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Adaptive Support Ventilation：
Review of the Literature and Clinical Applications

Shuo-Chueh Chen[1], Wei-Erh Cheng[1,2], Chuen-Ming Shih[1,2,]
Chia-Chen Chu[1,2], and Chin-Jung Liu[1,2]

[1]*Division of Pulmonary and Critical Care Medicine, Department of Internal Medicine,*
China Medical University Hospital, Taichung, Taiwan;
[2]*School of Respiratory Therapy, China Medical University, Taichung, Taiwan*

Abstract

Mechanical ventilation is a complex process involving interaction between pressure, flow, volume and time. Simply put, we classify the modes as one of either volume control, pressure control, or dual control. Adaptive support ventilation (ASV) is a newly developed dual control mode, using measured dynamic compliance and time constant, with an automated adjustment of tidal volume and respiratory rate combined to meet the preset minute ventilation. Several small randomized controlled or prospective observational studies have stressed that ASV can be used as a safe weaning mode for specific postoperative and chronically ventilated patient groups, save manpower and management, and reduce lung injury induced by mechanical ventilation. However, there is concern about the issue of asynchrony between ventilators and patients if there was no awareness of the underlying mechanism for respiratory distress in the patients, which would possibly worsen the patient's condition or prolong the weaning process. ASV should undergo large randomized controlled studies to clarify its role in clinical practice in the future.(J Intern Med Taiwan 2008; 19: 465-471)

Key Words：Respiratory mechanics, Strategy, Protective, Postoperative care, Weaning, Manpower management, Asynchrony

Introduction

Mechanical ventilation is frequently delivered to patients admitted to intensive care units to reduce the work of breathing (WOB), to improve oxygenation, or to assist ventilation. The interaction between patient and ventilator is complex with respect to a variety of variables including pressure, volume, flow, and time. Yet these variables can be adequately represented by a mathematical model, called the equation of motion for the respiratory system, which can be simplified as:

Airway opening pressure＋Pmus＝(Flow x Resistance)＋(Volume x Elastance)

Where Pmus is respiratory muscle pressure and is calculated based on the following general equation: Pmus＝Elastic Pressure＋Resistive Pressure. The equation shows that for any mode, only one variable (i.e., pressure, volume, or flow) can be controlled at a time. So we can simplify the modes to pressure control versus volume control.

Correspondence and requests for reprints : Dr. Wei-Erh Cheng
Address :Division of Pulmonary and Critical Care Medicine, Department of Internal Medicine, China Medical University Hospital, No. 2, Yu-Der Rd., Taichung 404, Taiwan R.O.C.

In volume-controlled breaths, the delivered flow is set by practitioners with a ventilator- or clinician-determined inspiratory flow. Delivered tidal volume (V_T) is constant, but airway pressure changes depend upon patient effort, respiratory system compliance, and airway resistance. Volume control allows a guarantee of V_T and minute volume, which can be particularly helpful in patients with varying levels of pulmonary compliance and hypercapnia, and in implementing a lung-protective strategy. However, the fixed delivered flow of volume control can lead to flow asynchrony and excessive WOB.

Pressure-controlled breaths are delivered using as much flow as is needed to meet the preset pressure support level and limit. For passive inspiration, the flow waveform is an exponential decrease, and peak flow depends on respiratory-system compliance and resistance. For active inspiration, flow is highly irregular, depending on the patient's inspiratory effort. Pressure control maintains the airway pressure, but the delivered V_T is a function of patient effort, respiratory-system compliance, and airway resistance. Both hyper-ventilation and hypoventilation may occur under pressure control ventilation.

The ventilator controls pressure or volume during inspiration, but not simultaneously. It may switch from one control variable to another during a single breath or between breaths, which is designated as dual control. Dual control is designed to assure patient-ventilator synchrony by allowing as much flow as the patient demands, while attempting to guarantee a minimum V_T. There are a number of ventilators that provide dual control modes, e.g., Autoflow (Drager Evita 4 and XL), Pressure Regulated Volume Control and Volume Support (Maquette Servo-ｉ), Volume Control＋ (Puritan Bennett 840), Pressure Regulated Volume Control (Viasys/Pulmonectics PalmTop ventilator and Viasys Avea), and the Adaptive Support Ventilation (ASV)(Hamilton Galileo). We will discuss ASV below.

