

VENTILATOR MONITORING

Understanding the Essentials of Waveform Analysis

by Timothy B. Op't Holt, EdD, RRT

Many of the newer ventilators have the ability to display waveforms that are the result of pressures, volumes, and flows generated by the machine or patient, during both inspiration and expiration, related to time. Pressure-volume and flow-volume waveforms are also available. Respiratory therapy texts and manufacturer-specific brochures explain the clinical application of waveforms. This article will summarize the essence of the many available references.

Plotting the waveform

Pressure, flow, and volume waveforms are plotted with the respiratory variable on the Y-axis and time on the X-axis (see Figure 1). Parameter values on each axis are clearly indicated, and ranges are adjustable according to the manufacturer's

specifications. In a pressure waveform (Figure 1), positive inspiratory pressure is above the X-axis. In most cases, the waveform will be generated from the point of positive end-expiratory pressure (PEEP). Expiration begins when the waveform turns toward the X-axis and continues to the PEEP level. Inspiratory effort is seen below the X-axis.

On flow waveforms (Figure 2), inspiratory flow is above the X-axis; expiratory flow is below the X-axis. Many would incorrectly interpret a downward turn in inspiratory flow above the X-axis as expiratory flow. However, the downward turn in inspiratory flow means that flow is decelerating, as in sine or decelerating flow waveforms.

The tidal volume curve (Figure 3) is similar to the pressure curve, in that inspiration is the

ascending curve above the X-axis, while expiration is the descending portion of the curve above the X-axis. No portion of the volume waveform should appear below the X-axis.

Reading trigger levels

At the beginning of the pressure waveform, a negative deflection indicates the inspiratory effort, or trigger level. An excessive trigger level or poorly responsive ventilatory system will yield a greater than -2 cm H₂O deflection. This is the therapist's indication that sensitivity or ventilator responsiveness needs to be improved (Figure 4). No deflection at the beginning of the pressure waveform indicates a time-triggered breath. If the patient is supposed to be sedated and paralyzed, and the respiratory ther-

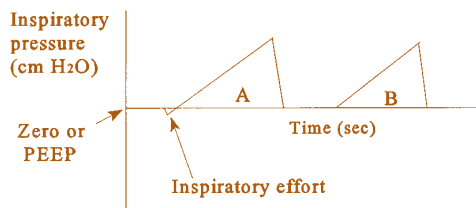


Figure 1. Pressure Waveform
Waveform A represents a pressure-triggered breath. Waveform B represents a time-triggered breath. Note the smooth ascent of the waveforms. Baseline may be zero or PEEP.

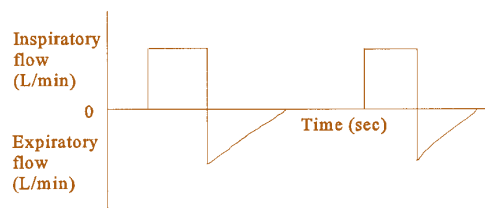


Figure 2. Flow Waveform
This is representative of a square wave inspiratory flow pattern. Note that inspiratory flow is above the X-axis and that expiratory flow, which is passive, is below the X-axis.

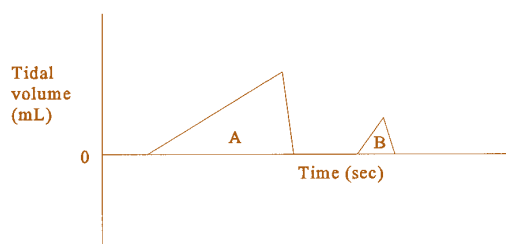


Figure 3. Tidal Volume Waveform
Waveform A represents a tidal volume generated by a square wave flow pattern. Note that it ascends smoothly, indicating adequate inspiratory flow. Waveform B represents a spontaneous breath, possibly generated during SIMV.

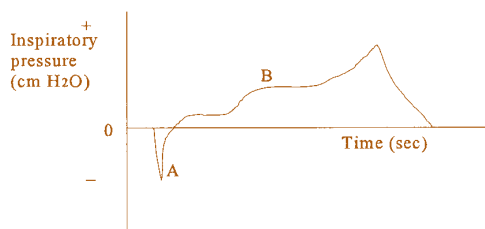


Figure 4. Irregular Pressure Waveform
An irregular pressure waveform depicting an insensitive system (A) and the result of an inadequate inspiratory flow (B).

apist sees a negative deflection, this is an indication that the sedative and/or muscle relaxant is wearing off. From baseline (the X-axis or PEEP), the pressure waveform should ascend smoothly, congruent to the volume waveform. Should the waveform vary from that expected, it is likely the result of the patient's inspiratory effort overcoming the preselected inspiratory flow. In this case, it is appropriate to increase the inspiratory flow until the ventilator's inspiratory flow meets the patient's demand.

