's manual for the ventilators that provide ASV recommends that the %MinVol setting be started at 100% (the 100%MinVol setting), but it is unclear whether that setting reduces WOB in patients with respiratory failure. METHODS: We studied 22 hemodynamically stable patients with respiratory failure who were on pressure-support ventilation. We switched the ventilation mode to ASV and started at the 100%MinVol setting. We then increased the %MinVol setting by 10% every 5 min until 1–3 mandatory breaths per min appeared, and called that setting the ASV target point. We then tested 2 additional %MinVol settings: 20% below the ASV target point (target-point–20%), and 20% above the ASV target point (target-point+20%). We tested each %MinVol setting for 10 min. At the end of each 10-min period we measured respiratory variables, pressure-time product (PTP), and airway occlusion pressure at 0.1 s after the onset of inspiratory flow ($P_{0.1}$). RESULTS: In 18 patients (82%), at the 100%MinVol setting, the actual minute volume ($\dot{V}_E$) was greater than the target $\dot{V}_E$. At the ASV target point the mean ± SD %MinVol setting was 165 ± 54% and was associated with a 40% decrease in PTP and $P_{0.1}$, but $\dot{V}_E$ did not change. At target-point+20%, $\dot{V}_E$ increased slightly, primarily due to a small increase in tidal volume, and PTP and $P_{0.1}$ further decreased. At target-point–20%, PTP and $P_{0.1}$ were similar to those at the 100%MinVol setting. At the ASV target point the 6 patients with chronic obstructive pulmonary disease had a lower mean %MinVol setting (125 ± 23%) than the 16 patients who did not have chronic obstructive pulmonary disease (180 ± 55%). CONCLUSIONS: The 100%MinVol setting was frequently not associated with lower WOB in patients with respiratory failure. The %MinVol setting that significantly reduced WOB could be detected by increasing the %MinVol setting until a few mandatory breaths began to appear, and was on average 165% of the MinVol setting. *Key words: closed-loop ventilation; respiratory failure; work of breathing; WOB; chronic obstructive pulmonary disease; COPD.* [Respir Care 2010;55(3):334–341. © 2010 Daedalus Enterprises]

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Introduction

Adaptive support ventilation (ASV) is a new mode of mechanical ventilation that is available on the Galileo and G5 ventilators (Hamilton Medical, Rhazuns, Switzerland). ASV relies on closed-loop regulation of settings in response to changes in respiratory mechanics and spontaneous breathing.[1-4] In ASV, the clinician enters a target minute volume ($\dot{V}_E$), using a parameter called %MinVol. ASV then automatically determines a target tidal volume (V_T) and respiratory rate combination based on the minimum work of breathing (WOB) principle proposed by Otis et al,[5] which states that for any given alveolar ventilation there is a respiratory rate and V_T combination that corresponds to minimum WOB. When the respiratory rate is too low, elastic work is increased due to the large V_T. When the respiratory rate is too high, resistive work is increased due to the turbulence and viscosity produced by the greater air flow. When the patient is on mandatory ventilator breaths, ASV is able to adjust both V_T and respiratory rate to meet the target. If the patient is breathing spontaneously (pressure-support breaths), ASV can adjust only the inspiratory pressure level and, thus, V_T. Clinical studies have shown the feasibility of ASV in supporting various patient populations, including acute respiratory failure, postoperative recovery, patients ventilated long-term, regardless of their breathing effort.[1,6-12] The relationship between ASV support and WOB, however, was not defined in those studies.

The current operator manuals for the 2 ventilators that offer ASV recommend that the %MinVol setting be initially set at 100% (the 100%MinVol setting), which provides a target $\dot{V}_E$ of 0.1 L/min/kg of ideal body weight (IBW). The %MinVol setting can then be adjusted based on the arterial blood gas values. Thus, for a patient with an IBW of 60 kg, the 100%MinVol setting would give a target $\dot{V}_E$ of 6 L/min. In normal individuals this $\dot{V}_E$ is quite adequate, and ASV will probably generate a respiratory pattern that corresponds to the minimum WOB.[5] It is unclear, however, whether the 100%MinVol setting would provide that same WOB benefit in patients with respiratory disease, and, if not, what %MinVol setting would be associated with decreased WOB. Establishing a relationship between the %MinVol setting and WOB in patients with respiratory diseases would give clinicians a useful guide for adjusting the %MinVol setting without the need to measure WOB, especially since WOB is not usually measured at the bedside.

