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Review

Real-time pulmonary graphics

Mark C. Mammel [a,*], Steven M. Donn [b]

[a] Children's Hospitals & Clinics of Minnesota – St Paul and Department of Pediatrics, Division of Neonatology, University of Minnesota, Minneapolis, MN, USA
[b] Department of Pediatrics, Division of Neonatal–Perinatal Medicine, C.S. Mott Children's Hospital, University of Michigan Health System, Ann Arbor, MI, USA

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S U M M A R Y

Real-time pulmonary graphics now enable clinicians to view lung mechanics and patient–ventilator interactions on a breath-to-breath basis. Displays of pressure, volume, and flow waveforms, pressure–volume and flow–volume loops, and trend screens enable clinicians to customize ventilator settings based on the underlying pathophysiology and responses of the individual patient. This article reviews the basic concepts of pulmonary graphics and demonstrates how they contribute to our understanding of respiratory physiology and the management of neonatal respiratory failure.

1. Introduction

Real-time pulmonary graphics are the graphical display of measured and derived values captured during the process of mechanical ventilation. These visual representations of the interaction between the mechanical ventilator and the baby receiving support for respiratory failure are critical in understanding both the support used and its effectiveness. Today, most current neonatal conventional ventilators and even a few high-frequency devices display a myriad of respiratory parameters. Sadly, the potentially valuable information available from these displays is often poorly understood or ignored. This discussion will review the history of pulmonary graphics, explain the basics of graphical analysis of respiratory support, and present some common problems.

Visual display of physiologic parameters is the culmination of intense study of the lung's mechanical and biochemical behaviors. As long ago as the 1920s, Von Neergaard and Wirtz graphically evaluated pressure–volume relationships in isolated liquid-filled and air-filled feline lungs. They observed a difference in the inspiratory and expiratory pressure–volume relationship in the air-filled lungs, which was not present when the lungs were filled with liquid. Based on this demonstration of hysteresis, they inferred the existence of a surface-acting material, which produced the different mechanical behaviors [1]. From the 1940s through the 1960s, many investigators worked to understand and define the composition, chemistry and biology of this surface-active alveolar layer. The classic work of Mary Ellen Avery and Jere Mead from 1959 established the critical role of this material, dubbed surfactant, in facilitating the normal transition from intra- to extrauterine life, and the respiratory distress syndrome (RDS) that resulted from its absence [2]. The use of Grass polygraphic recorders, to produce paper displays of lung mechanics, became a frequent component of the research laboratory and was also used some studies in human infants by investigators at the Cardiovascular Research Institute in San Francisco (Fig. 1) [3]. Unfortunately, this type of display was generally only available to physiologists and scientists in laboratory settings and not relevant to mechanical ventilation as performed in that era.

The 1960s were a time of tremendous advance in newborn respiratory support. Patrick Bouvier Kennedy, son of the president, was born at 34 weeks' gestation and died in a hyperbaric oxygen chamber in 1963, as mechanical ventilation was thought to be too extreme and experimental for this child. As the concept and practice of mechanical ventilation for newborns moved from a desperate, last-ditch therapy to something many were at least willing to consider, it was clear that almost nothing was understood about how to do it [4]. In retrospect, the relationship of delivered pressures, both peak and end-expiratory, to the delivery of tidal and minute volumes seems obvious. At the beginning of the 1970s, though the basic physiologic principles were known, these relationships were a mystery. Gregory and colleagues published a landmark paper in 1971 demonstrating how the application of continuous positive airway pressure (CPAP) could reduce mortality

* Corresponding author. Address: 347 N. Smith Ave, #505, Children's Hospitals & Clinics of Minnesota, St Paul, MN 55102, USA. Tel.: +1 651 220 6260.
E-mail address: mamme001@umn.edu (M.C. Mammel).

