INTRODUCTION

The modern anesthetic machine

Anesthetic machines have six basic subsystems: (i) gas supplies: pipelines and cylinders; (ii) gas flow measurement and control (flow meters); (iii) vaporizers; (iv) **gas delivery: *(ventilator* and breathing system);** (v) scavenging; and (vi) monitoring.

Antistatic measures improve flow meter performance and, where flammable vapors are used, reduce the risk of ignition. Companies offer modifications of the standard machine to suit different environments. Compact or wall-rail mounted designs may be suitable for areas where space is restricted. These may have a single position back bar. Frontline Genius Compact Anesthesia Machine, larger models may be trolley or ceiling mounted (pendant).

MRI-compatible models e.g. Prima SP Anesthetic Machine (Penlon), is made from non-ferrous metals and can be used safely. Workstations have been developed for total iv anesthesia. In these, syringe drivers are located on a 'back bar' or mounted onto tube and rail systems with integrated monitoring.

A typical modern workstation has open architecture with easily cleaned work-surfaces, and drawers, shelves and rails to accommodate customized accessories. Machines are mains powered and a rechargeable battery provides up to 60 min of backup **(Sinclair et al., 2006).**

History of Anesthesia Ventilators:

The first experiments of respiratory resuscitation have been reported in the middle of the 16^{th} century, describing insufflations of air into the lungs through a pipe introduced into the trachea. Between the 16^{th} and the 19^{th} century, various attempts of mechanical insufflations were made, using a positive airway pressure.

In the late 19^{th} century, the first ventilators were described, namely “tank respirators” the patient was put into the ventilator and inspiration was provoked by a negative pressure applied in the ventilator. This system was subsequently developed as “iron lung”, which was commonly used in the first half of the 20^{th} century.

The emergence of mechanical ventilation in its modern sense began in *Denmark* in the 1950, when an epidemics of poliomyelitis devastated northern *Europe.* In1952**,** hundreds of patients were hospitalized in *Copenhagen* because of respiratory paralysis related to poliomyelitis and were put in iron lungs **(Tung et al., 2005).**

A young anesthetist, named *Dr Bjorn Ibsen*, showed that the addition of an intermittent external positive airway pressure through tracheostomy would save lives, and described the first standardizes approach of treatment of respiratory failure, including tracheal intubation, tracheostomy, and artificial respiration by manual ventilation.

During several months, hundreds of medical students, nurses and physiotherapists spent hours applying manual ventilation and provided the 24 hours coverage. That was the starting point of mechanical ventilation and modern intensive care medicine.

Because of high requirements in human resources could not be easily filed, several types of machines were tried out during this period. *The Engstrom* respirator was then developed, widely used, and became the first respirator that could deliver a predetermined volume at a preset frequency.

The efficiency of this respirator was subsequently confirmed in *Stockholm Hospital* in1953, where 54 patients with poliomyelitis were ventilated. Meanwhile, major progress was made in understanding lung physiology and pathology. Several physiologists allowed a better understanding of respiration and gas exchanges. Measurements of PCO_2, pH and oxygen saturation were developed.

Similarly to *Ibsen*, *Astrup* gained great experience during the1952's epidemics in *Denmark*, and subsequently described the influence of artificial ventilation on modification of pH and PCO_2. He even reported the risk of over ventilation, which, 40years later, became a major issue in mechanical ventilation. During the following two decades, improvements in laboratory measurements helped clinicians evaluate the effectiveness of ventilation and various physiological conditions such as circulatory collapse, renal function or fluid balance. In addition, new knowledge and modern equipment facilitated safer and more successful use of mechanical ventilation.

From the 70^s, ventilators became more sophisticated, with new modes and the ability to continuously monitor various parameters such as pressures, volumes and flows that were actually delivered to the patients. Consequently, blood gas analysis, ventilator monitoring and other forms of physiologic monitoring were increasingly used to guide ventilator settings. Particularity of respiratory physiology of mechanically ventilated lungs was better understood thanks to both research works and daily use of monitoring system at the bedside.

In 1967 the first description of *Acute Respiratory Distress Syndrome (ARDS)* was published, and simultaneously *Positive End Expiratory Pressure (PEEP)* was found to be an effective treatment for severe hypoxemia in ARDS. The number of patients successfully treated with mechanical ventilation dramatically increased, as did the number of beds dedicated to intensive care medicine **(Tung et al., 2005).**

Advantages of Modern Anesthesia Ventilators

Traditional anesthesia ventilators combined with a circle anesthesia system have limitations which make it challenging to ventilate pediatric and difficult ventilatable patients accurately but Modern Anesthesia Ventilators have sufficient abilities to ventilate these patients **(Stayer & Olutoye, 2005).**

The compliance of the breathing system and changes in fresh gas flow interact in a subtle but significant fashion to influence the volume delivered to the patient. When caring for anesthetized pediatric patients, clinicians have used different strategies to ventilate their patients despite the limitations of traditional technology.