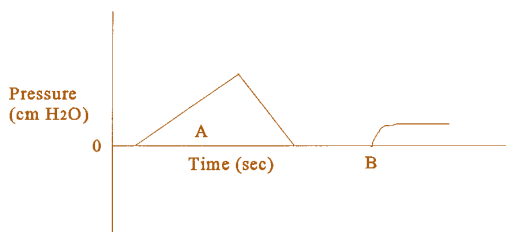


Figure 5. Pressure Waveform Depicting Auto-PEEP
Pressure waveform A is a time-triggered mandatory breath with a prolonged expiratory phase. At "B," expiratory pause is implemented. Thereafter, alveolar and airway pressure equilibrate, revealing the magnitude of auto-PEEP.

Encountering auto-PEEP

The pressure waveform should return to baseline before the beginning of the next inspiration. If not, auto-PEEP is suspected. Even if the waveform returns to baseline, if the next

breath starts very soon after the end of the previous breath, auto-PEEP is likely, since the waveform represents proximal airway pressure, not alveolar pressure, which is where auto-PEEP occurs. To determine the presence of auto-PEEP, the patient must be passively ventilated. At end expiration, the expiratory pause or auto-PEEP measuring function is activated. Within a few seconds, following the equilibration of alveolar and airway pressures, auto-PEEP will appear as a deflection above the baseline pressure. Appropriate measures

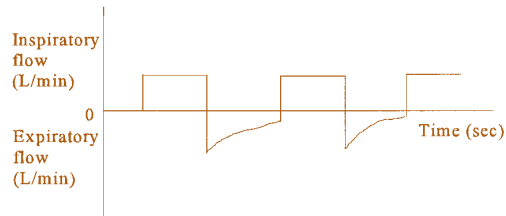


Figure 6. Auto-PEEP

Auto-PEEP is present when inspiratory flow for the next breath precedes the end of expiration. Quantification of auto-PEEP then requires the expiratory pause maneuver depicted in Figure 5.

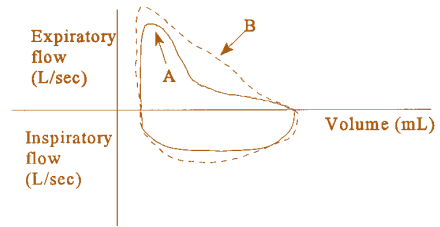


Figure 7. Flow-Volume Loops

Loop A represents obstruction. Loop B represents a normal loop or the anticipated results of bronchodilator therapy.

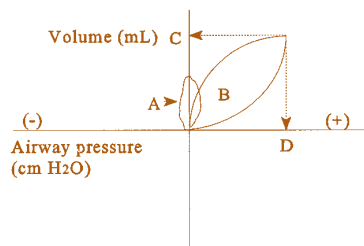


Figure 8. Pressure-Volume Loop

Loop A is a spontaneous breath. Loop B is a mandatory breath. Point C is tidal volume. Point D is peak inspiratory airway pressure.

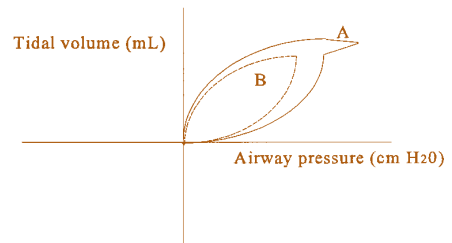


Figure 9. Overdistended Pressure-Volume Loop

Pressure-volume loop A represents hyperinflation. Loop B represents a lower tidal volume that is less likely to cause hyperinflation.

may then be taken to reduce the magnitude of auto-PEEP (Figure 5).

The flow waveform will begin at the beginning of inspiration and will conform to the selected inspiratory flow pattern. Combinations of waveforms are common, as in synchronized intermittent mandatory ventilation, wherein the mandatory breaths will have the selected waveform, interspersed with the waveform of the spontaneous breath. Non pressure-supported spontaneous breaths will have a sine wave flow pattern. Pressure-supported breaths will have a decelerating flow pattern. In some ventilators, the leading

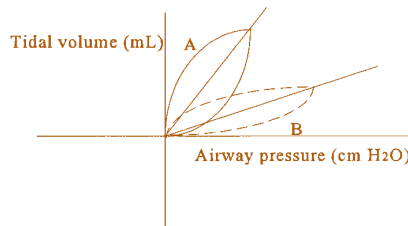


Figure 10. Pressure-Volume Loops

Loop A represents normal or increased lung-thorax compliance. Loop B represents decreased lung-thorax compliance. Slopes of the lines through the end-expiratory and end-inspiratory points are the lung thorax compliances.

edge of the inspiratory flow waveform will be tapered, corresponding to the setting of that particular function (i.e., Servo 300).