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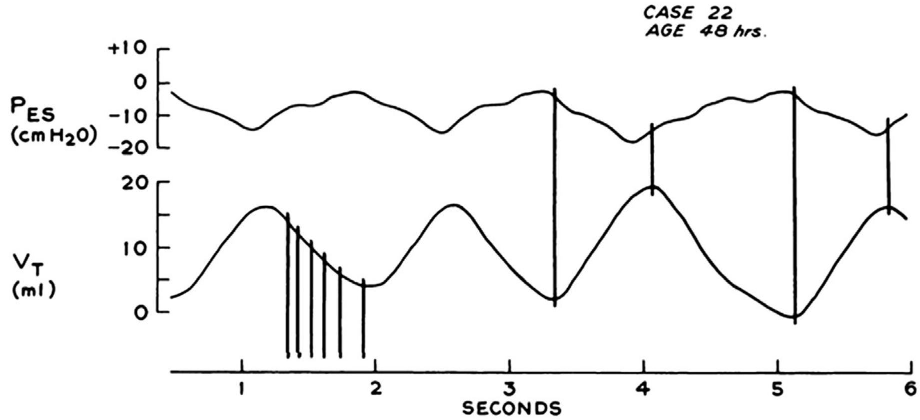

Fig. 1. Changes in esophageal pressure and tidal volume, displayed using a Grass recorder, in an infant with respiratory distress syndrome. Modified from Chu et al. [3].

in neonatal RDS, and in their discussion postulated what we now know to be correct – that CPAP recruits atelectatic lung and results in better oxygenation as a result. This advance, though widely adopted, did not fully inform the neonatal community about what they were actually doing during mechanical respiratory support [5]. In 1977, Boros and colleagues reported on a unifying variable, mean airway pressure (P_{aw}), as a technique to use something that could be easily measured and displayed, airways pressure, as a way to impact oxygenation [6]. They stated "Our studies … suggest that during mechanical ventilation there is an optimum airway pressure at which gas exchange is most efficient and after which alveolar overdistention occurs." Since the measurement of tidal volumes was not yet available as a routine bedside parameter, they did not make the leap to the relationship of these pressures to the delivered gas volumes. Instead, the ventilators of the era displayed peak and end-expiratory pressures against time, and stand-alone devices such as the Pneumogard® were marketed to display and record – on a display with strip chart capability – mean, peak, and intra-esophageal pressures for bedside monitoring (Fig. 2). Though of some use, without the ability to assess the change in tidal or minute ventilation, only limited information could be obtained [7].

This began to change during the 1980s, when the introduction of the bedside computer allowed the continuous real-time display of airway pressures, and the derivation of delivered volumes. These values could then be combined to provide more in-depth graphic analysis, as defined in the pulmonary physiology laboratory. Peak and end-expiratory pressures could be displayed over time, with a real-time tidal volume signal also shown. The first commercially available neonatal system, described by Bhutani et al. in 1988, provided real-time analysis, but widespread use was limited because it was a stand-alone device, rolled from bedside to bedside for intermittent as opposed to continuous measurements [8]. In spite of this limitation, a great deal of work was done, and many observations were made that continue to inform us today. Some of these observations include the impact of skeletal muscle relaxants, surfactant administration, caffeine therapy, closure of the ductus arteriosus, spontaneous and mechanical ventilation, and the effect of growth on the mechanical behavior of the lung [9].

By the 1990s, the manufacturers of neonatal respirators added graphic displays of various types, from simple to complex. Pressure–volume and flow–volume loops were easy to display. Trend screens, which allowed for analysis of these parameters over time, were also added. Since that time, the content has not changed all that much, though the sophistication and presentation has improved quite a bit. Still, the presentation of data is just the first step in the acquisition of new information about a patient's status. In fact, the addition of many new variables, rather than enlightening clinicians, often had the opposite effect. Too much information, some valuable and some secondary, can result in all of it being ignored. Additionally, the introduction of exogenous surfactant in 1990 made mechanical ventilation of the newborn infant easier, as long as the clinician paid attention during the first hours and days after treatment, when lung mechanics rapidly changed [10]. Finally, this period also saw the introduction of two important advances in the technology of neonatal ventilation: patient triggering, and volume targeting [11,12]. All of these changes made it possible for the neonatologist to observe in real-time how each neonate interacted with the devices used for support. The baby's respiratory drive could be assessed by how well he or she could trigger the device. The amount of needed support could change based on the respiratory effort the baby produced to deliver tidal volume, with the ventilator adding to it as required. The change in the mechanical behavior of the lungs with therapy could be seen immediately. Yet, all of these changes might be missed if the monitoring capabilities of these remarkable machines were not utilized.

The key components of a graphics monitoring system are the same for all ventilators. They include a sensor to measure flow and pressure, and allow the derivation of volumes. Most devices in use today employ the hot wire anemometer technology. This system has been miniaturized to allow its use in neonatal patients; it is

Fig. 2. The Pneumogard® (Novametrix Medical Systems, Inc., Wallingford, CT, USA).