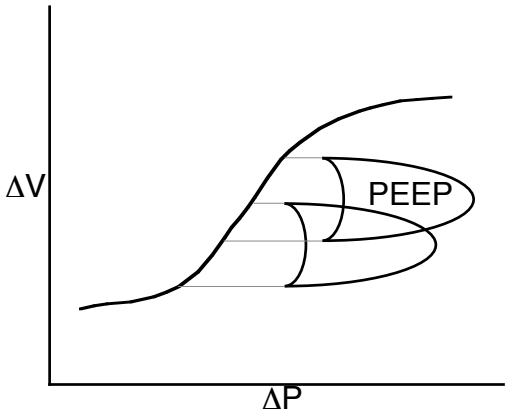
B. 10 Applied Respiratory Physiology

a. Describe the physiological consequences of intermittent positive pressure ventilation and positive end-expiratory pressure.

Intermittent positive pressure ventilation (IPPV) is artificial ventilation produced by imposing a positive pressure from a sealed circuit into the airway, followed by passive expiration, usually at atmospheric pressure. The major physiological difference from spontaneous ventilation is in the range of airway and intrathoracic pressures involved. Spontaneous ventilation involves small pressure excursions above and below atmospheric pressure in airway pressure. IPPV involves much higher airway pressures in inspiration, typically 15-25 mmHg in a healthy adult. Much of this pressure is transmitted to increase intrathoracic pressure.

Positive end-expiratory pressure (PEEP) is a modification of IPPV such that the expiratory airway pressure does not fall as low as atmospheric pressure. A typical level of PEEP is 5-15 mmHg.



Consequences of IPPV and PEEP:

respiratory
- end-expiratory alveolar pressure = PEEP,
- producing an increase in FRC according to PEEP level and compliance
  - may lift FRC above closing capacity in patients with a high closing volume
  - reduces airway resistance
  - alters relative compliance of upper and lower parts of the lung
- reduces pulmonary shunt
- intrapleural pressure rises according to the transmural pressure gradient (increased in most pathology)
- increases dead space with prolonged application due to bronchiolar dilation

cardiac
- increased intrathoracic pressure
  - reduced systemic venous return, reduced cardiac output, increased ADH, reduced ANF
- increased pulmonary capillary resistance
- increased "Zone 1" may make PCWP measurement unreliable

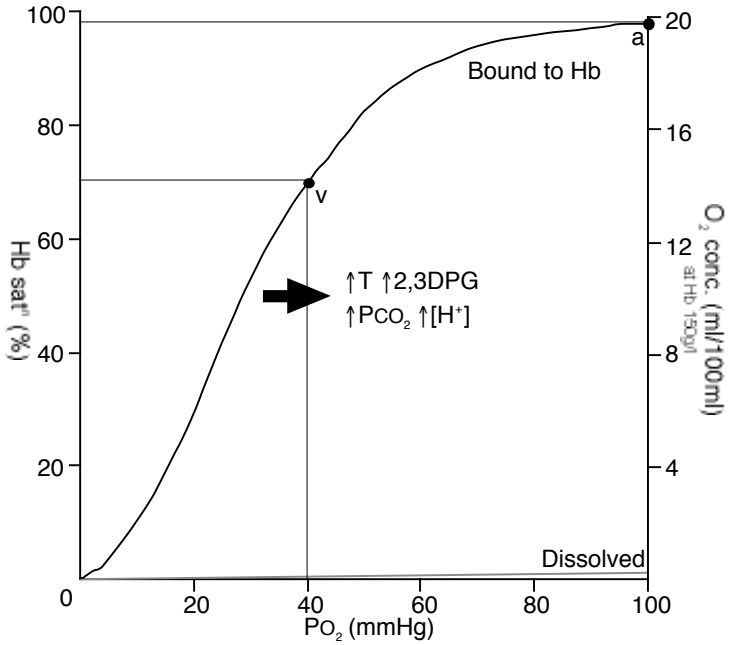
renal
- decreased perfusion pressure
- fluid retention

overall effect of PEEP
- increased P_aO_2 in diseased lung
- decreased cardiac output
- increased oxygen flux up to "best PEEP"
- not useful in healthy lungs
- mostly used in ICU setting

b. Explain the physiological consequences of hypoxaemia, hyper and hypocapnia and carbon monoxide poisoning.

