Week 10: Basal Metabolic Rate (BMR)

BIOE 320 Systems Physiology Laboratory

Objectives

1. To obtain BMR values through indirect calorimetry.
2. To determine Respiratory Exchange Ratio (RER) and use the collected data to make inferences about metabolism.
3. To observe the transient effects of diet and exercise on BMR and RER.

Background

Metabolism is characterized by a set of chemical reactions that expend and harvest energy for the body's use, which is measured in units of kilocalories. The body creates chemical energy and heat through the oxidation of foods:

$$Food + O_2 \rightarrow CO_2 + H_2O + Energy \tag{1}$$

The body's primary sources of energy involve the oxidative metabolism of foodstuffs (i.e. proteins, carbohydrates, and fats) to generate adenosine triphosphate (ATP). ATP is the main source of energy for the body because it releases a large amount of energy when broken down by the cells.

Metabolic Rate and Basal Metabolic Rate

Metabolism refers to the chemical reactions that occur in all the cells of the body, and as such, metabolic rate (MR) is usually expressed in terms of the rate of heat liberation during the chemical reactions (i.e. amount of energy released per unit time). MR can be measured using direct calorimetry (measuring the amount of heat given off by the entire body) or estimated using indirect calorimetry (measuring the volume of oxygen consumed by the body). Indirect calorimetry can be used due to the fact that the amount of heat (measured in kilocalories, kcal) released during the oxidation of food is directly proportional to the energy content of the food and the volume of oxygen required for complete oxidation. In other words, the MR is equal to oxygen consumption times the energy equivalent of oxygen. Average values of O_2 energy equivalents can be found in Table 1.

The human body is continuously oxidizing a mixture of carbohydrates, proteins, and fat, rather than using a single food as a sole energy source. Based on the ratio of intake of these molecules, one can calculate the average energy equivalent. For this lab, we will assume an average diet to consist of 15% protein, 45% carbohydrates, and 40%

Table 1: Physiologically available energy, energy equivalent, and respiratory quotient (RQ)

Macromolecule	Available energy (kcal/g)	O_2 energy equivalent (kcal/L)	RQ
Carbohydrates	4	5.01	1.00
Lipids	9	4.70	0.70
Proteins	4	4.60	0.80

fat. Factors other than diet, such as health, age, physical activity, and body size can also influence metabolic rate. The most important of these is the level of physical activity.

Basal metabolic rate (BMR) is considered the "metabolic cost of living" and is a measure of metabolic rate under standardized conditions:

- No food 12 hours before measurements
- Full night of restful sleep before
- No strenuous physical activity performed for 1 hour before measurements
- All factors that may cause excitement should be eliminated
- Comfortable room temperature (between 68 and 80°F)

A person's BMR is the rate of energy consumed by the body's essential activities of the central nervous system, heart, kidneys, and other organs. The BMR encompasses the majority of daily energy usage, as seen in Fig. 1.

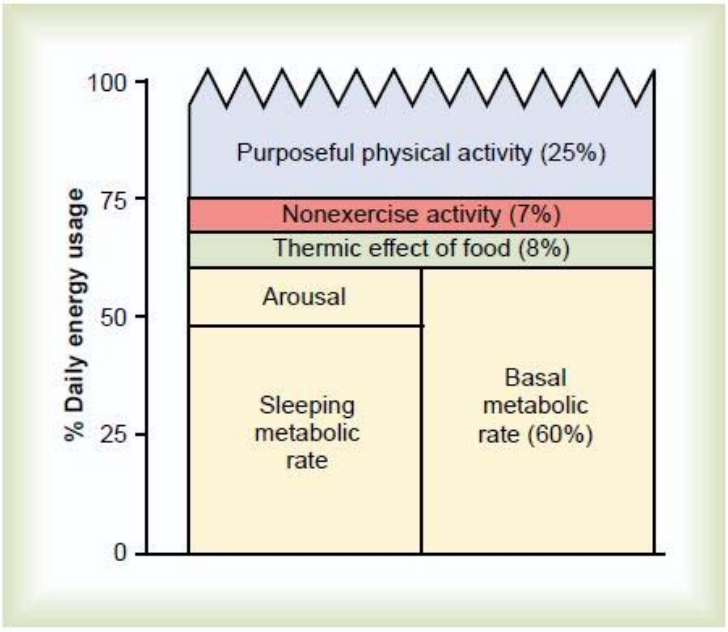

Figure 1: Percentage breakdown of daily energy usage

Respiratory Quotient and Respiratory Exchange Ratio

Because the amount of oxygen the cells consume and the amount of carbon dioxide they produce depends on the nutrients used for energy (i.e. enzymatic pathways for metabolizing carbohydrates, fats, and proteins generate different amounts of CO_2), we can use

these values to determine the fuel source.

