Chris Thompson 2003

VENTILATION

INTRODUCTION

Normally, Alveolar Ventilation is unconsciously regulated to maintain constant arterial blood gas tensions, despite variable levels of oxygen consumption and CO_2 production.

Many drugs and techniques used in anaesthesia interfere with control or mechanics of ventilation, and it is the Anaesthetists responsibility to ensure the adequacy of ventilation during the perioperative period.

Equipment related to ventilation is consequently of great importance to the Anaesthetist and Anaesthetic Technician. Correct use of the equipment relies on a good understanding of basic respiratory physiology as well as how the individual ventilator operates.

NORMAL PHYSIOLOGY

Basic Principles

Venous blood always has a lower PaO_2 (40 mmHg or 75% saturated or 15 ml O_2/100ml blood) and higher $PaCO_2$ (46 mmHg) than inspired gas (PiO_2 150 mmHg, $PiCO_2$ usually 0), so that there is normally a partial pressure gradient driving Oxygen in and CO_2 out of the pulmonary capillary blood.

Ventilation of the lungs with inspired gases results in mixing of the inspired gases with alveolar gas.

If there is no ventilation at all, there will be no replenishment of oxygen and no removal of CO_2, so the PAO_2 will fall and $PACO_2$ will rise towards the venous O_2 and CO_2 tensions.

If the ventilation is much greater than is needed, then the alveolar gas tensions will be much closer to inspired gas.

Definitions

Ventilation is the process by which Oxygen and CO_2 are transported to and from the Lungs.

Tidal Volume (VT) is the amount of gas expired per breath - typically 500ml at rest.

Deadspace Volume (VD) is the sum of the Anatomic Deadspace, due to the volume of the airways (typically 150ml), and Physiologic Deadspace, due to alveoli which are ventilated but not perfused (usually insignificant).

Minute Volume (VE) is the amount of gas expired per minute.

Alveolar Ventilation (VA) is the amount of gas which reaches functional respiratory units (ie, alveoli) per minute. VA = (Tidal Volume - Deadspace) x Respiratory rate

Lung Volumes

- FRC (Functional Residual Capacity) 2.2l.(supine)
- TLC (Total Lung Capacity) 6.2l.
- Maximum Inspiratory Volume 4.0l. above FRC.
- ERV (Expiratory Reserve Volume) 1.0l. below FRC.
- RV (Residual Volume) 1.2l.
- MVV (Maximal Voluntary Ventilation) 150 l/m.

Lung Mechanics

Inspiration

An active process requiring musular effort; 75% diaphragmatic at rest; intercostals used on exertion.

Inspiratory effort causes:

- Fall in intrapleural pressure
- Fall in Alveolar pressure
- Pressure gradient from mouth to alveoli
- Gas flow down pressure gradient

Maximum inspiratory force sometimes used as an index of resp. effort; if < 20 cmH_2O most patients have difficulty

Expiration

Usually a passive process due to lung recoil:

- Relaxation of inspiratory muscles causes:
- Intrapleural pressure becomes less negative

- Alveolar pressure rises
- Pressure gradient from alveoli to mouth
- Gas flow down pressure gradient

Airway Resistance

- Limits gas flow down airways
- Due mostly to airway/ETT diameter (fourth power of radius)
- Normal response to increased resistance is increased effort
- GA's increase resistance and decrease response, causing hypoventilation

Intrapleural Pressure

- Normally -10 cmH2O, due to elastic recoil of lung opposed by chest wall.
- Becomes more negative on inspiration.
- Less at the dependent regions of the lung, reducing alveolar size.

Compliance

"Static" Compliance is a measure of the "stiffness" of lung and chest wall, typically 50 ml/cmH2O in adults and proportionally less in kids. It is usually due equally to lung and chest wall compliances (100 ml/cmH2O each).

Surfactant improves lung compliance, especially at low lung volumes; its absence as in ARDS, results in stiff lungs and a tendency for the alveoli to collapse and fill with fliud.

"Dynamic" compliance includes the extra pressure needed to overcome resistance to airflow, inertia of chest wall, and viscoelasticity of tissues.

Total compliance varies from person to person and from time to time. A ventilator with pressure limited inspiration will deliver varying tidal volumes during an anaesthetic and from patient to patient. Most modern anaesthesia ventilators are of the "Volume Preset" type to minimise this problem.