A common approach is to adjust the ventilator settings based upon a clinical assessment which includes observation of chest expansion during inspiration and measurement of inspiratory pressure, as well as monitoring the effectiveness of ventilation with capnography and pulse oximetry or blood gas analysis. Clinical assessment is always important and new anesthesia ventilators are designed to make it even easier to satisfy the ventilation requirements of even the smallest patients. Depending upon the device and the manufacturer, different strategies are employed to overcome the influence of compliance and fresh gas flow on delivered volume.

When using volume controlled ventilation, the goal of modern ventilator designs is to deliver a volume to the patient that is as close as possible to the volume set to be delivered. To achieve this goal, the ventilator must be able to compensate for both the compliance of the breathing system and the influence of fresh gas flow on tidal volume independent of changes in lung compliance **(Stayer et al., 2000).**

Modern bellows ventilators utilize a flow sensor at the inspiratory limb to control the volume delivered by the ventilator. The ventilator output is controlled by the flow sensor such that the set volume is delivered to the breathing circuit independent of changes in fresh gas flow or the compliance of the system between the ventilator and the flow sensor.

Piston anesthesia ventilators measure the compliance of the breathing system during the preuse checkout. The compliance measurement is then used to determine how much additional volume must be added to each breath to deliver the set volume to the patient **(Stayer et al., 2000).**

Flexibility: The appearance of pressure control ventilation is a major advantage, allowing patients to be ventilated efficiently who were very difficult with control (CMV) mode, such as patients with ARDS or morbid obesity. PCV also allows safety in ventilating patients in whom excessive pressure must be strictly avoided, such as neonates and infants, and emphysematous patients. The future appearance of modes capable of supporting the patient with spontaneous respirations will extend our capabilities further **(Michael & Dosch, 2003).**

Accuracy at lower tidal volumes: Factors contributing to a discrepancy between set and delivered tidal volumes are especially acute in pediatrics and include.

1- *Large compression volume* of the circle system relative to the infant's lung volume.

2- *Leaks around uncuffed endotracheal tubes*.

3- *Effects of fresh gas flow on delivered tidal volume.*

4- *Mechanical difficulty of setting a small tidal volume using an adult bellows assembly*.

Because of the greatly increased accuracy in tidal volume delivery achieved through compliance and leak testing and compensation, modern ventilators have an unprecedented tidal volume range. They are able to ventilate smaller patients much more accurately than any previous anesthesia ventilator could. This will undoubtedly lessen the need for non rebreathing (Mapleson & Bain) circuits, and make care safer, since anesthetists will no longer have to disassemble and reconfigure to a non rebreathing circuit for a child in the middle of several adult cases. However, it is mandatory to substitute a pediatric circuit for tidal volumes less than 200 mL **(Michael & Dosch, 2003).**

Compliance and leak testing the accuracy comes with a price. An electronic leak and compliance test must be repeated every time the circuit is changed, particularly if changing to a circuit with a different configuration (adult circle to pediatric circle, or adult to long circuit). This test is part of the electronic morning checklist.

The placement of the sensor used to compensate tidal volumes for compliance losses and leaks has some interesting consequences. Some flow sensors are placed between disposable corrugated breathing circuit limbs and the absorber head. Here they are able to compensate tidal volumes for fresh gas flow, compliance losses and leaks internal to the machine and absorber head but not in the breathing hoses.

Other sensors are placed just distal to the Y-piece. In this position, it can compensate for all leaks and compliance losses out to the Y piece (thus including the breathing circuit hoses). However, at this point it adds appreciable and perhaps objectionable bulk and weight close to the patient's face. This may make mask ventilation a bit more cumbersome. Further, a sensor closer to the patient is exposed to more exhaled moisture, but the impact can be lessened with a heat and moisture exchanger between patient and sensor. Unfortunately, this adds further bulk and weight.

Some ventilators test compliance and leaks of all components to the Y-piece via a pressure transducer within the internal circuitry near the bellows. Here the sensor is relatively protected from moisture **(Michael & Dosch, 2003).**

Fresh gas decoupling versus compensation: A final factor adding to modern ventilator accuracy is that they compensate delivered tidal volume for the fresh gas flow. In traditional ventilators, which are not fresh gas decoupled, the delivered tidal volume is the sum of the volume delivered from the ventilator and the fresh gas volume. Thus, delivered tidal volume may change as FGF is changed. For example, consider a patient with a FGF of 4 L/min, a respiratory rate of 10, inspiratory: expiratory ratio of 1:2 and a tidal volume of 700 mL during each minute, the ventilator spend 20 seconds in inspiratory time and 40 seconds in expiratory time (1:2 ratios). During these 20 seconds, the fresh gas flow is 1,320 mL (4000 mL/min FGF times 1/3). So each of the 10 breaths of 700 mL is augmented by 132 mL of fresh gas flowing while the breath is being delivered, so the total delivered tidal volume is 832 mL/breath. This 19% increase is reasonably unimportant.