Respiratory Quotient (RQ) defines the ratio of CO_2 produced to O_2 utilized by the cells and will vary depending on the substrate being metabolized (Table 1), whereas Respiratory Exchange Ratio (RER) represents the ratio of CO_2 exhaled to O_2 consumed by the lungs. RER represents the average RQ of metabolism throughout the body under normal conditions.

Experimental Methods

General Hardware and Software Setup

1. Gas Analysis System
   (a) Connect Gas-System2 to power supply and turn on to allow it to warm up for 5 min before calibration.
   (b) Connect AFT7 tubing to 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 (do not duplicate). See Fig. 3 for a diagram.
   (a) Attach your disposable bacteriological filter (AFT1) to the 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.

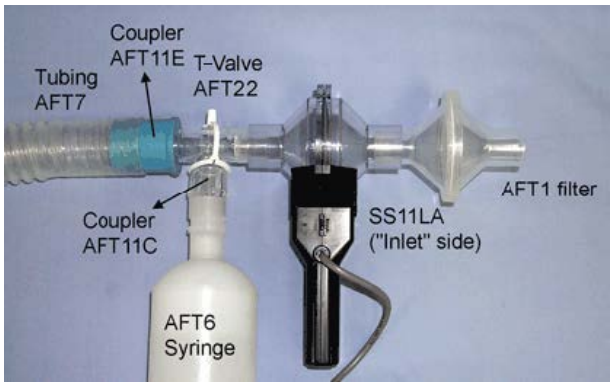

Figure 3: Schematic of airflow accessories connected to Gas-System2

Calibration

1. Open file H19rer.gtl, which can be downloaded from the course website.
2. Pump calibration syringe 15-20 times to flush Gas-System2 chamber with ambient air.
3. Change acquisition length (Fig. 4):
   (a) Select MP3X from the menu at the top of the screen.
   (b) Choose Setup Acquisition.
   (c) Make sure setup is set to *Record* and *Append*.
   (d) Enter 100 samples/second under sample rate.
   (e) Change the acquisition length to 50 minutes.

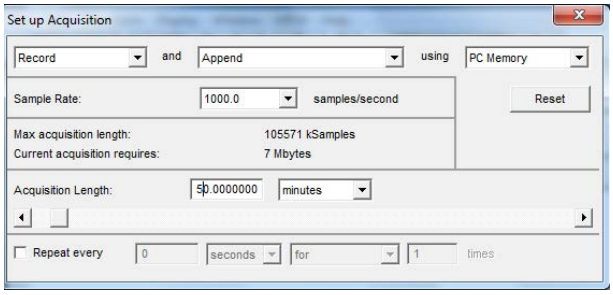

Figure 4: Setup acquisition window

4. Calibrate channels
   (a) Select MP3X from menu bar and select Setup Channels.
   (b) Check all boxes for C6, VCO2.
   (c) Uncheck all boxes for channel C7 (RER on MP30 and Vis on MP35).
   (d) Calibrate airflow (channel 1)
      i. Clock on wrench icon for channel 1.
      ii. Click Scaling button to arrive to Change Scaling Parameters.
      iii. Hold airflow transducer still and upright and press Cal1 button.
      iv. Subtract 3000 from Ca1 value and enter as Cal2 input value field.

v. Check Cal1 scale value is zero and Cal2 value is 10.
vi. Click OK twice to return to Setup Channels window.

(e) Calibrate O_2 (channel 2)
i. Click on wrench icon for channel 2.
ii. Click on Scaling button.
iii. Click on Cal2 button.
iv. Enter 20.93 as Cal2 scale value.
v. Confirm that both Cal1 input value and Cal1 scale value are zero.
vi. Click OK twice to return to Setup Channels window.

(f) Calibrate CO_2 (channel 3)
i. Click on wrench icon for channel 3.
ii. Click on Scaling button.
iii. Click on Cal1 button.
iv. Enter value 0.04 as Cal1 scale value field.
v. Add 10 to Cal1 input value and enter as Cal2 input value.
vi. Check Cal2 scale value is 1.04.
vii. Click OK twice to return to Setup Channels window.

(g) Click on wrench icon for C3 Vis (STPD).

(h) Update the formula to read C2*(0.898).

(i) Click OK to return to Setup Channels window.

(j) When done calibrating channels, press OK to return to principal window.

0.1 General Instructions

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 than that of total expiration.
4. Replace calibration syringe with AFT1 filter and AFT2 mouthpiece (Fig. 5).

The output from the BIOPAC Pro Software is summarized in Table 2.