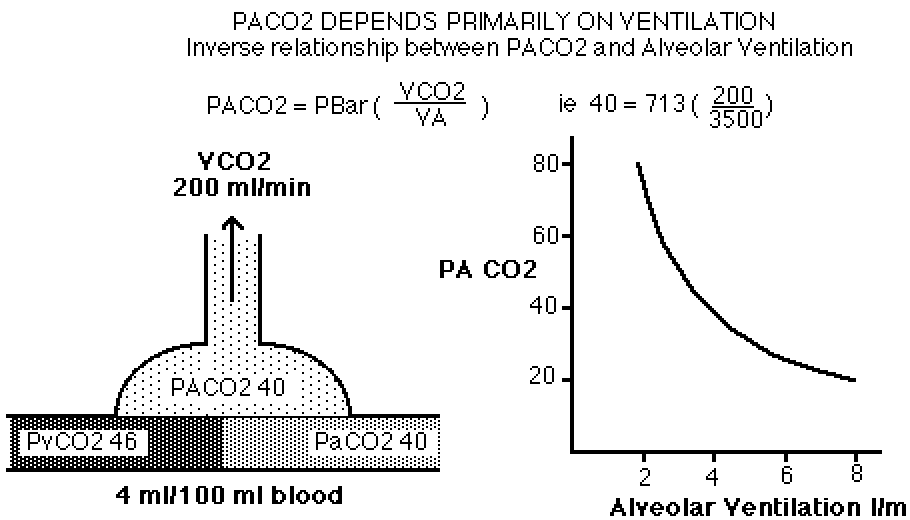
Work of Breathing

Work = Pressure x Volume

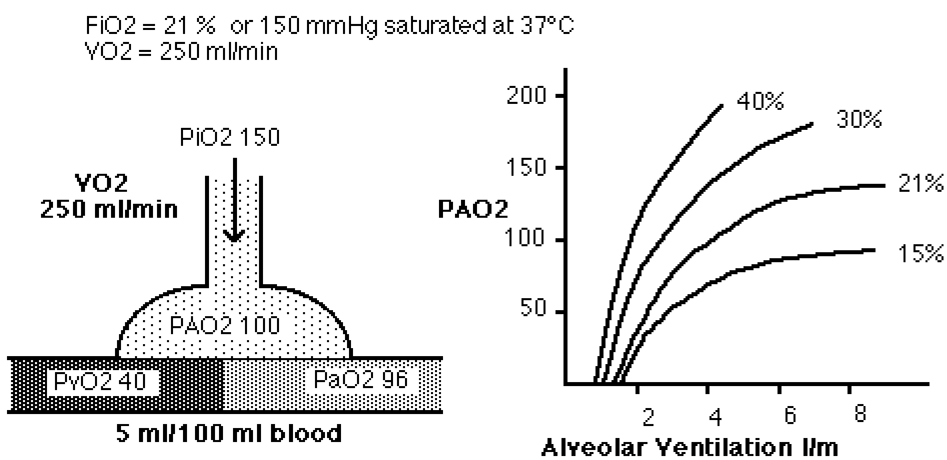
Respiratory work at rest or during exercise is seldom responsible for more than 5% of the total body work. Most of this is used to overcome the lung and chest wall stiffness during inspiration. Work to overcome airway resistance is usually very small, except during exercise or in athsmatics.

Patients with most respiratory diseases have increased respiratory workloads, which may be due to high respiratory rates, stiff lungs, or high airway resistances. When the patient becomes so exhausted that they can no longer keep up the workload, respiratory failure ensues. Anaesthetic machine tubing, one-way valves, and ETTs all increase total resistance and respiratory work, while drugs will diminish respiratory effort, so that the patient with poor respiratory function usually requires ventilating both during and after the operation.

CO2 Elimination



Oxygen Transport



Effect of Shunts

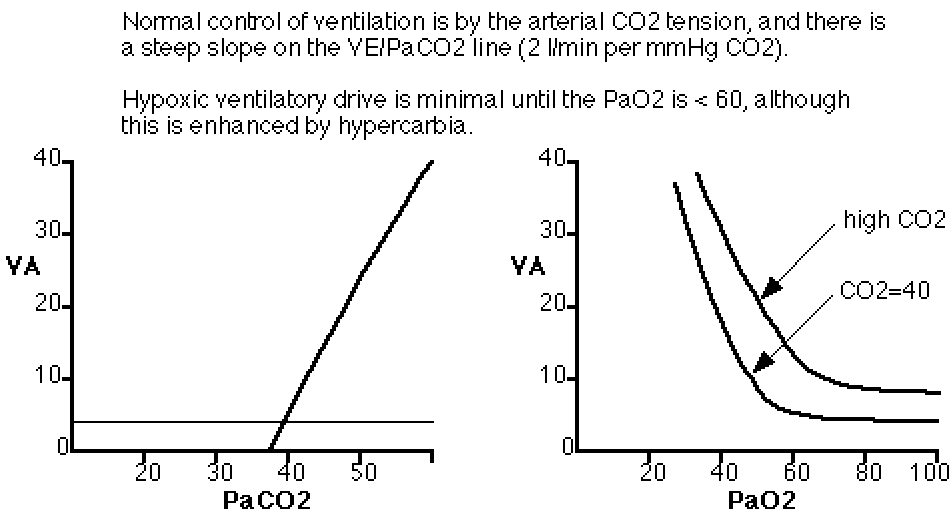
Some venous blood passes through the lungs without equilibration with Alveolar gas. This "Venous Admixture" or "Shunt" subsequently mixes with oxygenated blood in the pulmonary veins, and has the effect of reducing PaO2 and elevating PaCO2.