The present study was undertaken to test the hypothesis that patients with respiratory failure require higher $\dot{V}_E$ than predicted by ASV at the 100%MinVol setting. A secondary hypothesis was that WOB, as estimated based on the pressure-time product (PTP), is related to the %MinVol setting such that increasing the %MinVol setting above the 100% value will decrease the PTP.

Methods

Patient Population

This study was performed at Tri-Service General Hospital, Taipei, Taiwan. We enrolled 22 patients with respiratory failure in the medical intensive care unit of a tertiary-care medical center. All the patients were hemodynamically stable and did not need vasoactive agents. All were on pressure-support ventilation with a fraction of inspired oxygen (F_{IO_2}) $\leq$ 0.5 and positive end-expiratory pressure $\leq$ 10 cm H_2O. Six patients had chronic obstructive pulmonary disease (COPD). A patient was considered to have COPD if COPD was one of the diagnoses in the patient's medical record and spirometry showed airway obstruction. Patients with a recent (within 3 months) history of stroke or myocardial infarction were excluded. The study protocol was approved by the ethics committee of the Faculty of Medicine of the National Defense Medical Center, Taipei, Taiwan. Written informed consent was obtained from the closest available family member.

Adaptive Support Ventilation

ASV is a form of pressure-controlled intermittent mandatory ventilation with adaptive control schemes for V_T, respiratory rate, and $\dot{V}_E$.[3,13] The ventilator calculates the target $\dot{V}_E$ based on the patient's IBW. Mandatory breaths are machine-triggered, pressure targeted, and time-cycled. Machine triggering occurs if the spontaneous breath respiratory rate falls below the optimum respiratory rate. The optimum respiratory rate (ie, for minimum WOB) is calculated based on estimates of the ratio of dead space to V_T and the expiratory time constant, according to the equation of Otis et al.[5] The pressure target for mandatory breaths is adjusted to achieve a target V_T, which is calculated as the target $\dot{V}_E$ divided by the optimum respiratory rate. Because the expiratory time constant is dependent on the patient's lung compliance and resistance, the ASV target respiratory rate and V_T will adapt to both restrictive and obstructive pulmonary mechanics (eg, limiting V_T and pressure in restrictive diseases, while limiting intrinsic positive end-expiratory pressure in obstructive diseases). Additional lung-protective rules are also applied in determining the appropriate respiratory rate and V_T targets for mandatory breaths. Spontaneous breaths are patient-triggered, pressure targeted, and flow-cycled. The pressure target is automatically adjusted to deliver the same volume target as mandatory breaths. The respiratory rate is controlled by the patient.

To initiate ASV, the clinician first enters the patient's IBW and then sets a parameter called %MinVol. The IBW is calculated with Devine's[14] formulas:

$$\text{For males: IBW} = 50 + 2.3 \text{ (height in inches} - 60)$$

$$\text{For females: IBW} = 45.5 + 2.3 \text{ (height in inches} - 60)$$

Each %MinVol setting is associated with a recommended $\dot{V}_E$. The patient's actual $\dot{V}_E$ can be greater than the recommended $\dot{V}_E$. The operator manuals recommend that the %MinVol setting be started at 100%, which provides a target $\dot{V}_E$ of 0.1 L/min/kg IBW. There were no references provided with regard to that recommendation.

Measurement of Work of Breathing

We placed an esophageal balloon catheter (Ackrad Laboratories, Cranford, New Jersey) in the distal esophagus, and used the manufacturer's recommended procedures. The balloon was inflated with 0.6 mL of air to measure changes of intra-esophageal pressure. A miniature pneumotachograph and pressure transducer (VarFlax, Bicore Monitoring Systems, Irvine, California) was positioned between the Y-piece of the ventilator circuit and the endotracheal tube (ETT), to measure air flow and proximal airway pressure. All pulmonary mechanics data were recorded by a pulmonary monitor (CP-100, Bicore Monitoring Systems, Irvine, California), and the analog signals were collected with on-line software (PowerLab, ADInstruments, Bella Vista, Australia).