What is "Adaptive Support Ventilation" ?

ASV was introduced in 1994[1-3] as an "electronic ventilator protocol" that incorporates measurements of respiratory mechanics and algorithms of closed-loop pressure control to maintain a target minute ventilation.

ASV assumes that the adequate ventilation of normal subjects is 100 ml/min per kg of body weight (adult subjects), or 200 ml/min/kg of body weight (pediatric subjects). The minute ventilation (Ve) is calculated as the ratio between the ventilation resulting from ideal body weight (IBW) and the minute ventilation (MinVol) % set by the user (100% corresponding to normality)

V_E [l/min] = IBW [kg] * MinVol [%]/100

Then, ASV automatically selects the respiratory pattern in terms of respiratory rate (RR), V_T, Inspiratory time: Expiratory time (I:E) ratio (for mandatory breathing) and reaches the respiratory pattern selected. Basically, ASV uses the Otis equation to calculate the RR corresponding to the minimum respiratory work of breathing.[4]

Otis equation

$$f = \frac{1+2a*RC*\frac{MinVol-(f*Vd)}{Vd}-1}{a*RC}$$

f = respiratory rate

RC = airway resistance * respiratory compliance = time constant

MinVol = minute ventilation

Vd = dead space

a = $(2\pi^2)/60$ = 0.33 (constant for sinusoidal flow)Among the endless sets of data of V_T and RR, the extreme conditions can be dangerous for the patient, so the ASV selects the safety boundary, on the basis of cycle-by-cycle measurement of expiratory RC, a window of values of V_T and RR, inside which the targets are fixed (Figure 1). The inspiratory pressure is limited to 5 cm H_2O above PEEP to 10 cm H_2O below Pmax set by the operator. The maximum V_T is defined as 22(ml/kg) × IBW(kg) or V_E (L/min)/5, by whichever is lower. The limit of minimum V_T corresponds to twice the dead space of the patient calculated as 2.2 ml/kg of IBS.[5] The minimum and the maximum mandatory RR is set to a fixed limit of 5 breath/min and 60 breath/min. The other safety boundaries are (min. - max.): inspiratory time (0.5 - 2 secs), expiratory time (3 × RCe - 12 secs), and inspiratory/expiratory time ratio (1:4 - 1:1)[6].

The ASV, with two closed-loop mechanisms (on RR and on V_T), can adjust the inspiratory pressure and the mandatory rate to reach the targets. Depending on the patient's spontaneous respiratory rate, ASV can work as Pressure Controlled Ventilation (PCV), if there is no spontaneous breathing; as pressure Synchronize Intermittent Mandatory Ventilation (SIMV), when the patient's respiratory rate is less than the target; or as Pressure Support Ventilation (PSV), if the patient's respiratory rate is greater than the target. ASV recognizes spontaneous breathing and automatically switches between mandatory pressure-controlled breaths and spontaneous pressure-supported breaths in patients. The pressure level is then adapted to attain the target tidal volume (within limits imposed by pressure alarms). Cycling-off criteria is flow-based in the case of assisted ventilation or time-based for mandatory inspiration.

In summary, under ASV, changes in respiratory mechanics or patient effort are accompanied by a dynamic breathing pattern that gradually guides patients to a new target. The breath-to-breath safety rules maintain ventilation parameters within safety ranges, and if for any reason the patient fails to breathe actively, ASV automatically increases the number of mandatory pressure-controlled breaths needed to maintain the minute volume target. Additional safety limits prevent an extremely high or low respiratory rate and tidal volume from happening, in order to minimize intrinsic PEEP, hyperventilation, or a large dead space, and perhaps baro- and volu-trauma. By monitoring the trended total respiratory rate, spontaneous respiratory rate, and inspiratory pressure, the caregiver can determine the patient's condition and interaction with ASV.

