The Control of Breathing

Prof Doug Corfield
MBChB Programme Director
Head of the Division of Medical Education
Control of breathing ...

- To regulate gas exchange
- To execute behavioural acts
- To maintain airways and lung function

- Breathlessness in lung disease
- Sleep-disordered breathing
To achieve these functions the brain must:

• Control the pharynx and larynx
  – to maintain upper airways patency

• Control the pump muscles
  – for inspiration
  – for expiration
Control of Breathing

• Automatic & voluntary (behavioural) control of upper airways and pump muscles
  – Central nervous control is different
  – Peripheral nervous system is the same
    • Effectors are skeletal muscle controlled by somatic motor neurones
      • Not under control of autonomic nervous system

• Smooth muscle of conducting airways is under autonomic control
Somatic motor innervation of the pharynx and larynx

- Cranial nerves
  - glossopharyngeal (IX)
  - vagus (X)
  - spinal accessory (XI)
  - hypoglossal (XII)
Somatic motor innervation of the pump muscles

Diaphragm
  phrenic nerve
  cervical plexus (C3 - C5)

Intercostal Muscles
  T1 - T12

Abdominal muscles
  Thoracic, Lumbar
Automatic control of breathing - brainstem respiratory centres
Automatic respiratory rhythm generation (a model)

- Respiratory pacemaker in the medulla- will generate a respiratory rhythm in isolation, with no input.

- Pacemaker $\Rightarrow$ ‘pattern generation’ $\Rightarrow$ output to pump muscles and upper airways
  - Pre-Bötzinger – the pacemaker region
  - Ventral + dorsal respiratory groups of the medulla
  - Pontine respiratory group

- Modulation of ‘drive’ and pattern by sensory inputs
Sensory inputs to breathing

• Chemoreceptors
• Lungs & airways
• Chest wall
Sensory inputs to the respiratory centres

• Peripheral chemoreceptors
  – carotid bodies, aortic arch
  – Arterial stimulus:
    $\downarrow \text{pH (} \uparrow \text{H}^+\text{), } \uparrow \text{PCO}_2, \downarrow \text{PO}_2$ (hypoxia)

• Central chemoreceptors
  – located on the surface of the medulla
  – Arterial stimulus:
    $\uparrow \text{PCO}_2$
    *not* pH, *not* hypoxia
Central chemoreceptors

Capillary

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Ventilatory response to inhaled CO$_2$

**Graph**: Ventilation (l.min$^{-1}$) vs. $P_{ACO_2}$ (kPa)

- Ventilation increases with increasing $P_{ACO_2}$.
Ventilatory response to hypoxia

Ventilation (l.min$^{-1}$)

$P_{A}O_2$ (kPa)
Response to inhaled $\text{CO}_2 + \text{hypoxia}$

- **Ventilation (l.min$^{-1}$)**
- **$P_{\text{A}CO_2}$ (kPa)**

The graph shows the response of ventilation to changes in $P_{\text{A}CO_2}$ (kPa).
Sensory input from lungs, airways and chest wall

- Nose
  - Trigeminal (V)

- Pharynx
  - Glossopharyngeal (IX)
  - Vagus (X)

- Larynx
  - Vagus (X)

- Lungs
  - Vagus (X)

- Chest wall
  - Spinal nerves
Sensory input from lungs + airways

Pulmonary stretch receptors
- Predominantly in trachea and main bronchi
- Respond to lung inflation

Irritant receptors
- Naso-pharynx, larynx, trachea, bronchi
- Mechanical, chemical irritant stimuli, inflammatory mediators

C-fibres
- receptors “free” nerve endings
- Larynx, trachea, bronchi, lungs (J- receptors)
- Chemical irritant stimuli, inflammatory mediators, lung oedema (J-receptors)
A model so far

Central & peripheral chemoreceptors

Change in $\text{PCO}_2$/pH/$\text{PO}_2$

Ventilation

Respiratory centres

Respiratory muscles

Lung inflation
Control of breathing ...

