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Bedside measurement of work of breathing

T.E. Oh, S. Bhatt & Y.H. Tam
Department of Anaesthesia & Intensive Care, Chinese University of Hong Kong, Prince of Wales Hospital, Hong Kong

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Abstract

This paper describes the technique of measuring work of breathing, presented at the 13th International Symposium on Computers in Clinical Medicine and Anaesthesiology, Rotterdam, June 1992. Measuring work of breathing has clinical uses in the Intensive Care Unit. Oxygen consumption does not truly reflect work of breathing. Mechanical work of breathing can be measured by recording continuous pressure and flow and integrating the resultant power. This method is facilitated at the bedside with the use of a PC computer and a spreadsheet program. It is further simplified by software to measure the area under the inspiratory pressure: volume loop.

Work of breathing may be expressed as mechanical work or oxygen consumption by respiratory muscles. Oxygen consumption by respiratory muscles has been suggested to indirectly reflect work of breathing. Measuring oxygen consumption ($\dot{V}o_2$) at the bedside is much less complex than measuring mechanical work. $\dot{V}o_2$ increases during weaning from mechanical ventilation (Field, Kelly & Macklem 1982, Hubmayr et al. 1988, Lewis et al. 1988, McDonald et al. 1988, Shikora et al. 1990), attributed to increased respiratory muscle work, and this increase has been proposed as an index of weaning ability (Lewis et al. 1988, Shikora et al. 1990). However, weaning is both physically and psychologically stressful, and arterial plasma catecholamine levels are increased up to four times during weaning (Oh, Lin & Bhatt 1991). Since catecholamines are potent calorigenic hormones, they thus significantly increase $\dot{V}o_2$ in their own right. $\dot{V}o_2$ increases also lack sufficient accuracy to be a useful predictor of weaning ability. Hence $\Delta \dot{V}o_2$ cannot be equated primarily to oxygen consumption by respiratory muscles and thus to work of breathing.

Mechanical work of breathing is denoted by the area described by an inspiratory pressure-volume loop. The relevant distending pressure for the entire thorax (lung plus chest wall) is airway pressure (Paw). Thus, in mechanical ventilation, the work done by the ventilator on the whole respiratory system is given by the area under a plot of Paw against tidal volume. Conversely, in spontaneous ventilation, it is also the work done by the patient against the impedance of the ventilator or breathing circuit.

Transpulmonary pressure (Ptp) which is derived from Paw minus oesophageal (i.e. pleural) pressure, represents the distending force for the lung parenchyma. A Ptp-tidal volume loop thus measures the pulmonary elastic work done on the lungs plus the resistive work done in moving gas and lung tissues. In weaning patients with lung disease, the principal disorder is in the lungs and not the chest wall. Hence, measurement of work done on the lungs can reflect the major changes in the work of breathing.

Bedside measurement of work of breathing can be used to assess the mechanical work required by different modes of ventilation such as inspiratory pressure support (Brochard 1987), assist control ventilation (Marini 1986), and continuous positive airway pressure (Katz 1985). Mechanical work of breathing has also been suggested as a predictor of successful weaning (Fiastro et al. 1988). Work of breathing may also be used to assess the impedance of breathing systems e.g. the demand valves, gas delivery mechanisms and continuous flow systems of ventilators (Beydon et al. 1988, Cox, Tinloi & Farrimond 1988, Oh, Bhatt & Lin 1991), the resistance of humidifiers (Oh et al. 1991), and the impedance of circuits (Bersten et al. 1989, Bhatt et al. 1992).

Measurement of work of breathing at the bedside is derived from pressure and flow recordings. Paw (or Ptp) and flow are measured simultaneously at the patient airway, using a pressure transducer (e.g. strain gauge, Motorola MPX 10DP) and a flow transducer (e.g. platinum hot wire, Ohmeda SE 302T or a pneumotachograph, Fleisch No. 2). The transducers are calibrated with a RT-200 Calibration Analyzer (Timeter Instrument Corp, USA). Simultaneous pressure and flow signals are digitized at a rate of 200/second, and displayed and recorded on an oscilloscope (Gould DSO 1604). With each circuit, pressure and flow measurements are recorded over 3–10 consecutive breaths and repeated for another 3–10-breath sequence.

Mechanical work of breathing is derived from the area described under a pressure-volume loop or from integration of power (see below). Paired pressure and flow mV readings (200 pairs/second) stored in the oscilloscope are transferred to an IBM AT-compatible computer as a numerical ASCII text file. An IEEE-488 interface board (PC-LabCard PCL-848A/B) was installed in the computer to enable the data transfer from the IEEE-488 output of the oscilloscope. The ASCII text file is then imported into a spreadsheet program (Lotus 1-2-3 version 2.2), and pressure (kPa) and flow (L/min) values are computed from their respective calibration equations.

Mechanical work of breathing is derived from integration of power. The product of pressure (P) and flow ($\dot{V}$) gives instantaneous power ($\dot{W}$) at that point in time. Power over a defined time interval (t_O to t_T) is given by integration of P.$\dot{V}$ over that period. Work during that period is then given by

$$W = \int_{t_O}^{t_T} \dot{W}.\, dt$$

This method of determining work done has been previously described (Engstrom & Norlander 1962, Mecklenburgh et al. 1986). Inspired tidal volume (Vt) is then derived from integration of flow during the inspiratory phase.

This simple but time consuming method was grossly simplified by the application of a special program written in *Turbo C*. The program directly imports recorded pressure and flow signals into the PC and then automatically draws the pressure and flow waveforms. A single breath or a series of breaths can then be isolated using moveable vertical cursor lines. Tidal volume is calculated by integrating flow with time. A pressure-tidal volume loop (for a single breath) or loops (for a series of breaths) can be displayed. The area(s) of the loop (s) can then be easily computed to give mechanical work of breathing. Thus measuring of work of breathing at the bedside is made much less complex and more applicable.

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Address for offprints:
T.E. Oh, M.D.,
Department of Anaesthesia & Intensive Care,
Chinese University of Hong Kong,
Prince of Wales Hospital, Hong Kong