The patient's metabolic work of the respiratory muscles was estimated based on the PTP during the inspiratory phase.[15] PTP was calculated with the following equation from the pulmonary monitor operator manual:

$$\text{PTP} = [(\text{end-expiratory } P_{es} - \text{current } P_{es}) + (\text{current } V_T/\text{compliance})]\ (\Delta t/\Delta \text{min})$$

where P_{es} is esophageal pressure, compliance is the chest wall compliance (assumed at 200 mL/cm H_2O), Δt is the sampling time, and Δmin is the breath duration in minutes. PTP reflects the actual patient effort to breathe. PTP is expressed in cm $H_2O \cdot$ s/min.

With an esophageal balloon catheter we measured esophageal pressure 0.1 s after the start of inspiratory flow ($P_{0.1}$), which is a proxy measure of respiratory drive.[16] PTP and $P_{0.1}$ were measured during spontaneous breaths, and we used 3 consecutive breaths to calculate mean values.

Study Protocol

After consent was obtained, the patient was switched to ASV at the 100%MinVol setting, which corresponds to a $\dot{V}_E$ of 0.1 L/min/kg of IBW. F_{IO_2}, positive end-expiratory pressure, and sedation were kept unchanged throughout the ASV trials. After 10 min of ASV at the 100%MinVol setting, we increased the %MinVol setting by 10% every 5 min until the first appearance of mandatory (ie, machine-triggered) breaths (Fig. 1). We designated this %MinVol setting the ASV target point. Measurements at the ASV target point were performed in all patients. In most patients the measurements were performed in the presence of a few mandatory breaths. In some patients, once that transition was reached, the respiratory pattern continued to evolve into all mandatory breaths, so while these patients were receiving mandatory breaths we did not take measurements while at the ASV target point. We then tested 2 other %MinVol settings: 20% above the ASV target point (target-point+20%) and 20% below the ASV target point (target-point–20%). After target-point+20% and target-point–20%, we returned the patient to ASV at the 100%MinVol setting. Each ASV session (100%MinVol, ASV target point, target-point+20%, and target-point–20%) was for 10 min, and respiratory variables, PTP, and $P_{0.1}$ were recorded. V_T, respiratory rate, and $\dot{V}_E$ were calculated from the 1-min continuous recordings of flow and volume.

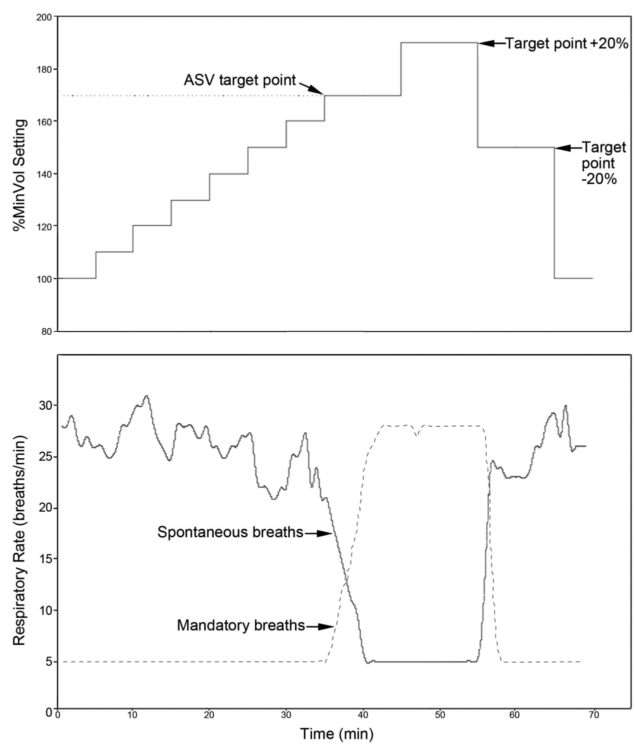

Fig. 1. An example of adjustments of the %MinVol setting during Adaptive Support Ventilation (ASV). Ventilation was started at the 100%MinVol setting, then the %MinVol setting (upper panel) was increased by 10% every 10 min, until mandatory breaths first appeared (lower panel). We called this the ASV target point. We then further increased the %MinVol setting to 20% above the ASV target point, and then decreased it to 20% below the ASV target point.

