Is Volume Inferior to Pressure?

The microprocessor has greatly changed ventilator technology. When I started residency, intubation and mechanical ventilation involved assuming complete control of a patient's breathing. Since then, advances in technology have fed the boundless human desire for improvement and spurred the ambition of engineers to overcome the challenges involved in creating better and better ventilators. The ventilators of today are totally different machines than those we used 3 decades ago. Far more sophisticated, current computer-controlled ventilators can accommodate a large degree of patient-ventilator synchrony. This enables a mechanically ventilated patient to retain a large amount of control over his or her own respiratory system.

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Even so, physicians and respiratory therapists decide how to set ventilator variables, and these decisions are influenced both by patient need and the type of ventilator used. Table 1 shows the variables that are controlled by the patient (italicized) versus set by the clinician and controlled by ventilator in volume control ventilation (VCV), pressure control ventilation (PCV), pressure support ventilation, and proportional assist ventilation. Different types of ventilators and different ventilation modes do different things well. The physician or respiratory therapist chooses the ventilation mode according to the patient's lung pathophysiology. We expect patient-ventilator synchrony to be best in the modes in which more variables are controlled by the patient, but mode selection depends on how well the mode meets the patient's current needs. We must choose the best mode for the circumstances of each patient, and understand how different ventilators behave differently and the advantages and disadvantages of each mode.

Mechanical lung models have also been improved to more closely simulate patient respiration. The simplest lung models, comprising bellows and springs to control compliance, are unable to simulate spontaneous breathing. While these simple models are adequate for investigating whether a ventilator accurately delivers a set tidal volume (V_T) under various respiratory mechanics conditions, to investigate trigger sensitivity or a ventilator's initial response, we need a lung model that simulates inspiratory effort. Since no lung model perfectly simulates patient breathing, it is important to choose a lung model that best fits the purpose of the investigation, and to set the lung model to simulate as closely as possible clinically encountered patient breathing. The Training and Test Lung (TTL, Michigan Instruments, Grand Rapids, Michigan) is a simple device that has been used to assess ventilator performance.

In this issue of RESPIRATORY CARE, Marchese et al[1] report a study in which they used a servo-controlled lung model (ASL 5000, IngMar Medical, Pittsburg, Pennsylvania) to assess the gas delivery of 6 sophisticated ICU ventilators. Albeit with the caveat that bedside clinical evaluation is needed, they conclude that some of the ventilators performed inadequately, especially during volume ventilation. The ASL 5000 is a sophisticated lung model that probably simulates patients' lungs more accurately than other models, although I have not used it in my laboratory. A lung model provides an effective means of comparing different ventilators' performance under the same respiratory conditions. The results, however, are only comparable with results from tests carried out with that same type of lung model. As Marchese et al point out,[1] the data cannot be compared to data obtained with other types of lung models.

VCV and PCV are 2 basic ventilation modes, chosen according to patient condition. During VCV we expect the ventilator to accurately deliver the set V_T, with a pre-set flow profile, regardless of the patient's respiratory mechanics. We do not expect the ventilator to deliver a high initial flow or a variable flow. In addition, low-V_T ventilation is a key strategy for improving outcomes in patients with acute lung injury/acute respiratory distress syndrome (ALI/ARDS). To decrease the output of the respiratory center, sedatives or analgesics, or both, and sometimes muscle relaxant, are administered. Clinicians are generally aware of the flow pattern in VCV, and this is usually not a major issue. VCV is still the most popular mode for adult patients.[2] In the paper by Marchese et al there was a very small standard deviation for V_T in VCV, with all the tested ventilators (see Table 2 in their paper). I conclude that all the ventilators delivered the same V_T, regardless of the lung model settings, and further that each of the ventilators performed very well in VCV. For VCV, I would be comfortable using any of the tested ventilators.

In PCV, because of the high initial flow, patient-ventilator synchrony is considered to be better than with VCV. As my Table 1 shows, initial flow during PCV is depen-

Table 1. Ventilation Variables Controlled by the Patient Versus by the Clinician or Ventilator*

Volume Control Ventilation	Pressure Control Ventilation	Pressure Support Ventilation	Proportional Assist Ventilation
F_{IO_2}	F_{IO_2}	F_{IO_2}	F_{IO_2}
PEEP	PEEP	PEEP	PEEP
Frequency	Frequency	*Frequency*	*Frequency*
Inspiratory flow	*Inspiratory flow*	*Inspiratory flow*	*Inspiratory flow*
Inspiratory time	Inspiratory time	*Inspiratory time*	*Inspiratory time*
Expiratory time	Expiratory time	*Expiratory time*	*Expiratory time*
Tidal volume	*Tidal volume*	*Tidal volume*	*Tidal volume*
Minute volume	*Minute volume*	*Minute volume*	*Minute volume*
Airway pressure	Airway pressure	Airway pressure	*Airway pressure*

* The italicized items are determined by the patient. All the other variables are clinician-set and controlled by the ventilator.

dent on patient effort; more correctly, the initial flow is determined by the ventilator's ability to deliver flow in response to the patient's respiratory-center output, respiratory muscle strength, and respiratory mechanics. The inspiratory flow demand of patients with ALI/ARDS is often high, and the flow delivered by the ventilator may be insufficient. This increases the patient work of breathing and may result in patient-ventilator asynchrony. When applying PCV, I prefer to use a ventilator capable of delivering high initial flow.

When carrying out ventilator comparisons, the lung model settings have to be carefully considered. Physicians and respiratory therapists are interested in clinically relevant results, so the lung model should be set to simulate the mechanics of clinically encountered situations. When designing a lung model study it is important to be clear about the types of patients, clinical situations, stages of disease, and other factors being simulated. We should also bear in mind that, at present, no lung model correctly simulates the response of the respiratory center. Marchese et al do not give a readily understandable account of the relevance of the respiratory mechanics they simulated in their tests.[1] In the ICU, patients with ALI/ARDS often breathe rapidly with high inspiratory flow. Lung models usually simulate this as high inspiratory flow, high airway compliance, low airway resistance, and high respiratory drive. In the study by Marchese et al, the highest inspiratory flow was with compliance of 60 mL/cm H_2O, resistance of 5 cm H_2O/L/s, and "inspiratory muscle pressure (P_{mus})" of 10 cm H_2O. I cannot imagine what patient type was being simulated. Those lung mechanics are not encountered in critically ill patients. Such vigorous breathing could conceivably be encountered with healthy volunteers doing exercise.

Lung models are very powerful tools that enable us to compare the performance of ventilators under the same conditions. These evaluations are not, however, foolproof. For example, unlike the breathing of patients, simulated spontaneous breathing is perfectly constant. While small deviations can lead to statistically significant differences between ventilators, it is not clear that these differences are important for patients. When designing different sets of respiratory patterns and mechanics for a study, it is more important that the researchers perform the role of the brain that the lung model does not have. Rather than randomly assigning settings, they should carefully simulate clinically reasonable respiratory mechanics. Even when this is done competently, the relevance of the results to our daily practice has to be carefully considered.

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REFERENCES

1. Marchese AD, Sulemanji D, Chipman D, Villar J, Kacmarek RM. Performance of current intensive care unit ventilators during pressure and volume ventilation. Respir Care 2011;56(7):928-940.
2. Metnitz PG, Metnitz B, Moreno RP, Bauer P, Del Sorbo L, Hoermann C, et al; SAPS 3 Investigators. Epidemiology of mechanical ventilation: analysis of the SAPS 3 database. Intensive Care Med 2009;35(5):816-825.