# Principles of artificial ventilation

Ben Brown

Justin Roberts

## Abstract

The application of intermittent positive pressure ventilation (IPPV) during the 1952 Copenhagen polio epidemic led to the development of the world's first intensive care unit. The requirement for ventilatory support is the most common indication for intensive therapy unit (ITU) admission and is a defining feature of the speciality. Ventilator technology continues to develop and there are many ways to deliver IPPV. The variety of modes of ventilation is increasingly complex and expanding, without evidence that any one mode is associated with improved outcome. Ventilatory support is part of the treatment for a range of conditions including acute respiratory failure, raised intracranial pressure (ICP) and circulatory shock. Ventilator-associated lung injury is reduced by using low tidal volumes and limiting plateau airway pressure to less than 30 cm$H_2O$. Prolonged artificial ventilation has an associated morbidity and mortality and thus should be reviewed by an expert clinician on a daily basis. Weaning aims to identify those patients who will be able to breathe spontaneously. Protocols exist to facilitate timely extubation without the need for re-intubation.

**Keywords** Artificial ventilation; lung-protective ventilation; weaning

**Royal College of Anaesthetists CPD Matrix:** 2C02

## Learning objectives

After reading this article, you should be able to:
- describe the classification and function of ventilators, including jet and oscillator ventilators
- describe how to initiate, manage and wean artificial ventilation
- list different modes of ventilation and the rationale for their use
- manage artificial ventilation in patients with asthma, COPD (chronic obstructive pulmonary disease) and ARDS (acute respiratory distress syndrome)

## History

During the early 20th century, mechanical ventilation of the lung was achieved by the application of negative pressure around the body leaving the head free ('iron lung') or around the thorax alone (cuirass ventilators). In 1952, a polio epidemic in Copenhagen resulted in hundreds of patients requiring long-term ventilation (due to respiratory and bulbar failure), massively overwhelming the system (they had seven old-fashioned ventilators at the time). Professor Larssen, the Chief Physician, appealed to Dr Bjorn Ibsen, an anaesthetist, with the idea that IPPV (as used in anaesthesia) may rescue the situation. Over 300 patients were manually ventilated around the clock (via tracheostomy) by 1000 medical and dental students. Dr Ibsen had the idea that these patients should be cared for on the same ward, and thus can be considered the 'father' of intensive care medicine. The first positive pressure ventilators were adaptations of respirators developed during World War 2 to oxygenate pilots at altitude. A key figure here was Forrest Bird, himself a WW2 pilot, who developed the first 'Bird' ventilators using household materials. The main difference between the two methods of ventilation is that 'iron lungs' decrease intrathoracic pressure to sub-atmospheric (sucking air in), whereas IPPV via endotracheal tube (ETT) increases alveolar pressure above atmospheric (blowing air in). This simple difference explains many of the physiological effects associated with IPPV.

***Ben Brown*** FRCA *is an Intermediate Level Trainee in Anaesthesia in the North West Deanery, UK. Conflicts of interest: none declared.*

***Justin Roberts*** FRCA FFICM *is a Consultant in Anaesthesia and Intensive Care at Salford Royal Hospital, Salford, UK. Conflicts of interest: none declared.*

## Basic classification of ventilators

The variety and complexity of ventilators and modes of ventilation continues to increase, but the basic principles of operation are still best understood by considering each phase of the ventilatory cycle — inspiration, change from inspiration to expiration, expiration, and change from expiration to inspiration.

### Inspiration

At any one instant during inspiration, a ventilator may deliver a pressure (pressure generator) or a flow (flow generator). To determine flow rate, practitioners will often dial a target volume and an inspiratory time ($t_{insp}$). Modern ventilators respond to feedback from within the circuit, and can therefore combine elements of flow and pressure generators simultaneously. For example in PRVC (pressure-regulated volume-control) the ventilator will deliver the required flow with the minimum possible plateau pressure ($P_{plat}$).

### Pressure generator

The ventilator produces inspiration by delivering a constant, preset pressure to the airway. Gas flows at a rate determined by airway resistance, and flow continues to a volume determined by lung compliance. If airway resistance increases, flow rate will decrease; if compliance increases, tidal volume ($V_T$) will decrease. So performance varies depending on the patient's physiology.

### Flow/volume generator

Flow generators produce a preset constant rate of flow to produce inspiration. Over a given inspiratory time this leads to a fixed inspiratory volume. The ventilator is driven by gas at approximately 400 kPa (with a high internal resistance), therefore it can vary pressure delivered to compensate for changes in compliance and resistance. Thus if compliance decreases (stiffer lungs) the rate of increase of alveolar pressure will be greater for the same rate of distension of the lungs, and the ventilator will compensate by delivering a higher pressure to the airway (therefore delivering a constant $V_T$). If airway resistance (a dynamic measure) increases, without a change in compliance, the pressure gradient between tracheal tube and alveoli will increase, but at a given flow rate the alveolar pressure will be the same. The ventilator will deliver higher pressure to the airway to maintain a constant flow rate in the face of increased resistance.

