Week 9: Pulmonary Function (PF) II

BIOE 320 Systems Physiology Laboratory

Objectives

1. To perform mass balances on O_2 and CO_2 during respiration.
2. To calculate alveolar and pulmonary ventilation rates.
3. To obtain a value for VO_2, the volume of oxygen consumed at STP per 1 minute interval, at rest, after exercise, and during hyperventilation.

Background

Dead Space

Defined as the volume of gas that does not participate in gas exchange.

- Anatomical dead space (150 mL) results from the dead space in the conducting airways (trachea, bronchi, and bronchioles). The air in the conducting airways does not reach the alveoli and, as a result, does not participate in gas exchange.
- Alveolar dead space (very small in healthy subjects) results from poor perfusion to the alveoli. When blood perfusion is limited, some alveoli (even when they contain air) will not participate in gas exchange.
- Physiological dead space is the sum of the anatomical and alveolar dead space and it represents the volume of air that is inspired but does not participate in gas exchange with blood flowing through the lungs.

Ventilation Rate

Defined as the number of breaths in a given time:

- Pulmonary or minute ventilation rate represents the volume of air breathed in and out in one minute.
- Alveolar ventilation rate represents the volume of air that reaches the alveoli and is available for gas exchange in 1 minute.

Gas Exchange

The goal of breathing is to provide a continuous supply of O_2 to the tissues and to constantly remove CO_2. This gas exchange at both the pulmonary and the tissue capillary levels involves simple passive diffusion of O_2 and CO_2 down partial pressure gradients.

Atmospheric air is a mixture of gases (about 79% nitrogen and 21% oxygen, with almost negligible percentages of CO_2, water vapor, other gases, and pollutants. Altogether, these gases exert a total atmospheric pressure of 760 mmHg at sea level. This total pressure is equal to the sum of the pressures that each gas in the mixture partially contributes. The pressure exerted by a particular gas is directly proportional to the percentage of that gas in the total air mixture. For example, the partial pressure (or the individual pressure exerted by a gas within a mixture of gases) of oxygen (P_{O2}) in atmospheric air is normally 160 mmHg, whereas the atmospheric partial pressure of CO_2 (P_{CO2}) is 0.03 mmHg. Since there is a difference in partial pressures between alveolar air and pulmonary capillary blood (e.g. $P_{O2,\text{ alveoli}} > P_{O2,\text{ blood}}$), gas will diffuse down its partial pressure gradient from the area of higher partial pressure to the area of lower partial pressure (Fig. 1).

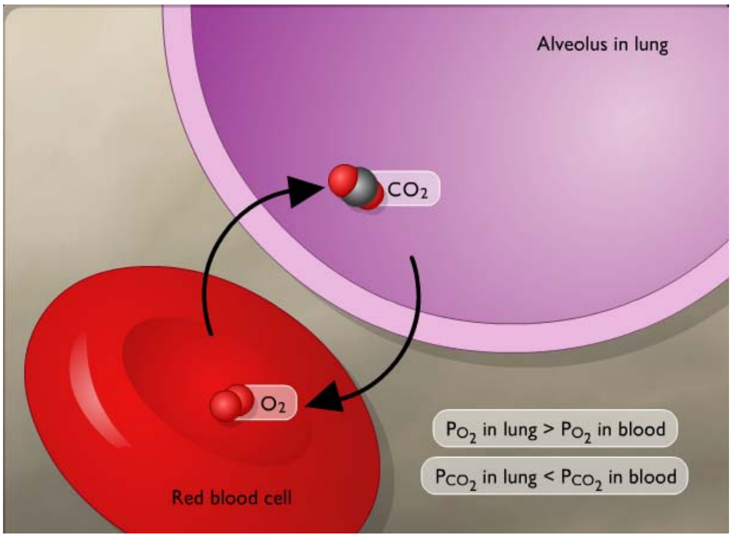

Figure 1: Gas exchange in the lungs

In addition to partial pressure gradients, there are several factors that can influence the rate of gas transfer:

- **Surface area**: An increase in surface area of the alveolar membrane will result in an increased rate of transfer. Surface area remains fairly constant under resting conditions, but can change with exercise by increasing the number of pulmonary capillaries open (as a result of changes in cardiac output) and by expanding the alveoli as breathing becomes deeper. Pathological conditions, such as emphysema or lung collapse, can decrease the surface area.
- **Membrane thickness**: As the barrier separating the air and blood across the alveolar membrane increases, the rate of transfer will decrease. Thickness can increase the pathologic conditions such as pulmonary edema and pulmonary fibrosis.
- **Diffusion coefficient**: As the diffusion coefficient (solubility of the gas in the membrane) increases, the rate of transfer will increase. The diffusion coefficient for CO_2 is 20 times higher than that of O_2 offsetting the smaller P_{CO2} gradient.