Perhaps the most important aspect of the flow waveform is its expiratory portion, which represents passive exhalation (below the X-axis). The end of expiration is represented by the return of

the flow curve to the X-axis. The shape of the curve should be linear from maximum expiratory flow (early in exhalation) to end exhalation. Any bow to the expiratory portion of the curve represents air flow obstruction (as in obstructive disease).

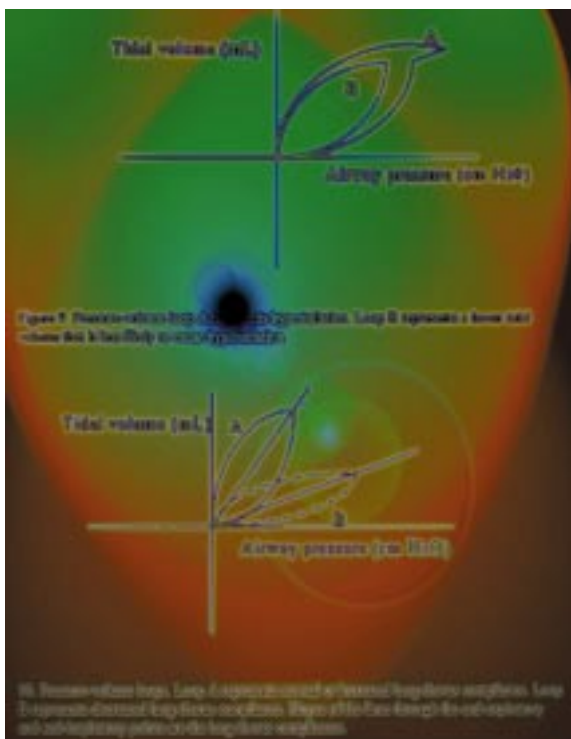
Should the curve fail to arrive back at the X-axis before the next breath starts, auto-PEEP exists (Figure 6).

The volume waveform is congruent with the pressure waveform. The same problems indicated by the pressure waveform are illustrated by the volume waveform. During expiration, should the volume waveform fail

to return to baseline, auto-PEEP is likely present.

Flow-volume and pressure-volume waveforms

The combinations of flow-volume and pressure-volume waveforms provide a vast amount of information. The flow-volume curve is represented by flow on the Y-axis and volume on the X-axis. Expiratory flow is represented by the waveform above the X-axis, the opposite of its appearance on the flow-time waveform. Some authors have speculated that the effectiveness of aerosolized bronchodilator therapy can be quantified by observation of the flow-volume waveform. Should the “bowing-in” of the waveform become more linear following bronchodilator therapy, it could be assumed that this was the effect of the drug (Figure 7). However, to my knowledge, there is little or



additional reading

Chatburn, R.L. (1999). Classification of mechanical ventilators. In R.D. Branson, D.R. Hess, & R.L. Chatburn (Eds.), *Respiratory care equipment* (2nd ed., pp. 383-389). Philadelphia, PA: JB Lippincott.

Pilbeam, S.P. (1999). *Mechanical ventilation: Physiological and clinical applications* (3rd ed., pp. 42-61). St. Louis, MO: Mosby.



no research on the validity of using passive expiratory flow patterns to determine the effects of bronchodilators.

The pressure-volume curve provides a wealth of information on the effectiveness of ventilation. This curve places tidal volume on the Y-axis and airway pressure on the X-axis. Observation of the pressure-volume curve reveals information about the tidal volume, airway pressure, breath source, compliance, and potential for lung injury. The tidal volume is indicated by the highest point of the loop above the X-axis. The airway pressure is indicated by the right- or left-most point of the loop. Loops pointed up and to the right represent mandatory or pressure-supported breaths. Loops rising up the Y-axis represent spontaneous breaths (Figure 8). A negative pressure deflection at the beginning of inspiration represents the inspiratory effort.

One of the most striking features of the pressure-volume loop is its shape in the presence of overdistention. In the presence of excessive mandatory tidal volume, the loop will suddenly turn to the right toward the end of inspiration, forming a “beak”

(Figure 9), which resolves at the beginning of expiration. The remainder of the curve will return to its normal shape.

The beak represents hyperinflation (excessive tidal volume and pressure) that has the potential to result in lung damage due to excessive shear forces. This event is more common in lung diseases such as acute respiratory distress syndrome (ARDS) due to decreased compliance. The therapist should reduce the tidal volume until the beak is eliminated. Compliance of the lung-thorax system is indicated by the slope of the line drawn through the origin of the loop, and the point at which exhalation begins. Loops that lie more flat represent a low lung-thorax compliance. Loops that are more upright (i.e., cling more closely to the Y-axis), represent an increased lung-thorax compliance (Figure 10).

The analysis of waveforms and use of the resultant data can and does make a difference in patient care. The respiratory therapist should observe and interpret these waveforms and provide indicated therapy based upon these data. 🧠

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