Is a Reduction in Ventilator-Generated Lung Work and Power Beneficial in ARDS?

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***Abstract*-Mechanical ventilation which uses low tidal volume, reduced distending pressure, and increased inspiratory time has been shown to be useful in treating patients with ARDS. These protective ventilator strategies may be thought of as a reduction in ventilator-delivered work and power.**

I. Introduction

Recently, both the morbidity and mortality associated with acute respiratory distress syndrome (ARDS) have been shown to be decreased with "protective" or "low-stretch" ventilatory strategies which incorporate reductions in tidal volume. The basis for these is primarily a reduction in ventilator-generated inspiratory pressure [1-4]. This reduction in applied pressure and resultant volume may correspond to an overall reduction in ventilator-generated work and power done to the lung.

II. Discussion

The following equation illustrates that the work, $W_{V \rightarrow L}$, performed from the ventilator to the lung, is a function of distending pressure, P_d, and positive end-expiratory pressure, P_{peep}, as well as pulmonary compliance, C. This formula also represents the area under the pressure-volume curve. This is illustrated in Fig. 1. Of note, this work is proportional to the square of the sum of both simultaneously applied pressures.

$$W_{V \rightarrow L} = \frac{C}{2}\left[P_d + P_{peep}\right]^2 \qquad (1)$$

As an example, for a constant compliance, a reduction of $[P_d + P_{peep}]$ from 35 to 30 cm H_20 would result in an approximately 27% reduction in ventilator-generated work.

Thus, the benefits of these ventilatory management techniques may possibly be thought of as a reduction in the work done to the lung from the ventilator.

It may be helpful to also examine the power, $\mathcal{P}_{V \rightarrow L}$, generated from the ventilator and dissipated by the lung as well:

$$\mathcal{P}_{V \rightarrow L} = \frac{dW_{V \rightarrow L}}{dt}. \qquad (2)$$

Substituting (1) into (2) and differentiating with respect to time yields:

$$\mathcal{P}_{V \rightarrow L} = C[P_d + P_{peep}]\left(\frac{dP_d}{dt}\right). \qquad (3)$$

$\frac{dP_d}{dt}$ can be approximated as:

$$\frac{dP_d}{dt} \cong \frac{\Delta P_d}{\Delta t}. \qquad (4)$$

Substituting (4) into (3) yields:

$$\mathcal{P}_{V \rightarrow L} = C[P_d + P_{peep}]\left(\frac{\Delta P_d}{\Delta t}\right). \qquad (5)$$

It should be noted that Δt represents inspiratory time t_i. Furthermore, $\Delta P_d = P_d$. Equation (5) can then be expressed as:

$$\mathcal{P}_{V \rightarrow L} = \frac{C[P_d + P_{peep}]P_d}{t_i} = \frac{C[P_d^2 + P_{peep}P_d]}{t_i}. \qquad (6)$$

Therefore, a reduction in the power that is dissipated by the lung, generated by the ventilator, may be beneficial in ARDS. For a given compliance, this power is minimized with a reduction primarily in P_d and by the use of as large an inspiratory time, t_i, as possible. It should be noted that a commonly used treatment for ARDS is with inverse I:E ratio such that inspiratory time exceeds exhalation time [5].

III. Conclusion

The use of "protective" ventilator strategies such as low tidal volume, and reduced distending pressure, as well as increased inspiratory time appear to be beneficial in the management of patients with ARDS. These techniques may be considered as decreased work and power done by the ventilator on the lung.

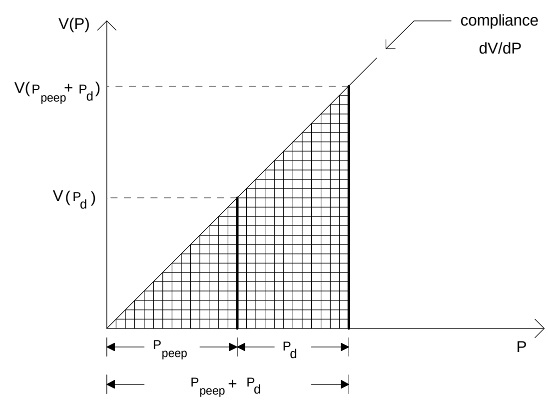

Fig. 1. The area under the pressure-volume curve corresponds to the work done to the lung from the ventilator. A reduction in this work may be beneficial in ARDS.

Derivation

The work done from the ventilator to the lung can be thought of as the sum of work, from the delivery of P_{peep} and during inflation, from P_{peep} to $[P_d + P_{peep}]$:

$$W_{V \rightarrow L} = \int_0^{P_{peep}} V(P)dP + \int_{P_{peep}}^{P_d + P_{peep}} V(P)dP = \int_0^{P_d + P_{peep}} V(P)dP \quad (1)$$

Note that volume is a function of pressure, V(P). Furthermore, V(P) is the product of compliance, C, and pressure: $V(P) = C \bullet P$. By definition, compliance corresponds to the slope of the pressure-volume curve.

$$W_{V \rightarrow L} = \int_0^{P_d + P_{peep}} V(P)dP = C\int_0^{P_d + P_{peep}} PdP \qquad (2)$$

Solving the above integral yields:

$$W_{V \rightarrow L} = \frac{C}{2}\left[P_d + P_{peep}\right]^2. \qquad (3)$$

References

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