Table 1. Clinical Characteristics

Patient Number	Age (y)	Sex	Ideal Body Weight (kg)	Airway Type	Ventilator Days	Diagnosis
1	75	M	57	Oral ETT	8	Pneumonia
2	76	M	76	Tracheostomy	111	Pneumonia
3	85	M	66	Tracheostomy	55	COPD
4	84	M	66	Oral ETT	2	COPD
5	34	F	48	Nasal ETT	19	Pneumonia
6	78	M	57	Tracheostomy	5	Pleural effusion
7	71	M	54	Tracheostomy	37	Pneumonia
8	76	M	57	Tracheostomy	2	Pneumonia
9	78	F	43	Oral ETT	12	COPD
10	93	M	57	Nasal ETT	1	Pneumonia
11	72	M	61	Tracheostomy	62	Pneumonia
12	76	F	43	Nasal ETT	6	COPD
13	89	F	43	Tracheostomy	67	Pneumonia
14	46	F	52	Oral ETT	2	Pneumonia
15	87	M	61	Nasal ETT	2	Pneumonia
16	67	F	50	Oral ETT	4	COPD
17	83	M	50	Nasal ETT	4	COPD
18	68	M	55	Tracheostomy	44	Pneumonia
19	78	F	52	Nasal ETT	4	Cirrhosis of liver
20	82	M	57	Tracheostomy	36	Sepsis
21	85	F	66	Oral ETT	1	Sepsis
22	84	F	57	Tracheostomy	37	Pneumonia

ETT = endotracheal tube
COPD = chronic obstructive pulmonary disease

Statistical Analysis

Data are expressed as mean ± SD. Respiratory variables, PTP, and $P_{0.1}$ among the 4 different ASV sessions were compared via repeated-measures analysis of variance, followed by Tukey's subtest for differences between the groups. The unpaired *t* test was used to compare the COPD and non-COPD patients. Statistical analyses were performed with statistics software (SPSS 13, SPSS, Chicago, Illinois). A $P < .05$ was considered statistically significant.

Results

Patient Clinical Data During Pressure-Support Ventilation

Table 1 describes the 22 patients. There were 13 men and 9 women. Their mean age was 76 ± 13 years. Their mean IBW was 56 ± 8.2 kg. The causes of acute respiratory failure were COPD (6 patients), pneumonia (12 patients), sepsis (2 patients), large pleural effusion (1 patient), and liver cirrhosis (1 patient). Ten patients had tracheostomy, and 12 had either oral or nasal ETT. The mean hospital stay was 45 days (range 2–234 d). The mean ventilator days was 7 days (range 1–111 d). Table 2 shows their baseline ventilation parameters during pressure-support ventilation.

Respiratory Variables During Adaptive Support Ventilation

All the patients were started on ASV at the 100%MinVol setting. The recommended $\dot{V}_E$ for ASV at the 100%MinVol setting (5.7 ± 0.6 L/min) was approximately 33% lower than the actual $\dot{V}_E$ (9.2 ± 2.9 L/min) (Fig. 2). The recommended respiratory rate and V_T at the 100%MinVol setting were 14 ± 1 breaths/min and 413 ± 52 mL, respectively. The actual respiratory rate and V_T were 23 ± 7 breaths/min and 431 ± 67 mL, respectively. The difference between the actual $\dot{V}_E$ and recommended $\dot{V}_E$ was because the patients were breathing spontaneously at a higher respiratory rate than the recommended respiratory rate.

In 18 patients (82%) the ASV target point was greater than ASV at the 100%MinVol setting, and in 4 patients the ASV target point was equal to the 100%MinVol setting. On average, the %MinVol setting was 165 ± 54% at the ASV target point. At the ASV target point, V_T increased by approximately 20% and total respiratory rate decreased

Table 2. Baseline Ventilation Parameters

Patient Number	F_{IO_2}	PEEP (cm H_2O)	Pressure Support (cm H_2O)	Respiratory Rate (breaths/min)	V_T (mL)	Arterial Oxygen Saturation (%)
1	0.40	5	5	23	513	96
2	0.40	5	22	10	590	96
3	0.40	5	23	26	403	100
4	0.40	5	13	11	560	99
5	0.35	5	12	18	355	98
6	0.35	5	30	20	478	100
7	0.30	5	26	22	480	100
8	0.35	5	12	23	387	99
9	0.25	5	13	12	308	99
10	0.35	5	22	15	467	97
11	0.35	5	16	22	560	100
12	0.40	5	17	16	300	94
13	0.35	5	15	10	420	95
14	0.35	5	16	16	480	99
15	0.50	5	12	30	492	90
16	0.30	5	16	17	359	97
17	0.30	5	12	25	316	96
18	0.50	5	25	20	520	96
19	0.50	5	12	21	395	95
20	0.40	5	20	28	370	96
21	0.40	5	12	20	495	100
22	0.35	5	14	24	454	99

