The Physiology of Mechanical Ventilation

2

The aim of this chapter is to try to describe, briefly and simply, the basics of how a ventilator works and provide some notions on the interaction between the ventilator and the patient.

A ventilator is a relatively simple machine designed to transmit and apply, following a set scheme, energy which serves to perform useful work. The energy is delivered to the ventilator in the form of electricity (= volts × amperes × time) or compressed gas (= pressure × volume) and conveyed from it in order to increase or replace the force that the respiratory muscles must expend to support the work of breathing.

However, let's take a step backwards and try to understand how we breathe. First of all, we have to define what must be translated from pure mechanics to respiratory physiology. Force is a mechanical concept that in physiology is defined as pressure (pressure = force/area), movement is the volume (volume = area × movement), and finally the measure of the change in movement is defined as flow (mean flow = Δ volume/Δ time). In the case of ventilation, we consider a pressure generated by a subject and/or by a machine which produces a flow of gas that enters the airways and increases the volume of the lungs.

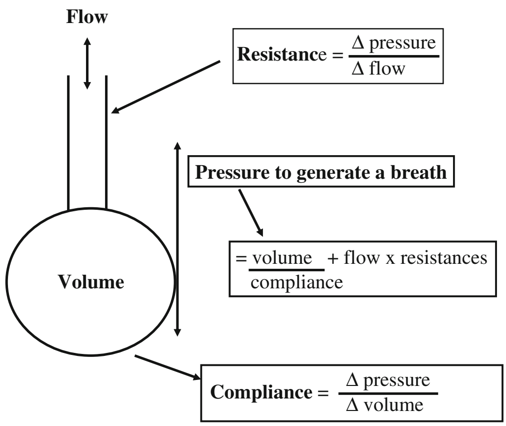
Figure 2.1 is a diagram showing, simply we hope, how breathing works. To begin with there are three pressures that determine the flow and, therefore, the generation of volume; these are:

1. the atmospheric pressure (Patm);
2. the alveolar pressure, that is, the pressure within the lungs (Palv);
3. the pleural pressure, that is, the pressure generated between the lungs and the thoracic cage (Ppl).

The movement of air from outside the body into the lungs and vice versa is ensured by a pressure gradient between the exterior (Patm) and interior of the lungs (Palv). If the Palv decreases, with respect to the Patm, we talk of negative pressure ventilation, which is the natural condition. If the Patm (pressure at the mouth) increases, with respect to the Palv, we talk of positive pressure ventilation

S. Nava and F. Fanfulla, *Non Invasive Artificial Ventilation*,
DOI: 10.1007/978-88-470-5526-1_2, © Springer-Verlag Italia 2014

Fig. 2.1 How the respiratory system works



(during mechanical ventilation). The greater the flow, the greater the pressure; as a corollary, for the same flow, if the resistance increases, the pressure rises.

The expansion of an elastic balloon is caused by the so-called transpulmonary pressure, that is, the difference between Palv and Ppl. The force that generates a breath is produced during mechanical ventilation by the sum of the pressure of the patient's muscles (Pmusc) and the pressure generated by the ventilator (Pvent).

Two other pressures are important in determining the physiology of a spontaneous or an assisted breath: the pressure of elastic recoil (i.e., elastance or E = Δ pressure/Δ volume, with compliance being its reciprocal), and the resistive pressure (i.e., R = Δ pressure/Δ flow), which depends on the patient's characteristics. In the final analysis, the so-called equation of motion of the respiratory system can be simplified as follows:

$$P_{vent} + P_{musc} = \text{Elastance} \times \text{Volume} + \text{Resistance} \times \text{Flow}$$

Thus, in the ventilated patient, the pressures generated by the ventilator and the patient, in various proportions depending on the pathology and the method of ventilation, determine the flow and volume that the patient receives. For example, a totally passive patient has no Pmusc and so all the force is generated by Pvent; the opposite condition exists if the patient is breathing spontaneously.

Pressure, volume, and flow are functions of time and are called *variables*. It is assumed that elastance and resistances remain constant during breathing and, by convention, these are called *parameters*. This applies to the inspiratory phase.

Supposing that expiration occurs passively, as it does in the majority of cases, Pmusc and Pvent are absent and the equation of motion therefore becomes:

$$-\text{Resistance} \times \text{Flow} = \text{Elastance} \times \text{Volume}$$

The minus sign at the left of the equation indicates the negative direction of the expiratory flow and suggests that during passive expiration the flow is generated by the energy stored in the elastic component during inspiration. These are the basic concepts that we must keep in mind when we ventilate a patient, remembering that probably the only difference between invasive ventilation and NIV is given by the resistance of the nose and the upper airway, which are by-passed by the endotracheal tube in invasive ventilation.

Suggested Reading

Bates JH, Rossi A, Milic-Emili J (1985) Analysis of the behaviour of the respiratory system with constant inspiratory flow. J Appl Physiol 58(6):1840–1848

Chatburn RL (2006) Classification of mechanical ventilators. In: Tobin M (ed) Principle and practice of mechanical ventilation. Mc-Graw Hill, New York

Mead J, Lindgren I, Gaensler EA (1955) The mechanical properties of the lungs in emphysema. J Clin Invest 34:1005–1016

http://www.springer.com/978-88-470-5525-4

Non Invasive Artificial Ventilation
How, When and Why
Nava, S.; Fanfulla, F.
2014, X, 214 p. 47 illus., Softcover
ISBN: 978-88-470-5525-4