Experimental Methods

Hardware and Software Setup

1. Set up the gas analysis system.
   (a) Connect Gas-System2 to power supply and turn on to allow it to warm up for 5 minutes before calibration.
   (b) Connect AFT7 tubing to the inlet of Gas-System2 (Fig. 2).

Figure 2: Inlet of Gas-System2 connected to AFT7 tubing

2. Assemble airflow accessories and connect them to the gas chamber. Keep in mind that some of these components might already be assembled (Fig. 3).
   (a) Attach your disposable bacteriological filter (AFT1) to inlet side of the airflow transducer (SS11LA).
   (b) Connect AFT22 T-valve to opposite side of airflow transducer. Check that the arrows indicating airflow are pointing away from the airflow transducer.
   (c) Connect AFT11C couplers to remaining two ports of T-valve.
   (d) Use AFT11E (blue coupler) to connect AFT7 tubing to T-valve in the port opposite of SS11LA connection.
   (e) Attach AFT6 calibration syringe to remaining port of T-valve.
3. Connect SS11LA airflow transducer to channel 1.
4. Connect O_2 output from Gas-System2 to channel 2.
5. Connect CO_2 output from Gas-System2 to channel 3.
6. Turn on MP3X.

Calibration

1. Open file H19rer.gtl, which can be downloaded from the course website.
2. Pump calibration syring 15-20 times to flush Gas-System2 chamber with ambient air.
3. Change acquisition length (Fig. 4).

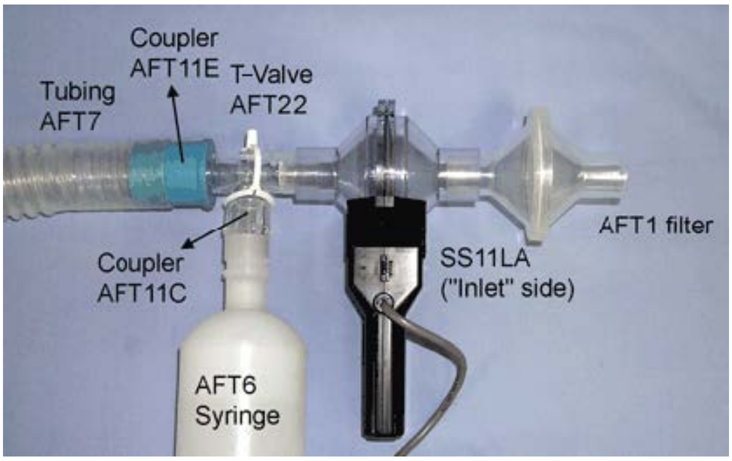

Figure 3: Schematic of airflow accessories connected to Gas-System2

(a) Select MP3X from the menu at the top of the screen.
(b) Choose Setup Acquisition.
(c) Enter 100 samples/second under sample rate.
(d) Change the acquisition length to 60 minutes.

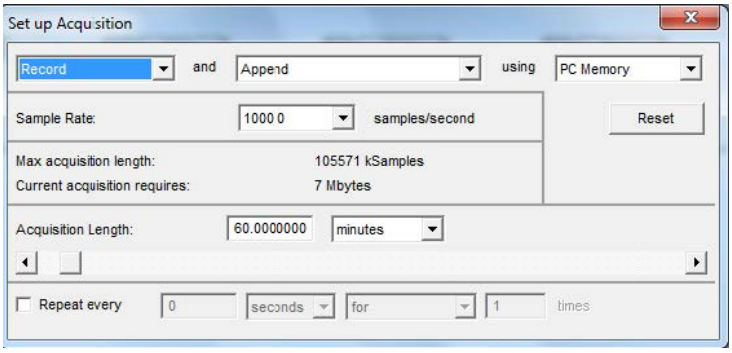

Figure 4: Set up acquisition window

4. Select MP3X from the menu bar, then select Setup Channels. Click the checkboxes such that it mirrors Fig. 5.
5. Calibrate airflow (channel 1).
   (a) Click on wrench icon for channel 1.
   (b) Click on the Scaling button to arrive to Change Scaling Parameters.
   (c) Hold airflow transducer still and upright and press Cal1 button.
   (d) Subtract 3000 from Cal1 value and enter as Cal2 input value field.
   (e) Check Cal1 scale value is zero and Cal2 value is 10.
   (f) Click OK twice to return to Setup Channels window.
6. Calibrate O_2 (channel 2).
   (a) Click on wrench icon for channel 2.
   (b) Click on Scaling button.

