Lecture 18
The Respiratory System Measurements
Measurements of the Pulmonary Function

Assessment of the pulmonary function is primarily based on the measurements of the
- lung volumes,
- lung capacities,
- air flow,
- airway resistance,
- lung compliance and elasticity,
- Intrathoracic and intraalveolar pressures

These measurements make use of one or more of four main gas laws
Gas Laws

ën Boyle’s Law

ён Volume of gas varies inversely with the pressure, if temperature is held constant

\[ \frac{V_2}{V_1} = \frac{P_1}{P_2} \]

ën Charles’ Law

ён Volume of a gas is directly proportional to its absolute temperature, if pressure is held constant

\[ \frac{V_2}{V_1} = \frac{T_2}{T_1} \]
**Dalton’s Law**

Total pressure exerted by a mixture of gases is equal to the sum of the partial pressures of various gasses. Furthermore, the partial pressure of a gas in a mixture is equal to the pressure of that gas if it were alone (in the container).

\[
P_{total} = P_1 + P_2 + \cdots + P_n
\]

\[
P_{total} \approx P_{O_2} + P_{CO_2} + P_{N_2}
\]

**Henry’s Law**

If temperature is held constant, the quantity of a gas that will dissove in a solution is proportional to the partial pressure of that gas. This is why more O₂ is dissolved into the tissues from the arterial blood and more CO₂ into the venous blood from the tissues.
Partial Pressure Changes

Atmospheric air:
- $P_{O_2} = 159$ mmHg
- $P_{CO_2} = 0.3$ mmHg

CO$_2$ exhaled

O$_2$ inhaled

Alveolar air:
- $P_{O_2} = 105$ mmHg
- $P_{CO_2} = 40$ mmHg

(a) External respiration: pulmonary gas exchange

To lungs

Pulmonary capillaries

To left atrium

(b) Internal respiration: systemic gas exchange

To right atrium

Systemic capillaries

To tissue cells

Systemic tissue cells:
- $P_{O_2} = 40$ mmHg
- $P_{CO_2} = 45$ mmHg
Measurable variables in the Respiratory System

Very few parameters can actually be directly measured, typically those that have direct connection to external air

- Flow of gas through the mouth and nose (flowmeter)
  - The integral of this flow provides the volume of gas
- Pressure at the mouth, nose and body surface
- Partial pressures of various gases in mixtures passing through air way opening (AWO)
- Partial pressures of gases in blood samples (in vitro)
- Temperature / core body temperature

Most other parameters need to be inferred / computed from other measurements
Other Parameters

Airway resistance

Airway resistance relates to the ease at which air flows through the tubular respiratory structures. Higher resistances occur in smaller tubes (bronchioles and alveoli)

\[ R_{AW} = \frac{\partial(\Delta P)}{\partial Q} = \frac{\partial(P_{AWO} - P_{ALV})}{\partial Q_{AWO}} \]

Lung compliance

The ability of the alveoli and lung tissue to expand on inspiration

\[ C = \frac{\partial V}{\partial(\Delta P)} = \begin{cases} \frac{\Delta V_{Lungs}}{\partial(\Delta P_{Lungs})} & \text{lung compliance} \\ \frac{\Delta V_{Lungs}}{\partial(\Delta P_{Wall})} & \text{chest wall compliance} \end{cases} \]

\[ \Delta P_L = (P_{AWO} - P_{Pleural}) \]

\[ \Delta P_W = (P_{Pleural} - P_{Body surface}) \]
Other Parameters

- **Lung Elasticity**
  - The ability of the lung’s elastic tissues to recoil during expiration

- **Intrathoracic Pressure**
  - Positive and negative pressure occurring within the thoracic cavity, critical to proper inspiration (negative internal pressure during inspiration and positive internal pressure during expiration)

- **Intraalveolar Pressure**
  - Pressure within the alveoli. Important in maintaining proper respiration and gas exchange to and from blood
The easiest parameter that can be measured is the airflow, particularly at the airway opening.

Various flowmeters have been developed for this purpose:

- Rotating-vane flowmeters
- Ultrasonic flowmeters
- Thermal convection flowmeters (hot-wire anemometer)
- Differential pressure flowmeters: most commonly used in clinical applications: they provide bidirectional flow information, sufficient accuracy, sensitivity, linearity and frequency response.
Pneumotachometers

- Based on the principle that convective flow occurs as a result of a difference in pressure between two points.
- There is a linear relationship between pressure difference and volume-flow rate through any system, which is then used to estimate the flow by measuring the pressure difference using a pressure transducer.
- They consist of:
  - (one or more) fine mesh screen(s) placed perpendicular to the flow.
  - or a tightly packed bundle of capillary tubes / channels.
Pressure across the barrier must be $< 1$ cm H$_2$O, otherwise normal breathing may be affected. A typical mesh is a 50 mm diameter with 158 wires / cm (400 / inch).
Airflow causes pressure drop $\Delta P$

$\Delta P \propto Q$

$\Delta P = c \cdot Q$

$Airflow = Q = K \frac{\Delta V}{\Delta t} \Rightarrow V = K' \int_{t}^{t} Q dt$
Pneumotachograph

- Differential Signal
- Pressure Tap
- Hose Barbs
- Non-Heated Shell
- Triple Screens
- Tube Adapter Small Flange
- Bi-Directional Gas Flow
- Tube Adapter Large Flange
PNEUMOTACHS
Many functional indications of the respiratory system can be obtained by measuring various lung volumes and capacities.

- **Inspiratory Reserve Volume (IRV)**: 3,100 mL
- **Tidal Volume**: 500 mL
- **Expiratory Reserve Volume (ERV)**: 1,200 mL
- **Residual Volume (RV)**: 1,200 mL
- **Inspiratory Capacity**: 3,600 mL
- **Vital Capacity**: 4,800 mL
- **Total Lung Capacity**: 6,000 mL
Other major Measurements

- **Maximum Voluntary Ventilation:**
  - Deep, rapid breathing

- **Forced Expiratory Volume -1:**
  - Volume of air expired in maximal forceful effort in 1 second

- **Maximum Expiratory Flow Rate**
  - Rate of air flow during maximum forceful expiration

- **Minute Volume**
  - Inspiratory volume measured in a period of 1 minute
A practical way to measure / test the pulmonary function is to integrate the output of a flowmeter placed at a subject’s mouth.

However, the most common procedure used for estimating the lung volumes (since 19th century) is to continuously collect the gas passing through the airway opening and to compute the volume it occupies in the lungs using a system called spirometer.

The spirometer automatically does the integration due to its structural nature.

Today, most measurements of respiratory functions, whether done by flowmeters, spirometers or pletysmographs, are simply referred to as spirometry.
Semester Project

- Design of an experiment to be used in future offerings of this class and/or other ECE courses. The experiment need NOT be on material that is covered in this class, however, it should certainly be relevant to class material.

- We have two Iworx Human / Animal Physiology kits available for check out, as well as an ECG/Arrhythmia simulator. We do have funding available for other minor equipment/parts purchase (compliments of NSF)

- The deliverable is a complete and detailed lab protocol along with sample results obtained from the described experiment. The lab report is due December 16, 2004. Proposals are due next MONDAY, Nov. 22, 2003.

- You will be working in groups of 2-3 of your own choosing.