While the slight rise in PaCO2 can be overcome easily by increasing the ventilation to normal alveoli, the same is not true for PaO2. For example, a 50% shunt needs 100%

inspired oxygen to get a PaO2 of about 60 mmHg, but only a doubling of ventilation for normocarbia.

This is because the normal alveoli can blow off lots more CO2 than normal, but can never saturate the Hb any more than 100%.

Control of Ventilation



Effects of Anaesthesia

- Impaired control of ventilation; volatile agents almost totally abolish hypoxic responses, narcotics, sedatives, anaesthetics impair CO2 responses
- Increased Deadspace (equipment and physiological)
- Increased work of ventilation due to:
- Increased circuit and airway resistance
- Decreased lung compliance
- Increased Shunt, leading to hypoxia, due to:
- Atelectasis of dependent parts of the lung
- Impaired sputum clearance (cilia, atropine, sedation, pain)
- Decreased FRC

VENTILATION

Classification

- Mouth-to-Mouth/mask/ett etc
- IPPV - "Conventional" Mechanical Ventilation
- PCV - Pressure Control Ventialtion
- IMV - Intermittent Mandatory (Volume) Ventilation
- MMV - Mandatory Minute Ventilation
- SIMV -- Synchronised IMV ("Assisted")

- PRVC - Pressure Regulated Volume Controlled (volume preset pressure ventilation; machine alters pressure on a breath by breath basis to generate the tidal volume set by the user)
- BiPAP - Two-level CPAP (pt can breathe during inspiration and expiration)
- J et Ventilation (Sanders Injector)
- HFV - High-Frequency Ventilation
- HFO - High-Frequency Oscilation
- HFJV - High-Frequency Jet Ventilation
- PEEP - Positive End-Expiratory Pressure
- CPAP - Constant Positive Airway Pressure (pt can breathe duting expiration)
- NPV - Negative Pressure Ventilation
- TRIO - Tracheal Insufflation of Oxygen
- Apnoeic oxygenation

Effects of IPPV/PEEP

Respiratory:

- Decreased PaCO2 due to increased Alveolar Ventiilation
- Improved PaO2 (see previous graphs)
- Intrapleural Pressure less negative
- Work of breathing reduced
- Decreased lung water
- Optimum PEEP increases alveolar size, FRC, compliance, etc
- Hazards associated with intubation, paralysis or sedation, equipment failure.

Cardiovascular:

- Pressure gradient for venous return decreased whenever intrathoracic pressure rises
- CVP and peripheral venous pressure rise
- Reduced RV filling and increased RV afterload; opposite effects on LV
- May cause fall in Cardiac Output, particularly in hypovolaemic patients, causing reflex increase in contractility, heart rate, MVO2, vasoconstriction to augment venous pressure, reduced mixed venous oxygen tension, which may worsen aterial PO2

Renal

- Decreased renal function due to fall in Cardiac Output & Renal perfusion
- Increased ADH due to decreased central venous wall tension

Effects of CPAP/IMV or BiPAP

- Patient can breathe spontaneously; paralysis not always required
- Optimum CPAP and a low-resistance circuit reduces work of breathing

- Intrapleural pressure not as high as for IPPV so less depression of C.O.

But most IMV/CPAP systems do not maintain CPAP well and finding "Optimal" CPAP is difficult.