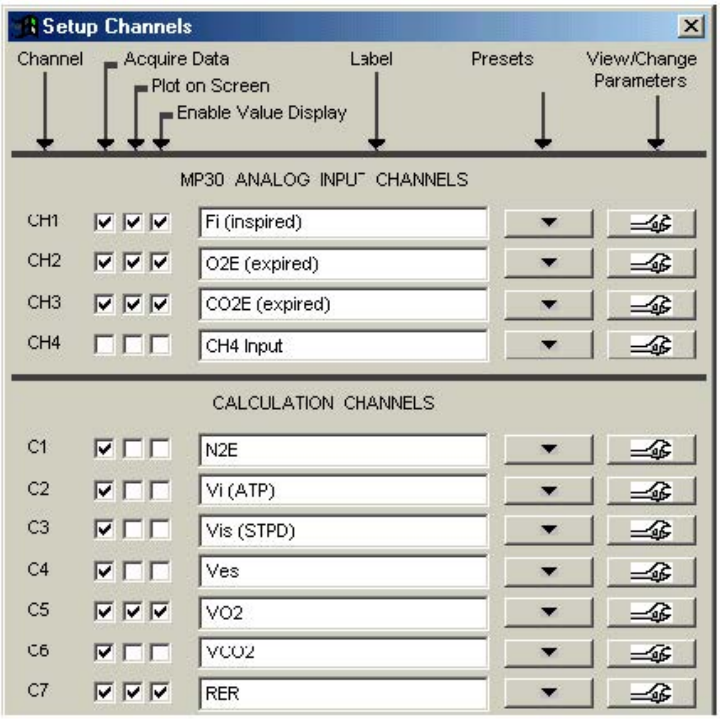

Figure 5: Setup Channels window for MP3X

   (c) Click on Cal2 button.
   (d) Enter value 20.93 as Cal2 scale value.
   (e) Confirm that both Cal1 input value and Cal1 scale value are zero.
   (f) Click OK twice to return to Setup Channels window.

7. Calibration CO_2 (channel 3).
   (a) Click on wrench icon for channel 3.
   (b) Click on Scaling button.
   (c) Click on Cal1 button.
   (d) Enter value 0.04 as Cal1 scale value field.
   (e) Add 10 to Cal1 input value and enter as Cal2 input value.
   (f) Check Cal2 scale value is 1.04.
   (g) Click OK twice to return to Setup Channels window.

8. Calibrate for gas normalization.
   (a) Click on wrench icon for C3 Vis (STPD).
   (b) Update the formula to read C2*(898). This is the normalization factor for gas at an assumed 72°F.
   (c) Click OK to return to Setup Chanels window.
   (d) When done calibrating channels, press OK to return to principal window.

Test Procedure

General Guidelines

1. Before every trial, pump calibration syringe 15-20 times to flush the mixing chamber with ambient air.
2. While recording, hold airflow apparatus very still parallel to floor. Make sure to keep the airflow transducer handle perpendicular to floor.
3. Begin every recording with inhalation and end with exhalation. This will prevent receiving O_2 inspiration values less that that of total expiration.
4. Record for a few second without breathing at the beginning of each experiment to ensure that the baselines are correct. Hit the vertical autoscale button, as needed, to confirm the magnitude of the baseline traces. If baseline values are not correct, stop and troubleshoot.
5. Replace calibration syringe with AFT1 filter and AFT2 mouthpiece (Fig. 6).