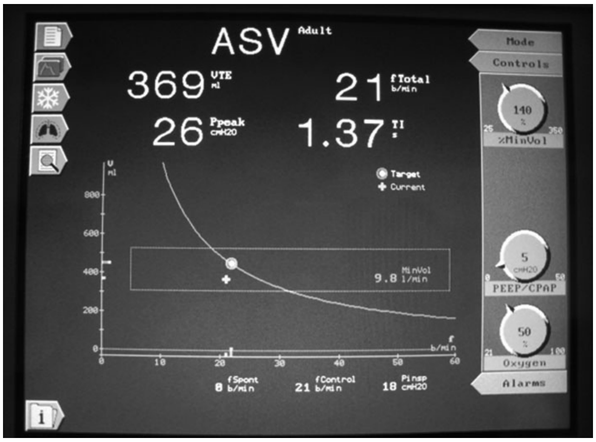

Fig.1.The ASV screen as implemented on GALILEO, Hamilton. The ASV target graphics screen shows: mode; minute ventilation%; PEEP; fraction of inspiratory oxygen concentration; minute volume curve target volume; safety boundary; actual tidal volume/respiratory frequency combination; and the optimal tidal volume/respiratory frequency combination with which the patient will be ventilated.

Review of the Literature

Evidence justifying the role of ASV in mechanically-ventilated patients is yet to be fully demonstrated. We did a PubMed search on the subject of ASV, and included data from original clinical trials in English-language publications in the present manuscript.

Postoperative Care

Several papers reported a preference for using the ASV mode for postoperative care. Sulzer[7] conducted a prospective randomized controlled study in uncomplicated fast-track patients recovering from cardiac surgery, and found that patients receiving ASV required a shorter period of mechanical ventilation than patients receiving SIMV followed by PSV.

Petter[8] conducted a similar randomized controlled study to compare automatic weaning in ASV with standard management for early tracheal extubation after cardiac surgery. The two approaches were equal in terms of outcome. In ASV, they observed fewer ventilator setting manipulations and fewer alarms. The results confirmed the possibility of conserving medical resources with ASV.

Cassina[9] conducted a prospective observational study of a cohort of 155 consecutive patients after fast-track cardiac surgery, and confirmed the safety aspects of ASV. One hundred thirty-four patients (86%) were extubated within 6 hours, with a median intubation time of 3.6 (2.53-4.83) hours (quartiles). No reintubation due to respiratory failure was required. This ventilation mode allowed rapid extubation in suitable patients and may facilitate postoperative respiratory management.

Weaning

ASV can be used for weaning purposes in both acute and chronic facilities. In a step-down center for chronically ventilated patients, Linton[10] conducted weaning trials using the ASV mode and demonstrated the economy of automated weaning without the need for respiratory therapists or continuous attendance by intensivists. Twenty-seven patients were placed on ASV at 90% of target minute ventilation on arrival, and were reduced by 10% weekly to 60% of target minute ventilation, if tolerated by the patients. Twelve patients were successfully weaned from the ventilator within 2 weeks to 2 months of admission in the first twelve months following establishment of the facility.

Lung protective strategy

There is evidence that inappropriate mechanical ventilation settings can induce lung injury[11] So, choosing an appropriate setting in ventilated patients is a priority, in order to reduce airway pressure, asynchrony and WOB. Belliato[12] tested ASV in patients with normal lungs and in those with restrictive lungs, in COPD patients and in a physical lung model, with a normal level of and an increased minute ventilation. In postoperative patients with normal lungs, the ASV selected a ventilatory pattern close to the physiological one. In COPD patients, the ASV selected a high expiratory time pattern, and in restrictive lungs, a reduced tidal volume pattern. In the model, the selection was similar. In the hyperventilation test, the ASV chose a balanced increase in both V_T and RR. The authors explained that ASV would select an adequate ventilatory pattern for a variety of lung conditions.

Recently, Arnal[13] conducted a similar prospective observational cohort study to determine the respiratory pattern generated by ASV for various lung conditions, and included 243 patients receiving 1327 days of invasive ventilation on ASV. The underlying respiratory conditions were categorized as normal lungs, lung with acute injury, obstructive lungs and chest wall stiffness. Data on the ventilator settings, breathing patterns, and arterial blood gases were collected daily. Only in passively ventilated patients did ASV deliver different V_T-respiratory rate (RR) combinations based on the underlying condition, providing higher VT and lower RR in the obstructive lung than in the lung with acute injury. But, no difference was observed in patients with active triggering.