Hypoxaemia
- low P_aO_2
- classified as hypoxic hypoxia (low P_AO_2), anaemia hypoxia (low O_2 carrying capacity),

stagnant hypoxia (poor tissue perfusion) and histotoxic hypoxia (failure of cellular respiration)



cellular
- anaerobic metabolism (P_aO_2<20 mmHg or histotoxicity)
  - accumulation of lactate, acidosis
  - depletion of high energy phosphates: ATP and phosphocreatine
  - time to cellular "arrest" depends on energy requirements vs stores

respiratory
- control
  - hypoxia detected by peripheral chemoreceptors (carotid & aortic bodies)
  - hyperventilation at P_aO_2<55 mmHg, maximal at P_aO_2<30 mmHg
  - secondary hypocapnia
  - central respiratory depression with severe hypoxia
- pulmonary vasoconstriction (primarily related to P_AO_2)

cardiovascular
- systemic vasodilation (especially cerebral): ↑ CO, ↓ MAP
- acidosis and increased 2,3-DPG shifts Hb-O_2 dissociation curve to the right
- increased erythropoietin and haematocrit in chronic hypoxia

Hypercapnia
- high P_aCO_2
- causes acidosis (in blood, ECF and CSF) via carbonic anhydrase

neurological
- cerebral vasodilation, ↑ ICP
- convulsant at high P_aCO_2
- central depressant effect at high P_aCO_2 (>95 mmHg, MAC=32%)
- autonomic
  - increased sympathetic outflow
  - increased sensitivity to parasympathetic tone via ↓ AChE activity in acidosis

respiratory
- control
  - hypercapnia detected at central chemoreceptor (80% of sustained response) in the ventral medulla and in peripheral chemoreceptors (rapid response)
  - hyperventilation up to P_aCO_2 of 100-150 mmHg
- pulmonary vasoconstriction (weaker effect than hypoxia)

cardiovascular
- systemic vasodilation
- ↑ contractility and heart rate via sympathetic action (direct depressant action)
- arrhythmogenic
- acidosis shifts Hb-O_2 dissociation curve to the right

renal
- chronic hypercapnia results in renal compensation by retention of HCO_3^-

endocrine
- sympathetic response raises blood glucose and K^+

Hypocapnia

low P_aCO_2
mainly opposite effects to those of hypercapnia
alkalosis (↓ free Ca^{2+})

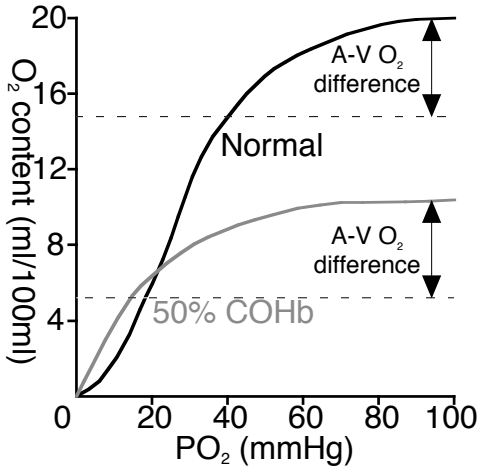
neurological
cerebral vasoconstriction: ↓ ICP
↑ neural excitability at low P_aCO_2

respiratory
detected at central and peripheral chemoreceptors
reduced respiratory drive (dangerous in labour)
can produce apnoea in anaesthetized patients, but not usually when conscious
pulmonary vasodilation

cardiovascular
↑ peripheral resistance
↓ cardiac output
Hb-O_2 dissociation curve shifted to the left

Carbon-monoxide (CO) poisoning

CO binds to haemoglobin (Hb) with approximately 270 times the affinity of oxygen under physiological conditions (P_{50}=0.1 mmHg). It binds at the same site and in the same manner as O_2, so binding is cooperative with either CO or O_2: CO poisoning moves the Hb-O_2 dissociation curve to the left. The toxicity of CO is mediated by its reduction of the oxygen carrying capacity of blood by binding with Hb and by impairing tissue oxygenation through its effect on the Hb-O_2 dissociation curve.



The reduction in oxygen concentration at a given oxygen tension results in reduced oxygen delivery and tissue hypoxia if there is sufficient reduction in oxygen concentration. The P_aO_2 is not reduced, but normal oxygen extraction results in a lower mixed venous PO_2 and a lower tissue PO_2.

This reduction in oxygen carrying capacity causes hypoxaemia, and the physiological responses are given above.