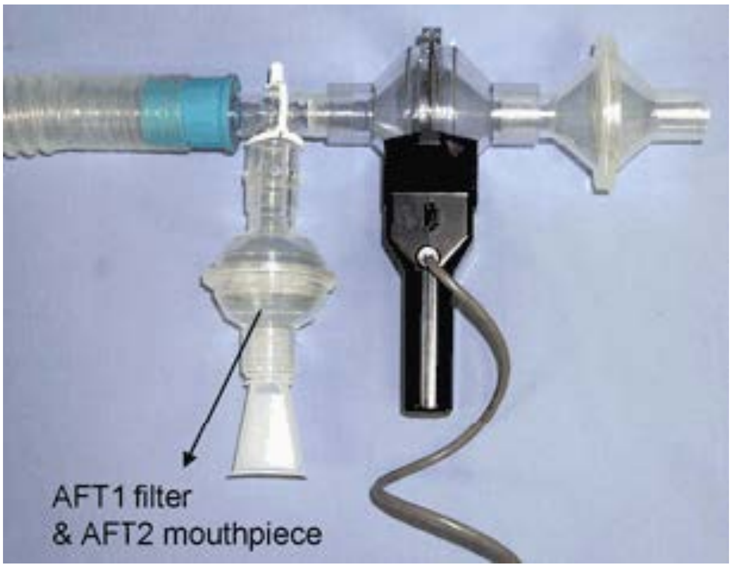

Figure 6: Schematic of airflow accessories with AFT1 filter and AFT2 mouthpiece

The output from the BIOPAC Pro Software is summarized in Table 1.

Table 1: BIOPAC Pro Software output

Output	Abbreviation	Units
Airflow through the pneumotachometer	Airflow	[L/sec]
O_2 concentration in the mixing chamber	O2E (expired)	[volume %]
CO_2 concentration in the mixing chamber	CO2E (expired)	[volume %]
Volume of O_2 consumed at STP per 60 sec interval	VO2*	[L/min]
Respiratory Exchange Ratio	RER	[-]

Test Procedure

Normal Breathing

1. Have the subject put a nose clip on.
2. Press Start button in the lower right corner of the Pro Software.
3. Record for a few seconds without breathing to ensure the baselines are correct.
4. Have the subject breathe normally in and out of the mouthpiece for at least 2 minutes. This ensures that mixing occurs and that the tank fills completely with exhaled air.
5. Press the Stop button in the Pro Software and save your data.

Hyperventilation

1. Have the subject put a nose clip on.
2. Press Start button in lower right corner of the Pro Software.
3. Record for a few seconds without breathing to ensure the baselines are correct.
4. Have the subject breathe normally for 1 minute.
5. Have the subject hyperventilate for 1 minute.
6. Resume normal breathing for 1 minute.
7. Press the Stop button in the Pro Software and save your data.

Recovery from Exercise

1. Perform the exercise of your choice that gets your heart rate up.
2. Following exercise, immediately attach nose clip.
3. Press Start button in lower right corner of the Pro Software.
4. Record for a few seconds without breathing to ensure the baselines are correct.
5. Breathe in an out of the mouthpiece for at least 2 minutes.
6. Press the Stop button in the Pro Software and save your data.

Data Analysis

Use the following values, if necessary:

- Ambient air composition by volume: 20.93% O_2, 0.04% CO_2, 79.03% N_2
- Vapor pressure of water is 22.4 mmHg and 75°F and 47.07 mmHg at 98.6°F

1. Complete the chart for O_2 %, CO_2 %, and VO_2 over the three test conditions.
2. Complete the chart for molar concentrations of O_2 over the listed conditions.

3. Compare and explain the results. Focus on comparisons between A & B, B & C, D & E, and B & E.
4. For each of the three test conditions, determine the mean measured breathing or respiratory rate and the tidal volume. *Hint*: obtain tidal volume from the airflow trace.
5. Explain your method for determining the breathing rate and the tidal volume.
6. Based on your data, how many moles of O_2 are consumed per breath for normal breathing? How many moles of CO_2 are produced per breath for normal breathing? The volume of the mixing chamber is 5 L. Record these numbers for the post-lab.
7. Calculate the pulmonary ventilation rate for each of the three conditions through the following steps:
   (a) Calculate the minute respiratory rate (total pulmonary ventilation rate) and record in the chart below. Explain how you performed the calculation.
   (b) Compare and briefly explain differences in minute respiratory rate among the test conditions.
   (c) Calculate the alveolar ventilation rate and record in the chart below. Assume a dead space volume of 150 mL/breath. Explain how you performed the calculation.
   (d) Compare and briefly explain differences in alveolar ventilation rate among the test conditions. Use the dead space of 150 mL to fill in the table.
   (e) Which of the two ventilation rates is a more accurate indicator of the efficiency of actual breathing/ventilation? Explain.
8. The rate of oxygen consumption is equal to the rate of oxygen diffusion across the respiratory membrane. Determine the rate of oxygen consumption for the normal and exercise conditions based on your experimental data.
9. How do the measured O_2 consumption rates at rest and after exercise compare?