Tasseaus[14] conducted a crossover prospective study in the early weaning period of ten patients with acute respiratory failure of diverse causes. The results demonstrated that at a similar level of minute ventilation, patients receiving ASV had a lower level of respiratory drive (P0.1), lower WOB (based on EMG respiratory muscle activity), and improved patient-ventilator interactions, compared to SIMV-PS.

Discussion

According to the literature review, there appear to be several advantages to using the ASV. First, the ASV can provide automated weaning and achieve shorter weaning time for suitable surgical patients. The weaning rate in chronically ventilated patients is acceptable, as well. Second, fewer human resources are needed at bedside to make sure the ventilator is meeting the patient's needs. Third, the ASV can carry out a lung protective strategy by adjusting the V_T-RR setting based on various underlying lung conditions.

However, while the ASV can guarantee a minimum V_T, it cannot guarantee a constant tidal volume. One concern is that the ventilator cannot distinguish between improved pulmonary compliance and increased patient effort[15]. Jaber compared volume support ventilation (VSV), another volume-guaranteed dual control mode, with pressure support ventilation (PSV) to patient behavior and ventilator response when ventilatory demand was increased by the addition of dead space. Adding dead space significantly increased minute ventilation, PaCO2 values, and indexes of respiratory effort in both PSV and VSV, but the increases were 2.5-4 times greater with VSV than with PSV. VSV induced respiratory distress in some patients[16] We personally found similar situations occurred in chronically ventilated patients using the ASV mode. Patients became progressively distressed as their respiratory drive increased, which was the opposite of the desired response.

The underlying problem is that ASV is not based on transpulmonary pressure (PL), and thus respiratory mechanics. PL equals the difference between the alveolar pressure and the pleural pressure (Ppl), and determines the degree of lung distension. Since direct measurement of Ppl may cause detrimental effects, we measured the pressure in the lower third of the esophagus (Pes), closely approximating the pressure of the adjacent pleurae, to estimate Ppl. We also measured Paw by ventilator to calculate compliance.

In patients with a very active drive (due to fever, pain, anxiety, delirium or distress induced by underlying disease), the Ppl becomes more negative and the PL increases, while the Paw remains constant or decreased. The ventilator could mistakenly consider this situation as an improvement of the patient's compliance, and thus reduce the supportive pressure, leading to insufficient ventilation support. Weaning time would be prolonged without adequate management.

Clinically, as the ventilated patient gets progressively distressed with his P0.1, the pressure generated 100 ms after the onset of an occluded inspiratory effort progressively increases. Based on personal experience, we suggest closely monitoring the spontaneously breathing patient's P0.1 while on the ASV mode, and trying to keep the P0.1 reading less than 2 cm H20 by adjusting the minute ventilation %. The optional alternative is to suggest the manufacturer incorporate the measurement of Ppl or Pes into their product to calculate respiratory mechanics.

Conclusions

The ASV mode is a newly developed dual control ventilator mode, and has the advantages of lung protection, the use of fewer medical personnel resources and facility, the weaning of both acutely and chronically ventilated patients. However, ASV and other dual-control adaptive pressure control modes cannot distinguish improving lung mechanics from a deranged ventilatory demand, which might lead to some patients being distressed or prolonging the weaning process without recognition and adequate management. Large randomized controlled studies of the ASV are needed to clarify the role of ASV in clinical practice.

