Respiratory Physiology: Control and Regulation of Breathing

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Respiration is the process by which our body takes in air containing oxygen into the lungs and exchange oxygen with carbon dioxide in the alveoli. Breathing is an involuntary, rhythmic process of inhalation and exhalation of air. Respiration includes both breathing and ventilation (gas exchange in the alveoli). Lungs along with the respiratory tract are the major organ system involved in respiration. The part of the respiratory tract where gas exchange occurs is the alveolar space. The part of the respiratory tract where no gas exchange occurs is called the dead space.

A normal adult breathe's with a respiratory rate less than 25 breaths per minute. The rate of respiration varies with state of the body. It changes with body activity, body temperature, heart status and during various disease processes. Target of the mechanism controlling respiration is to maintain arterial partial pressure of oxygen($P_{O_2}$) and the partial pressure of carbon dioxide($P_{CO_2}$) in normal range, even in the state of respiratory distress.
What can be controlled?

1. Frequency of breathing
2. Depth of breathing maintaining the tidal volume

Neural Inputs or Sensors

1. **Chemoreceptors**
   a. Central chemoreceptors which are in the Central nervous system i.e in the brain and the spinal cord.
   b. Peripheral chemoreceptors that are in the carotid artery and the aorta.

2. **Pulmonary Receptors (Mechanoreceptors) - Receptors in the lungs**
   a. Stretch Receptors which prevent over-inflation of the lungs.
   b. Juxta-capillary receptors and Bronchial C fibers - These sense chemicals, stretch and pulmonary edema and respond by producing shallow breathing and producing mucous secretion.
   c. Joint and muscle receptors responsible for chest wall position and muscle tension.

3. **Irritant Receptors**: These sense the presence of dust, chemicals and cold air and respond by producing cough reflex and/or bronchoconstriction.

Chemoreceptors in the CNS sense the changes in H+ ion concentration while the peripheral chemoreceptors sense the changes in the Po₂ and Pco₂ in the blood as well as the H+ ions concentration.

Pulmonary receptors are present in the visceral pleura surrounding the lungs and in the lung parenchyma. These receptors sense the stretch in the lungs produced when the lungs expand.

Feedback Mechanism

Stimuli from the chemoreceptor, pulmonary receptors and receptors in the joints and muscles around the chest stimulate the respiratory control center which in return commands the effectors to produce the desired effects.
Effectors

These are the muscles and related tissues which are controlled by the CNS to regulate the respiratory effort. These maintain the respiratory activity as ordered by the brain through the respiratory control center. Effectors include diaphragm and the respiratory muscles (external and internal intercostal muscles; accessory muscles and abdominal muscles). Inspiration is controlled by the external intercostal muscles and the accessory muscles. Expiration is controlled by the internal intercostal and the abdominal muscles.

Respiratory Control Center

The respiratory center in the CNS lies in the brainstem in the pons and medulla. Effectors are signaled by the neurons in the medulla. These centres control the automatic, unconscious breathing activity. The motor cortex of the cerebrum has the voluntary control.
The control centers in the brainstem include the following:

1. The apneustic center
2. The pneumotaxic center
3. Medullary Respiratory Centers (in the reticular formation of the brain)
   a. Ventral respiratory group of nuclei
   b. Dorsal respiratory group of nuclei

**Input to the Inspiratory Center**

Sensory fibers from the peripheral chemoreceptor reach the respiratory centers through the glossopharyngeal nerve and the vagus nerve and from the mechanoreceptor in the lungs through the vagus nerve.

Stretch receptors in the lungs send signals through vagus nerve. Pco2 receptors in the bone-dura arachnoid matter in the CSF space also send signals through IX and X cranial nerves.

**Output from the Inspiratory Center**

Output or efferent fibers through the spinal cord synapse on the lower motor neuron in the cervical and thoracic region and through the phrenic nerve signal the diaphragm and through intercostal nerves signal the intercostal muscles. Contraction of these muscles produces the inspiratory activity.

Inspiration usually lasts for 2 seconds which is followed by the expiration, in which relaxation of the inspiratory muscles and contraction of the expiratory muscles occur leading to expiration.

**Expiratory Center**

The center for expiration lies in the ventral respiratory neurons in the medulla. These neurons are not fully active during quiet breathing. They are activated during exercise or in conditions when more gas exchange is required.

**Apneustic Center**

**Location:** It is located in the reticular formation in the lower pons.

**Function:** This center is responsible for the coordination between inhalation and exhalation. It specifically facilitates in the process of inspiration. This center sends signals to the dorsal respiratory group of neurons to prevent the switch off inspiratory ramp signals. It is responsible for deeper and longer inspiration. On stimulation, the duration of inspiration is increased resulting in deeper and prolonged inspiratory effort.

**Pneumotaxic Center**

**Pneumotaxic Center** is located in the upper pons. On its activation, it sends inhibitory impulses to the inspiratory area and turn off inspiration. It helps in limiting action potentials in the phrenic nerve in order to control the function of the diaphragm. As a result it limits the size of tidal volume and regulates the respiratory rate. If strong signals are produced, the rate of breathing is increased to 30 – 40 breaths /min and weak signals
reduce the rate to few breaths /min.

Chemical Regulation Respiration

The respiratory system functions to maintain proper levels of CO₂ and O₂ and is very responsive to changes in the levels of these gases in body fluids.

Chemoreceptor

Sensory neurons responsive to chemicals, monitor levels of CO₂, H+ and O₂ and provide input to the respiratory center which adjusts pulmonary ventilation to keep these variables within the homeostatic limit.

Stimuli for Central Chemoreceptors

Main function of the central chemoreceptors is to keep arterial P_{CO₂}. Within limits. CO₂ is not the main stimulus for the central chemoreceptors; instead H+ ions in CSF is the main stimulus. CO₂ in blood passes through brain barrier and forms carbonic acid in CSF which disassociate into H and HCO₃⁻ ion. This H ion stimulates the respiratory center.

Function of Central Chemoreceptors

Main function is to maintain PCO₂ in the brain and the CSF. H+ generated maintains the pH of the CSF and stimulates the respiratory center causing an increase in the breathing rate. Rise in respiratory rate leads to washing out of more CO₂, P_{CO₂} falls to normal.

Peripheral Chemoreceptors

These are located at the carotid bifurcation in the carotid body and in the arch of aorta in the aortic bodies. Sometimes they may also be present in thoracic and abdominal region along major arteries. These receptors detect changes in arterial O₂, along with changes in CO₂ and pH. Signals from these receptors are transmitted to respiratory centers in order to regulate respiratory activity. Each chemoreceptor receives special blood supply.

Stimulus for Peripheral Chemoreceptors

1. **Decrease in arterial Po₂**: Any decrease in arterial PO₂ is detected by these receptors. They relatively respond to decrease in Po₂ to less than 60mmHg. When PO₂ of 100 to 60mmhg, rate remains almost constant; but, if arterial po2 falls below 60mmhg, respiratory rate increases slowly.
2. **Increase in arterial pco₂**: These receptors also detect increase in PCO₂ but it is lesser effect. Changes in PCO₂ is detected and responded properly by the central chemoreceptors.
3. **Decrease in arterial pH**: A fall in the arterial pH leads to an increase in ventilation, mediated by peripheral chemoreceptor after sensing an increase in the H+ ions in the arterial blood. Only chemoreceptors of the carotid bodies respond to this change; not the aortic bodies.

In conditions like metabolic acidosis, decreased arterial pH stimulates the peripheral chemoreceptors directly and increase the respiratory rate. This is called the Kausmaal breathing.
References


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