F_{IO_2} = fraction of inspired oxygen
PEEP = positive end-expiratory pressure
V_T = tidal volume

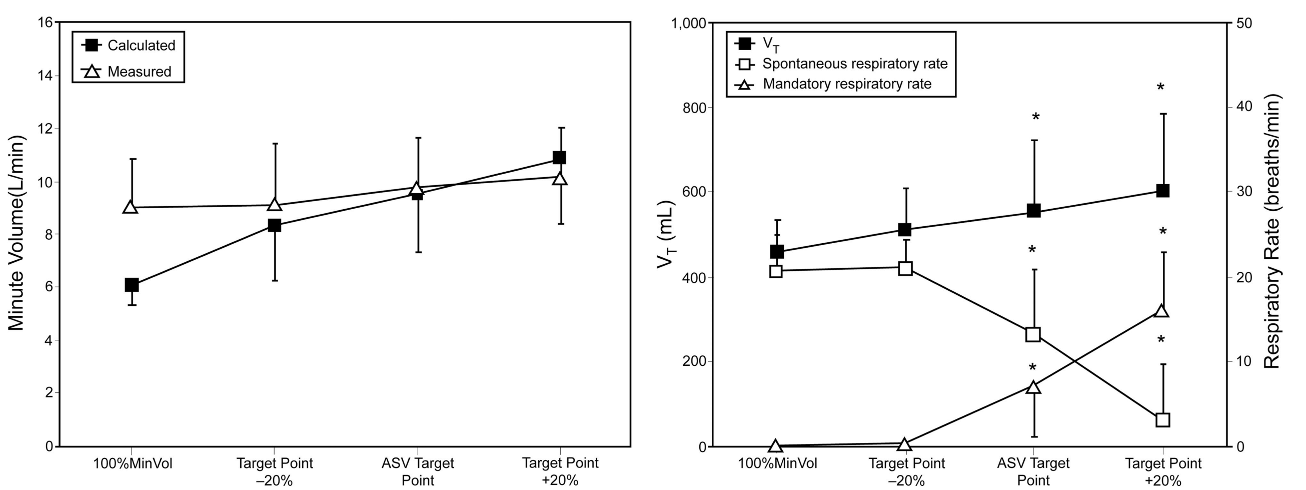

Fig. 2. Calculated and measured minute volume ($\dot{V}_E$), tidal volume (V_T), and spontaneous and ventilator-controlled (mandatory) respiratory rate during Adaptive Support Ventilation (ASV) at the 100%MinVol setting, the ASV target point (see Methods section), the ASV target point minus 20%, and the ASV target point plus 20%. The calculated $\dot{V}_E$ is the $\dot{V}_E$ predicted at the given %MinVol setting. The measured $\dot{V}_E$ is the $\dot{V}_E$ measured by the ventilator. * Significantly different versus ASV at the 100%MinVol setting.

slightly compared to that at the 100%MinVol setting (see Fig. 2B), but measured $\dot{V}_E$ did not change (see Fig. 2). Raising the MinVol setting to target-point+20% further increased V_T, the number of mandatory breaths, and $\dot{V}_E$. When the %MinVol setting was decreased to target-point–20%, the respiratory rate was similar to that at the 100%MinVol setting, and all breaths were spontaneous breaths. $\dot{V}_E$ was similar to that at the 100%MinVol setting.

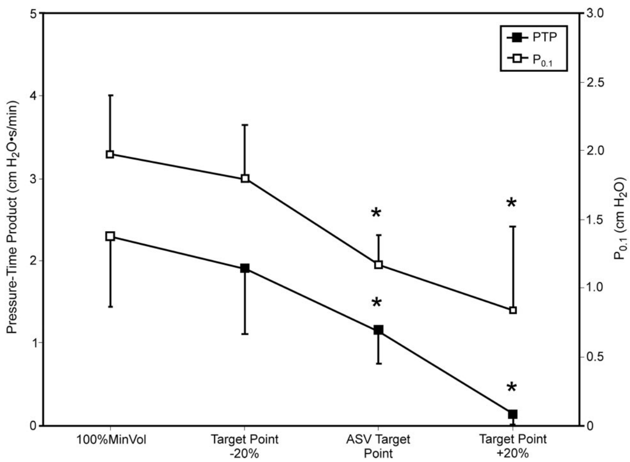

Fig. 3. Pressure-time product (PTP) and airway occlusion pressure ($P_{0.1}$) during Adaptive Support Ventilation (ASV) at 100%MinVol setting, the ASV target point (see Methods section), the ASV target point minus 20%, and the ASV target point plus 20%. The values were obtained by averaging 3 spontaneous breaths. * Significantly different versus ASV at the 100%MinVol setting.