References

1. Laubscher TP, Heinrichs W, Weiler N, et al. An adaptive lung ventilation controller. IEEE Trans Biomed Eng 1994; 41: 51-9.
2. Weiler N, Heinrichs W, Kessler W. The AVL-mode: a safe closed loop algorithm for ventilation during total intravenous anesthesia. Int J Clin Monit Comput 1994; 11: 85-8.
3. Linton DM, Potgieter PD, Davis S, et al. Automatic weaning from mechanical ventilation using an adaptive lung ventilation controller. Chest 1994; 106: 1843-50.
4. Otis AB, Fenn WO, Rahn H. Mechanics of breathing in man. J Appl Physiol 1950; 2: 592-607.
5. Martin CJ, Das S, Young AC. Measurements of the dead space volume. J Appl Physiol 1979; 47: 319-24.
6. Macintyre N, Branson RD. Feedback enhancements on ventilator breaths. In: Tobin MJ. Principles and practice of mechanical ventilation. 2nd ed. New York: McGraw-Hill Co. 2006; p. 398.
7. Sulzer CF, Chiolero R, Chassot PG, et al. Adaptive support ventilation for fast tracheal extubation after cardiac surgery: a randomized controlled study. Anesthesiology 2001; 95: 1339-45.
8. Petter AH, Chiolero RL, Cassina T, et al. Automatic "respirator/weaning" with adaptive support ventilation: the effect on duration of endotracheal intubation and patient management. Anesth Analg 2003; 97: 1743-50.
9. Cassina T, Chiolero R, Mauri R, et al. Clinical experience with adaptive support ventilation for fast-track cardiac surgery. J Cardiothorac Vasc Anesth 2003; 17: 571-5.
10. Linton DM, Renov G, Lafair J, et al. Adaptive Support Ventilation as the sole mode of ventilatory support in chronically ventilated patients. Crit Care Resusc 2006; 8: 11-4.
11. Tremblay LN, Slutsky AS. Ventilator-induced lung injury: from the bench to the bedside. Intens Care Med 2006; 32: 24-33.
12. Belliato M, Palo A, Pasero D, et al. Evaluation of adaptive support ventilation in paralysed patients and in a physical lung model. Int J Artif Organs 2004; 27: 709-16.
13. Arnal JM, Wysocki M, Nafati C, et al. Automatic selection of breathing pattern using adaptive support ventilation. Intens Care Med 2008; 34: 75-81.
14. Tassaux D, Dalmas E, Gratadour P, et al. Patient-ventilator interactions during partial ventilatory support: a preliminary study comparing the effects of adaptive support ventilation with synchronized intermittent mandatory ventilation plus inspiratory pressure support. Crit Care Med 2002; 30: 801-7.
15. Branson RD, Chatburn RL. Controversies in the critical care setting. Should adaptive pressure control modes be utilized for virtually all patients receiving mechanical ventilation? Respir Care 2007; 52: 478-485; discussion 485-78.
16. Jaber S, Delay JM, Matecki S, et al. Volume-guaranteed pressure-support ventilation facing acute changes in ventilatory demand. Intens Care Med 2005; 31: 1181-8.

順應性支持型呼吸模式：文獻回顧與臨床應用

陳碩爵[1]　程味兒[1,2]　施純明[1,2]　朱家成[1,2]　劉金蓉[1,2]

[1]中國醫藥大學附設醫院　胸腔暨重症系
[2]中國醫藥大學　呼吸治療學系

摘　要

機械通氣是一個複雜的過程，包括了壓力、氣流、容積、以及時間之間的交互作用。理論上，我們將通氣模式簡化成容積控制、壓力控制或雙重控制模式。順應性支持型呼吸模式(Adaptive Support Ventilation, ASV) 是一新發展的雙重控制模式，根據呼吸器所測量得到的動態順應性及吐氣的時間常數，自動調整潮氣容積和呼吸次數來達到所預設的每分鐘通氣量。針對順應性支持型呼吸模式的優缺點，過去數年間有一些小型的隨機控制或前瞻觀察性研究結果。順應性支持型呼吸模式對於特定的手術後病人是一種安全的脫離呼吸器的方式；可用於呼吸器依賴病人的脫離；可節省醫療人力及管理；也可減少因呼吸器不當使用引起的肺損傷。但是另一方面在病人發生呼吸窘迫情形時，若不了解發生原因及病人的呼吸生理病理機轉，將造成病人與呼吸器間的不協調，甚至有可能使呼吸窘迫情形惡化或延長脫離過程。未來對順應性支持型呼吸模式進行進一步的大型隨機控制研究，對於釐清其臨床角色及應用方式是有必要的。