**In essence:** in a pressure generator, pressure is fixed, flow rate and $V_T$ are the dependent variables. In a flow generator, flow rate (and therefore $V_T$) is fixed, and airway pressure is the dependent variable (Figure 1).

### Change from inspiration to expiration (cycling)

**Volume-cycling:** the ventilator cycles into expiration once a set $V_T$ has been achieved. The inspiratory time is determined by the inspiratory flow rate.

**Pressure-cycling:** the ventilator cycles into expiration when a set airway pressure has been achieved. This mode will compensate for small air leaks, but $V_T$ will depend on compliance and resistance, as will inspiratory time. A modern ventilator may also compensate for small leaks in volume-control mode, by measuring expired volume ($V_E$) and making appropriate adjustments.

**Time-cycling:** the most common method in modern ventilators. The duration of the inspiratory phase is pre-determined. With a flow generator, a tidal volume is usually programmed. When this has been delivered, there may be an inspiratory pause while gas re-distributes within the lung, aiding gas-exchange (a phenomenon known as pendelluft) before the inspiratory cycle ends. This preset-volume setting is not the same as volume-cycling, where expiration will automatically begin once the target volume has been achieved.

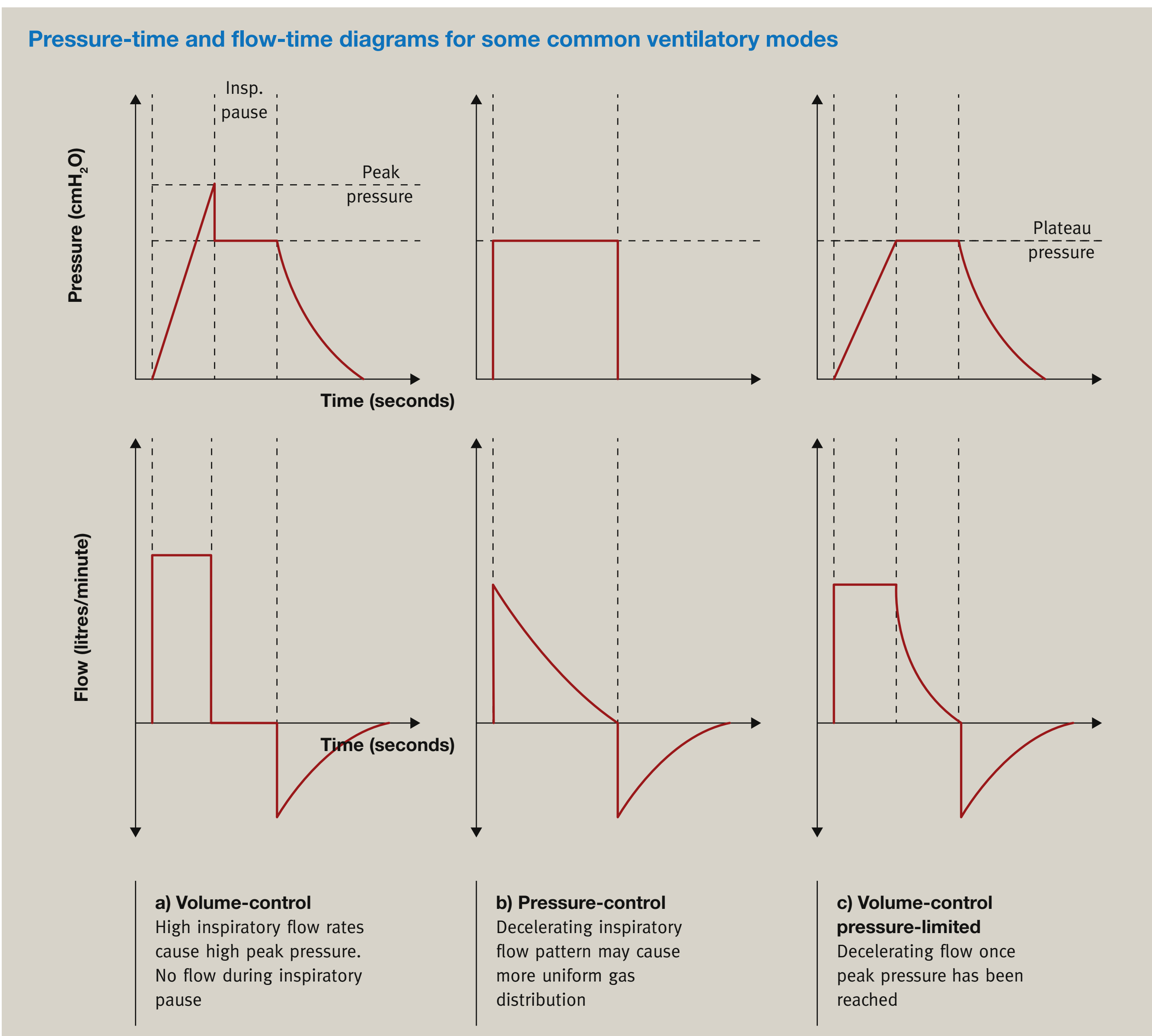


**Figure 1**

 