We further examined the %MinVol response in the 6 patients with COPD. The average %MinVol at the ASV target point in these 6 patients was significantly smaller (125 ± 23%) than that in the 16 non-COPD patients (180 ± 55%) (P = .04). In the non-COPD patients, tracheostomy had no significant effect on %MinVol at the ASV target point, compared to ETT (187 ± 64% for tracheostomy vs 171 ± 37% for ETT, $P > .10$).

Respiratory Muscle Loading During Adaptive Support Ventilation

Both PTP and $P_{0.1}$ decreased by approximately 40% during ventilation at the ASV target point (Fig. 3), which indicates decreased respiratory effort and unloading of the respiratory muscles. At target-point+20% both PTP and $P_{0.1}$ decreased further, whereas at target-point–20% both PTP and $P_{0.1}$ increased toward those at the 100%MinVol setting. Figure 4 shows tracings of V_T, airway pressure, flow, and esophageal pressure during ASV at the 100%MinVol setting, at target-point–20%, and at target-point+20% from one patient.

Discussion

In this study we found that in patients with respiratory failure, when the %MinVol setting was gradually increased, there was a sharp transition from all spontaneous breaths to the appearance of mandatory breaths, a stage we designated the ASV target point. Once the patient reached that transition, mandatory breaths would quickly take over and the WOB was reduced by approximately 40%. The %MinVol at the ASV target point was greater than 100% in more than 80% of the patients. The average %MinVol setting at the ASV target point was 165% in our overall patient population, and it was higher (180%) in the non-COPD patients than in the COPD patients (125%).

Our results indicate that the operator manual's suggested starting %MinVol setting of 100% is probably inadequate for reducing WOB in most patients with respiratory failure. To reduce WOB the %MinVol can be increased until mandatory breaths appear. This procedure does not have to be guided by arterial blood gas values, because the $\dot{V}_E$ is virtually unchanged from ASV at the 100%MinVol setting to the ASV target point. Increasing the %MinVol setting by 20% above the ASV target point increased $\dot{V}_E$ and further reduced WOB, whereas decreasing the %MinVol setting by 20% below the ASV target point let the patient breathe with metabolic work similar to that at the 100%MinVol setting. The mechanisms for the decrease in metabolic work and $P_{0.1}$ as %MinVol reached the ASV target point, despite a constant $\dot{V}_E$, were probably related to the higher V_T, as recommended by the ASV algorithm. The higher V_T lowers the muscle pressure the patient has to generate to get the desired V_T. The higher V_T may also stimulate pulmonary stretch receptors, sending action potentials via the Hering-Breuer reflex, to lower the respiratory rate. This latter hypothesis is supported by further reduction in the WOB and $P_{0.1}$ when %MinVol is increased above the ASV target point, which further increased V_T but not respiratory rate.

At the ASV target point the %MinVol setting in the COPD patients was lower than that in the non-COPD patients. The %MinVol at the ASV target point was approximately 180% for non-COPD patients and 125% for COPD patients. This result underscores the importance of using lower %MinVol in COPD patients to encourage spontaneous breathing, so as to not adversely affect the progress of weaning. In addition, keeping the patient at target-point+20%, which was associated with further reduction in the WOB and respiratory drive, may not be desirable clinically because it may lead to muscle atrophy and weakness.

Our results have several clinical implications. First, the %MinVol needed to reduce WOB in patients with respiratory failure is greater than the 100%MinVol setting in most patients. Therefore, if the patient appears to be "working hard," the %MinVol setting may be adjusted upward quickly, using 165% as a guide. Non-COPD patients may need a higher %MinVol setting, whereas COPD patients probably will need less. Second, when a %MinVol setting is associated with at least a few mandatory breaths, the WOB is probably reduced. Since WOB is not usually measured at the bedside, our proposed procedure and target for adjusting %MinVol should help clinicians quickly find a "comfortable" ventilation setting for the patient.

