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REVIEW

Interpretation of ventilator curves in patients with acute respiratory failure☆

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Abstract Mechanical ventilation (MV) is a therapeutic intervention involving the temporary replacement of ventilatory function with the purpose of improving symptoms in patients with acute respiratory failure. Technological advances have facilitated the development of sophisticated ventilators for viewing and recording the respiratory waveforms, which are a valuable source of information for the clinician. The correct interpretation of these curves is crucial for the correct diagnosis and early detection of anomalies, and for understanding physiological aspects related to MV and patient–ventilator interaction. The present study offers a guide for the interpretation of the airway pressure and flow and volume curves of the ventilator, through the analysis of different clinical scenarios.

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Insuficiencia respiratoria aguda

Interpretación de las curvas del respirador en pacientes con insuficiencia respiratoria aguda

Resumen La ventilación mecánica es una intervención terapéutica de sustitución temporal de la función ventilatoria enfocada a mejorar los síntomas en los pacientes que sufren insuficiencia respiratoria aguda. Los avances tecnológicos han facilitado el desarrollo de ventiladores sofisticados que permiten visualizar y registrar las ondas respiratorias, lo que constituye una fuente de información muy valiosa para el clínico. La correcta interpretación de los trazados es de vital importancia tanto para el correcto diagnóstico como para la detección precoz de anomalías y para comprender aspectos de la fisiología relacionados con la ventilación mecánica y con la interacción paciente-ventilador. El presente trabajo da una orientación de cómo interpretar las curvas del ventilador mediante el análisis de trazados de presión en la vía aérea, flujo aéreo y volumen en distintas situaciones clínicas.

Introduction

Positive pressure MV constitutes life support management for patients with ARF. The devices used for positive pressure ventilation evolved enormously between the mid-1970s and the late 1990s. The first-generation ventilators (between the early XIX century and the mid-1970s) were little more than mechanical anesthesia bags, unable to respond to patient demand and with very rudimentary monitorization systems (if any). The latest (fourth) generation ventilators were introduced two decades later. The new devices are efficient in responding to patient demand, offer new ventilation modes, allow noninvasive ventilation, have started to incorporate automatic control systems (open lung tools, weaning tools, dual modes),[1] and have enormous monitorization capacities–including onscreen visualization of pressure, flow and volume curves.[2] In addition, the need has recently arisen to introduce telemedicine-based systems as online monitoring tools at the patient bedside.[3–5]

The real-time examination of these waves allows us to analyze and understand elements of respiratory system mechanics and of patient–ventilator interaction. Wave interpretation requires training, however. The present review offers a graphic description of some of the main phenomena which careful inspection of the curves can reveal, based on representative examples of each of them. The descriptions are limited to the three modes which presently may be regarded as standard in MV: volume-controlled ventilation (VCV), pressure-controlled ventilation (PCV), and pressure support ventilation (PSV). Examples of curves will be used to explore concepts in respiratory system mechanics and how to interpret patient–ventilator interaction from such curves.

Concepts in respiratory system mechanics

Auto-positive end-expiratory pressure

Expiration occurs because alveolar pressure (Palv) is greater than airway pressure (Paw), thereby generating a flow (Q) against the expiratory resistance (R). The following equation shows the relationship among the determinants of Q:

$$Q = \frac{\text{Palv} - \text{Paw}}{R} \qquad (1)$$

Normally, at the end of calm expiration, the respiratory system has reached its functional residual capacity (FRC). However, if the expiratory time (Te) is not long enough to allow full exhalation, then the respiratory system does not reach FRC, and the trapped volume (Vtrap) determines the appearance of auto-positive end-expiratory pressure (PEEP).[6–8]

$$\text{Auto-PEEP} = \text{Vtrap} \times E \qquad (2)$$

where E is the elastance of the respiratory system.

Fig. 1 shows that the persistence of end-expiratory flow at the end of the respiratory cycle on the flow–time curve indicates that the Palv–Paw gradient is >0, which determines the existence of auto-PEEP.[9] Likewise, on examining the Paw–time curve, we observe the existence of pressure above the PEEP, indicating the trapping of air.

Stress index

Fig. 2 shows that the pressure–volume ratio (PVR) tracing of the respiratory system is not linear; rather, in general it is sigmoid in shape with two extremities where E is greater, and a relatively linear intermediate zone in which E is smaller.[10] The three segments of the inspiratory arm of the curve are separated by lower inflexion point (LIP) and upper inflexion point (UIP)[11] (Fig. 2) that allow us to identify the pressures at which recruitment and derecruitment begin and end. Accordingly, it has been postulated that tidal ventilation (TV) should occur in the central zone of the PVR tracing, between the two inflexion points.[12,13]

The determination of PVR is instrumentally complex,[14] and evaluation based on the classical super-syringe method (static PVR) requires disconnection of the patient from the ventilator and generates hypoventilation while the maneuver is carried out.[15] For this reason surrogates have been sought, based on the use of low flows during the tracing, among others, as an approximation to the static