CO poisoning can be reversed with removal of the source of CO, and hyperventilation with high FiO_2 to accelerate dissociation of COHb. In the conscious patient, use of a raised $FiCO_2$ is described as a method of increasing spontaneous ventilation.

c. Explain the effects of the supine and erect postures on ventilatory function.

Changing from erect to supine:

increased
diffusing capacity (due to reduced V/Q scatter)

decreased
FRC by 500-1000 ml, approaching closing capacity
anatomical dead space by 100-150 ml
physiological dead space by 5% (from 35% of V_T to 30%)
alveolar dead space (due to reduced V/Q scatter)

d. Define humidity and give an outline of the importance of humidification.

Absolute humidity
the mass of water vapour per unit volume of a gas.

Humidity at saturation
the maximum mass of water which can be present in a gas per unit volume at a

specified temperature.

Relative humidity

the ratio of absolute to saturation humidity at a specified temperature expressed as a percentage.

Air at 37˚ with a 100% relative humidity contains 44gm^{-3} of water (SVP=47 mmHg)

Inspired gas is normally humidified in the nose and mouth before entering the lower respiratory tract. Inadequate humidification of inspired gas due to use of dry gas by mask or bypassing of the upper airway by intubation results in:

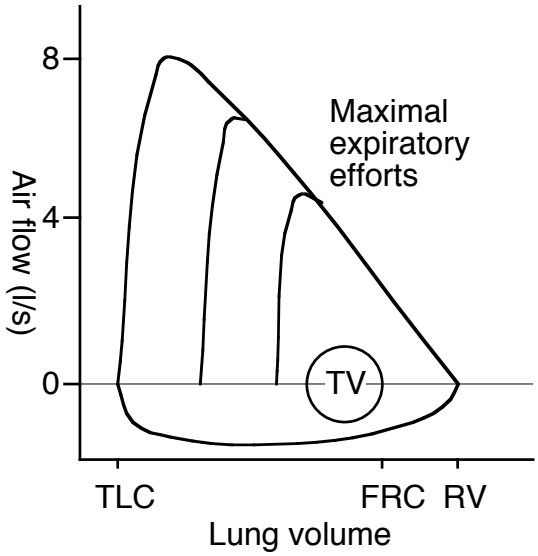
acute

- impaired ciliary and mucous belt function
- tenacious mucus, crusting of secretions
- increased airway resistance and reduced compliance
- heat loss by evaporation

chronic

- squamous metaplasia
- ↓ FRC
- ↑ shunt
- impaired surfactant function
- atelectasis

e. Explain the importance of the cough reflex and describe the relationship between lung volume and ability to cough.



The cough reflex is the major mechanism for clearing the upper and lower airways of foreign material larger than can be carried by the mucociliary elevator. It is initiated by mechanical or chemical irritation of the airway. It consists of a deep inspiration to about $^{2}/_{3}$ of V_T followed by tight closure of the glottis and contraction of expiratory muscles causing a rise in airway pressure often in excess of 100 mmHg, then a forceful expiration through upper airways narrowed by high transmural pressure, producing a high air velocity to dislodge foreign material.

The maximum expiratory flow rate and velocity which can be generated depends on both expiratory muscle strength and lung volume. With normal strength, it is limited by lung volume due to airway closure which makes expiratory flow effort independent as lung volume decreases.

f. Explain the effects of general anaesthesia on respiratory function.

Intraoperative

Control

- Altered patterns with depth of anaesthesia and agent used
- Hyperventilation in excitatory stage
- Depressed ventilation when deep
  - ↓ response to PCO_2 with ↑ MAC value
  - abolished hypoxic response with minimal anaesthetic agent
  - in Respiratory Control (1.B.2)

Mechanics

- Supine position ↓ FRC
- Altered $\dot{V}/Q$ matching with anaesthesia

- ↑ shunt, ↑ A-a gradient
- V_D altered by position and instrumentation
- Gas exchange
  - Altered inspired gases or volatile agents
  - Second gas effect
- Defence mechanisms
  - Drying of mucosa, volatiles, tube cuff: ↓ ciliary function

Postoperative

- Immediate
  - Drug effects (above)
  - Diffusional hypoxia
  - ↑ O_2 requirement with shivering
- Pain-related
  - ↓ FRC, ↓ VC most with upper abdominal surgery
  - Narcotic respiratory depression
  - Posture effects