Ventilators

Classification

- TYPE OF VENTILATION
- Positive/Negative
- OTHER CAPABILITIES
- PEEP/CPAP/IMV/MMV/HFV/HFO/HFJV etc
- CYCLING (reason inspiration commences)
- a) Automatic
- Time (Campbell, Bird)
- Pressure
- Other
- b) Manual c) Patient-Triggered
- INSPIRATION LIMIT
- Automatic
- Volume +/- Pressure limit (Bird with Bellows)
- Time (Campbell)
- Pressure (Bird)
- Flow
- Manual
- INSPIRATORY FLOW PATTERN
- Constant (Bird with Air-Mix control closed)
- Decelerating (Venturi-type, ie Campbell)
- Programmable
- Sinusoidal (Piston driven)
- CONTROL MECHANISM
- Pneumatic +/- Magnetic (Bird)
- Electronic (Servo)
- Fluidic Logic (Campbell)
- PATIENT CIRCUIT
- Single or Dual
- POWER REQUIREMENTS CONTROLS

Use in Anaesthesia

- Aim for normocarbia or slight hypocarbia
- Usually Volume preset IPPV devices
- Tidal volume and rate adjusted to suit patient (CO2 analysers useful)

With CO_2 absorber ON:

- All inspired gas is free of CO_2
- Effective ventilation depends only on Ventilator settings
- Very low Fresh Gas Flows may be used in the circle circuit

With the CO_2 Absorber off:

- Provided that the ventilator settings deliver normal alveolar ventilation, the effective ventilation depends on Fresh Gas Flow.
- CO_2 rebreathing occurs

Hazards

- Disconnection from circuit
- Failure to deliver ventilation
- Barotrauma

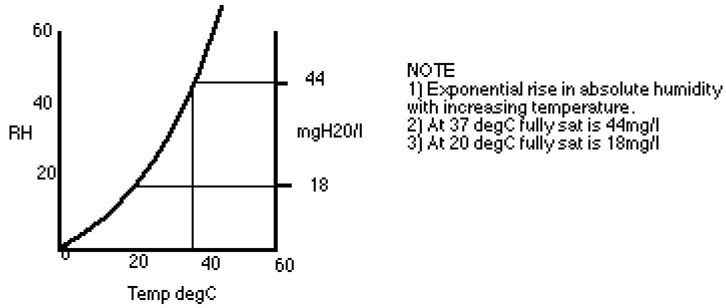
Monitoring Ventilation

- Colour of the Patient
- Watching the chest move
- Precordial/Oesophageal Stethoscope +/- telemetry
- Listening to sound of ventilator
- Measurement of Circuit Parameters, such as pressure or tidal volume
- Measurement of Patient Parameters, such as $ETCO_2$, SpO_2, chest wall impedance,etc

HUMIDIFICATION

Physics

- Vapour - Gas Phase of a liquid below boiling point
- Aerosol/Mist - suspension of fine droplets of a liquid in a gas
- Absolute Humidity - amount of water vapour per unit of gas (mg/l)
- Relative Humidity - Absolute humidity of the sample as a % of the absolute humidity of fully saturated gas at the same temperature



Measurement of Humidity

- Dew Point Hygrometer
- Hair Hygrometer
- Wet/Dry thermometer
- Humidity Sensors
- Measurement of water used by humidifier

Physiology

The nose is a very efficient humidifier:

- 60% RH at the post-nasal space
- 5% RH in the mouth
- 100% at 37 degC in the bronchi

Mouth-breathing is less efficient (60% RH in the upper trachea)

Heat and water loss through the nose is minimised by cooling on inspiration and warming on expiration.

Humidification is required to maintain of ciliary activity, prevent squamous epithelial changes (Mucosal changes in 2-3 hours), prevent dehydration and thickening of secretions and possible ETT obstrucion, minimise atelectasis and tracheitis, and to decrease heatloss

Methods

ANAESTHETIC CIRCUIT CONSIDERATIONS

- Cylinder gas is completely dry, and tracheal intubation bypasses the nose
- Waters CO2 absorber heats and humidifies gas very effectively
- Circle CO2 absorbers are of slight benefit only
- Bain circuit allows some warming but very little humidification

HEAT AND MOISTURE EXCHANGERS

- Relatively cheap
- 70%-80% effective humidification
- Increased deadspace, resistance, risk of disconnection

HUMIDIFIERS

Up to 100% humidification, essential for longterm respiratory care. Modern types heat both the water bath and patient hose to prevent rainout. Disadvantages:

- Cost
- Potential for leaks, disconnection
- Drowning if tipped
- Source of infection
- Unreliable
- Airway burns
- Increased airway resistance

EQUIPMENT

FISHER & PAYKEL

- Water heated to 37 degC , servo controlled hose heaters in newer units

GRANT - NICHOLAS

- Water heated to 45 degC , hose servo to 37 degC. Inefficient at >10l/min flows

BOURNS

- Basic Kettle type

NEBULISERS

- Produce aerosols with humidity depending on temperature.
- Air is usually cooled by the droplets ->cold wet air
- Most useful for drug delivery