Table 2: 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]
Volume of CO_2 expired at STP per 60 sec interval	VCO2*	[L/min]

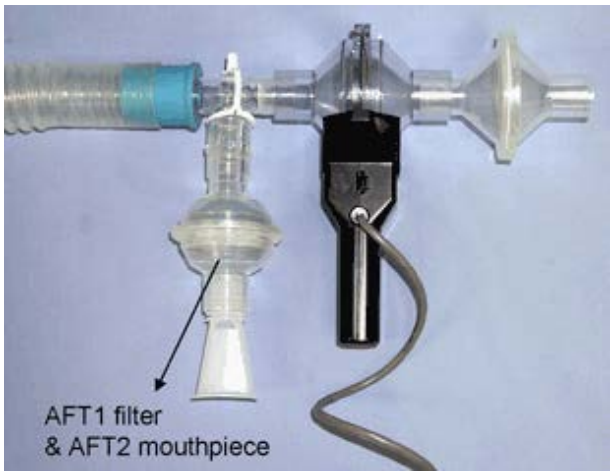

Figure 5: Schematic of airflow accessories with AFT1 filter and AFT2 mouthpiece

Trial A: Basal/Abnormal Breathing Metabolic Measurements

Trial A measures the BMR of a subject during normal breathing conditions and hyperventilation.

1. Have the subject put on a nose clip.
2. Start recording data by pressing the Start button located at the bottom left corner. Record a few seconds prior to breathing to ensure baselines are correct.
3. Have the subject begin breathing normally through the mouthpiece for 2 minutes.
4. Insert a marker in the recording and have the subject hyperventilate for 1 minute.
5. Place a second marker and have the subject return to normal breathing. Collect 3 additional minutes of data.
6. Stop recording and save your file with a unique name.
7. Make sure that the data looks similar to Fig. 6. If it does, the subject should eat lunch.

   Warning: If your data does not look similar to Fig. 6, rerun the test. Once the subject eats, this test cannot be redone, so obtain good data before continuing!

8. Once finished, subject may eat lunch in preparation for Trial B.
9. While the subject is eating, begin Trial C using a different subject.

Trial B: Effects of Diet on BMR

Trial B measures the metabolic rate of the subject after a meal.

1. Wait approximately 30 minutes after the BMR subject's meal.
2. If needed, repeat the calibration procedure described above.
3. Use the calibration syring to purge the mixing chamber with 10-20 pumps.

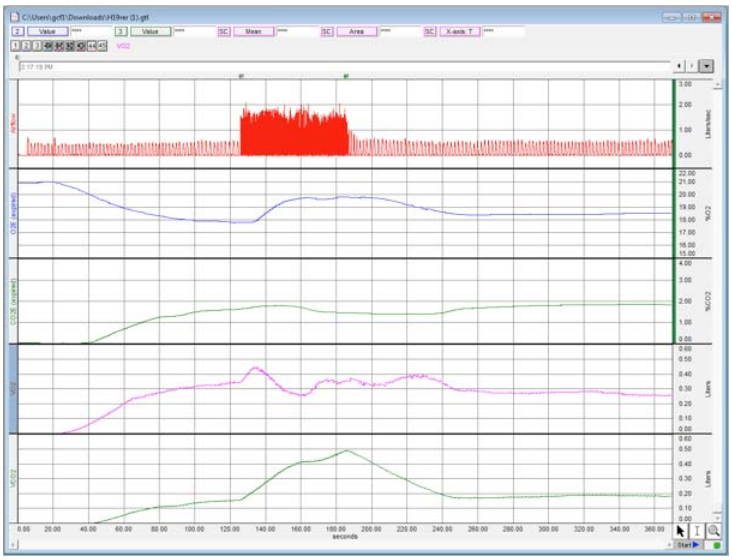

Figure 6: Expected data from Trial A

4. Have the subject put on the nose clip.
5. Start recording data by pressing the Start button located at bottom left corner. Record a few seconds prior to breathing to ensure baselines are correct.
6. Collect breathing data for 3 minutes.
7. Stop recording and save your file.

Trial C: Effects of Exercise on Metabolic Rate

Trial C measures the metabolic rate and respiratory exchange ratio before and after exercise.

1. If needed, repeat the calibration procedure described above.
2. Use the calibration syringe to purge the mixing chamber with 10-20 pumps.
3. This trial should be performed by a different subject that the subject from Trials A and B.
4. Replace the inlet bacterial filter and mouthpiece at the T-valve. Do not replace the other filter at the air inlet.
5. Have a new subject put on a nose clip and record 2 minutes of normal breathing data.
6. Place a marker and stop recording.
7. Flush the gas chamber with 15-20 pumps.
8. Have the subject perform 5 minutes of aerobic exercise.
9. Immediately after exercise, replace the nose clip and begin recording data from your subject.
10. Record a few seconds without breathing to verify baseline gas values, then collect 6 minutes of breathing data.

11. Stop data collection and save your file.

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. Use data collected during Trial A. After equilibrium is reached in the mixing chamber (O_2 and CO_2 traces are stable and flat), report the metabolic rate (MR) and RER in the table in the handout using the following relationships:

$$MR\ [kcal/m^2/hr] \frac{}{Body\ Surface\ Area\ [m^2]} \tag{2}$$