But what happens if we decrease to lower fresh gas flow? Assume the same parameters, but a FGF of 1,000 mL/min. During each minute, the ventilator spends 20 seconds in inspiratory time and 40 seconds in expiratory time (1:2 ratios). During these 20 seconds, the fresh gas flow is 330 mL (1000 mL/min FGF times 1/3). So each of the 10 breaths of 700 mL is augmented by 33 mL of fresh gas flowing while the breath is being delivered, so the total delivered tidal volume is 733 mL/breath. This means that changing FGF from 4,000 mL/min to 1,000 mL/min, without changing ventilator settings, has resulted in a 14% decrease in delivered tidal volume (832 to 733 mL). It would not be surprising if the end tidal carbon dioxide rose as a result.

The situation is more acute with a traditional anesthesia ventilator in children. Assume a 20 kg patient with a FGF of 4 L/min, a respiratory rate of 20, inspiratory: expiratory ratio of 1:2 and a tidal volume of 200 mL during each minute, the ventilator spend 20 seconds in inspiratory time and 40 seconds in expiratory time (1:2 ratios). During these 20 seconds, the fresh gas flow is 1,320 mL (4000 mL/min FGF times 1/3). So each of the 20 breaths of 200 mL is augmented by 66 mL of fresh gas flowing while the breath is being delivered, so the total delivered tidal volume is 266 mL/breath. This is a 33% increase above what is set on the ventilator.

Thus, fresh gas decoupling helps ensure that the set and delivered tidal volumes are equal. The action of the piston closes a one way (check) valve, diverting FGF to the manual breathing bag during the inspiratory cycle so the visual appearance of the bag is unusual.

1- *The manual breathing bag,* normally quiescent during mechanical ventilation, moves with each breath

2- *The manual breathing bag movement* is opposite to the movement seen in a mechanical ventilator bellows, the manual breathing bag inflates during inspiration (due to fresh gas flow), and deflates during expiration as the contents empty into the absorbent and move on towards the patient.

With fresh gas decoupling, if there is a disconnect, the manual breathing bag rapidly deflates, since the piston retraction draws gas from it. The second approach is fresh gas compensation, which is utilized in some ventilators. The volume and flow sensors provide feedback which allows the ventilator to adjust the delivered tidal volume so that it matches the set tidal volume, in spite of the total fresh gas flow, or in case of changes in fresh gas flow **(Michael & Dosch, 2003).**

Suitability for low flows: Low fresh gas flow is desirable to reduce pollution and cost of volatile agents and nitrous oxide, preserve tracheal heat and moisture, prevent soda lime granules from drying, and preserve patient body temperature.

Factors which enhance the safety and efficiency of low flows in modern ventilators include

1- *Compliance and leak testing, automatic leak detection*

2- *Fresh gas compensation or decoupling*

3- *Warmed absorber heads*

4- *Low volume absorber heads* allows faster equilibration of dialed and delivered agent concentration.

5- *Low fresh gas flows allowed by gas machine* most no longer have mandatory minimum oxygen flows of 200-300 mL/min (except some ventilators with a minimum flow of 500 mL/min).

6- *Electronic detection of bellows not filling.*

7- *Low flow wizard* an electronic monitor that gives indications when fresh gas flow is excessive or too low by monitoring gas volume passing through the scavenger **(Michael & Dosch, 2003).**

Piston ventilators:

Piston ventilators use an electric motor to compress gas in the breathing circuit, creating the motive force for mechanical ventilator inspiration to proceed. Thus they use no driving gas, and may be used without depleting the oxygen cylinder in case of oxygen pipeline failure. In some ventilators, the bellows are occult, being placed horizontally under the writing surface. Although they can be viewed by lifting the writing surface, their to and fro movement is not normally visible during mechanical ventilation. The anesthetist relies on pressure and capnography waveforms to guard against disconnects or other problems.

The Fabius GS has a piston ventilator, but the bellows travel vertically, and their movement is continuously visible through a window to the left of the flow meter bank. The piston ventilator has positive and negative pressure relief valves built in. If the pressure within the piston reaches 75 + 5 cm H_2O, the positive pressure relief valve opens. If the pressure within the piston declines to -8 cm H_2O, the negative pressure relief valve opens, and room air is drawn into the piston, protecting the patient from NEEP (negative end expiratory pressure) **(Michael & Dosch, 2003).**

There are several advantages to the piston ventilator system.

1- *Quiet*

2- *No PEEP* (2-3 cm water are mandatory on standing bellows ventilators due to the design of the ventilator spill valve)

3- *Greater precision in delivered tidal volume* due to compliance and leak compensation, fresh gas decoupling, and the rigid piston design.

4- *There are less compliance losses* with a piston as compared to a flexible standing bellows compressed by driving gas.

5- *Measuring compliance and leaks* with a transducer near the piston eliminates a bulky, costly sensor close to the patient's airway.

6- *Electricity is the driving force for the piston,* so if oxygen pipeline pressure fails and one must rely on oxygen from the emergency cylinder, mechanical ventilation may