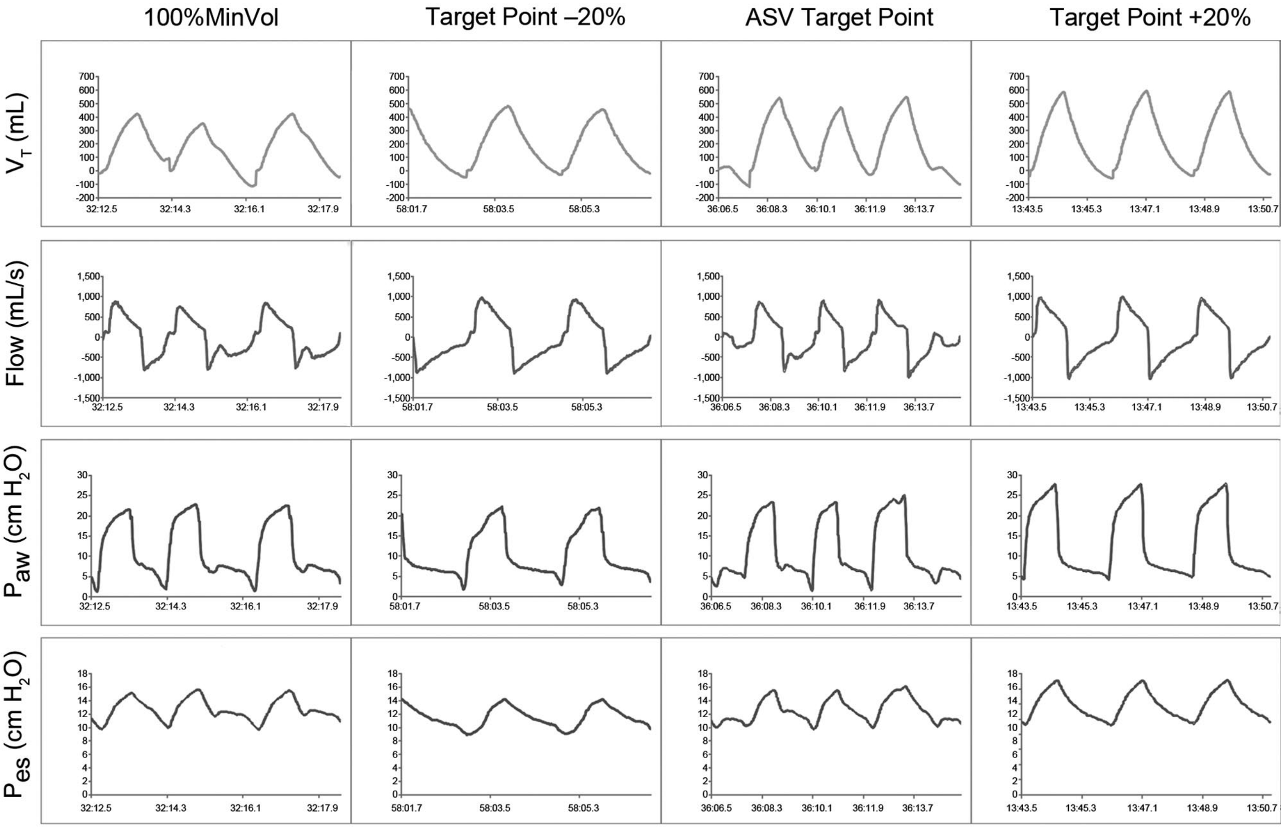

Fig. 4. Tidal volume (V_T), flow, airway pressure (P_{aw}), and esophageal pressure (P_{es}) waveforms during Adaptive Support Ventilation (ASV) at the 100%MinVol setting, the ASV target point (see Methods section), the ASV target point minus 20%, and the ASV target point plus 20%, from patient 22 (see Table 1). At the ASV target point the V_T was unchanged, and the negative inflection of P_{es} decreased, indicating decreased respiratory effort. At target-point plus 20% the V_T increased and the negative inflection of P_{es} further decreased.

Limitations

The sample size in our study was relatively small. We studied only patients with respiratory failure who had a stable breathing pattern. And our ASV target point %MinVol setting may not be identifiable in all patients, particularly in patients with acute respiratory failure who have high respiratory drive. Our results need validation in larger studies.

Conclusions

When decreasing WOB is needed in a patient on ASV, the clinician can try increasing the %MinVol setting until a few mandatory breaths appear. That %MinVol setting is associated with reduced WOB, with little change in $\dot{V}_E$.

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