• To execute behavioural acts
  – requires supra-brainstem structures
The motor cortex:

Motor homunculus

Voluntary breathing
Other motor related areas of the brain

- Supplementary motor area
- Primary motor cortex
- Pre-motor cortex
- Basal ganglia
- Primary sensory cortex
- Cerebellum
Locked in syndrome

- Loss of voluntary control of movement except the eyes
- Fully conscious
- Normal sensation
- What happens to breathing?
Locked in syndrome

\[ V_T (1L) \]

"Deep breath"  "Deep breath"  "Deep breath"

\[ \frac{\dot{V}}{\text{Insp/Exp}} \]

10 sec
Locked in syndrome

Spontaneous "laughter"
Respiratory centres

Change in PCO$_2$/pH/PO$_2$

Ventilation

Lung inflation

Motor cortex

Emotion/behaviour

Limbic system

Central & peripheral chemoreceptors

Respiratory muscles

Respiratory centres
Why do patients feel breathless?
What is dyspnoea?

• A clinical term to describe troublesome shortness of breath reported by a patient

• It occurs at inappropriately low levels of exertion and thus limits exercise tolerance and life quality

• A unpleasant and frightening experience. In severe cases it can be associated with feelings of impending suffocation
Definition of dyspnoea

• American Thoracic Society consensus statement
  – “Dyspnea is a term used to characterise a subjective experience of breathing discomfort that is comprised of qualitatively distinct sensations that vary in intensity. The experience derives from interactions among multiple physiological, psychological, social and environmental factors, and may induce secondary physiological and behavioral responses.”

Am J Respir Crit Care Med. 1999; 159:321-340
Symptom perception model

Information input

- Emotions
- Physiology
- Pathology
- Environment

Attention

- External information

Detection

- Somatic sensations

Attribution

- Psychological attribution

Experience

- Psychological symptoms

Behaviour

- Illness behaviour
  - Subjective health
  - Sick role behaviour
  - Medical care use

- Subjective health

Somatisation

- Negative affectivity

Personality characteristics
Components of dyspnoea

• Work or effort of breathing
• Chest tightness
• Shortness of breath
  – The element of dyspnoea that contains the affective component
Neural basis for dyspnoea

Cognition
Emotion
Experience

Lungs and chest wall
Exercising muscles
PCO₂, pH, PO₂
The perception of breathlessness is dependent on a network of cortical and sub-cortical brain regions, particularly limbic and para-limbic structures.
Sleep-disordered breathing
Sleep disorder causes car crashes

A large number of car accidents are caused by drowsiness.

People who suffer from a common sleep disorder are much more likely to have a road accident than other drivers, according to a study.
Sleep
Control of breathing

- Reflex/automatic
  - Brainstem

- Voluntary/behavioural
  - Motor cortex

- Emotional
  - Limbic system

- Respiratory muscles
Respiratory and cardiovascular changes during sleep

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Control of breathing ...

- To regulate gas exchange
- To execute behavioural acts
- To maintain airways and lung function
Anatomy of the upper airway
Upper airway patency

Extraluminal forces
- Gravitational forces
- Adipose tissue

Neuromuscular forces
- Dilator muscles actively dilate and/or stiffen the pharynx
Obstructive Sleep Apnoea

- Arousal
  - ↑ ↑ BP and HR

- Apnoea
  - ↓ UA muscle function
  - Hypercapnia
  - Hypoxia

- Patent airway
  - – Ventilation

- Sleep

\[40\]
Consequences for the brain

- Hypoxia
- Sleep fragmentation
- Sleepiness
- Cognitive impairment
- Increased cardiovascular morbidity
- Increased risk of stroke
Upper airway patency

Extraluminal forces
- Gravitational forces
- Adipose tissue

Neuromuscular forces
- Dilator muscles actively dilate and/or stiffen the pharynx
Continuous Positive Airway Pressure
Control of breathing ...

- To regulate gas exchange
- To execute behavioural acts
- To maintain airways and lung function

- Breathlessness in lung disease
- Sleep-disordered breathing