Energy, Work and Power of the body

INTRODUCTION

- All activities in the body involving energy changes.
- The conversion of energy into work such as lifting a weight or riding a bicycle represents only a small fraction of the total energy conversion of the body.
- Under resting conditions about 25% of the body's energy is being used by the skeletal muscles and the heart, 19% is being used by the brain, 10% is being used by the kidney, 5% is being used by the feces and urine, and 27% is being used by the liver and spleen.
- The body's basic energy (fuel) source is food.
- The food is generally not in a form suitable for direct energy conversion. It must be chemically changing by the body to molecules that can combine with oxygen in the body cells.

- The body uses the food energy to:

1. Operate its various organs.
2. Maintain a constant body temperature.
3. Do external work for example, lifting things.
4. Any energy that is left over is stored as body fat. The energy used to operate the organs appears as body heat.

Conservation of energy

■ Our own bodies, like all living organism, are energy conversion mechanism.

■ The fraction going into each form depends both on how much we eat and on our level of physical activity.

■ If we eat more than is needed to work or stay warm, the remind convert body fat.

■ The conservation of energy in the body can be written as a simple equation.

(Change in stored energy i.e., food energy, body fat, and body heat) = [Heat lost from the body] - [Work done]

$$\Delta U = \Delta Q - \Delta W$$

ΔU= the in stored energy

ΔQ= the heat lost or gained

ΔW= work done by the body, (a body done work $\Delta W=0$)

- This equation, which is really **the first law of thermodynamics** assumes that no food or drink is taken in &no feces or urine is excreted during the interval of time considered.
- The first law of thermodynamics can be written as:

$$\Delta \boldsymbol{U} = \Delta \boldsymbol{Q} - \Delta \boldsymbol{W}$$

Where,

ΔU is the change in stored energy.

ΔQ is the heat lost or gained.

ΔW is the work done by the body in some internal of time.

- When a body doing no work ($\Delta W=0$). At a constant temperature, continues to lose heat to its surroundings, ΔQ is negative, therefore ΔU is also negative indicating a decrease in stored energy.
- The previous equation can be written as

$$\frac{\Delta U}{\Delta t} = \frac{\Delta Q}{\Delta t} - \frac{\Delta W}{\Delta t}$$

$\Delta U / \Delta t$ is the rate of change of stored energy.

$\Delta Q / \Delta t$ is the rate of heat loss or gain.

$\Delta W / \Delta t$ is the rate of doing work.

ENERGY CHANGES IN THE BODY

- The energy and power units that are used in relation to the body by the physiologist are:
- *Kilocalories (kcal):* used for food energy.
- *Kilocalories per minute (kcal/min):* used for the rate of heat production (power).

In physics, the energy and power units are

- *Newton-meter or joule (J):* for energy.
- *Joule per second or watt (W):* for power

- The energy unit in the cgs (centimeter gram second) system is the erg. And in English system is foot-pound (ft-lb).
- ***Met:*** is the convenient unit used for expressing the rate of energy consumption of the body and is defined as 50 kcal/m2 of body surface area per hour.
- For a normal person, 1 met is about equal to the energy consumption under resting conditions. A typical man has about 1.85 m2 of surface area (a woman has about 1.4 m2), and thus, for a typical man 1met is about 92 Kcal/hr or 107 W.

- ***NOTE THAT***

  1kcal =4184 J
  1J=10^7 ergs=0.737 ft-1b
  1 kcal/min=69.7 W =0.094 hp
  100 W=1.43 kcal/min
  1 hp=642 kcal/hr =746 W=550 ft -1b/sec
  1 met = 50 kcal/m2 hr=58 W/m2
  1kcal/hr=1.162 W
- In oxidization process which occurs in the cells of the body, heat is released as energy of metabolism. The rate of oxidation is called metabolic rate.
- The oxidation process of 1 mole (n) of glucose ($C6H12O6$)

is:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + 686$ Kcal

1 mole 6 mole 6 mole 6 mole Releasing (heat energy)

1 (180 g) 6 (32 g) 6 (18 g) 6 (44 g)

• We have 1 mole of $C6H12O6$, to find the molar mass

$molar\ mass\ of\ C6H12O6 = 12 \times 6 + 1 \times 12 + 16 \times 6 = 180\ g/mol$

$m(g) = n \times molar\ mass = 1 \times 180 = 180\ g$

By the same procedure we have:

- 6 moles of $O2 \rightarrow 192\ g$
- 6 moles of $H2O \rightarrow 108\ g$
- 6 moles of $CO2 \rightarrow 164\ g$
- 1 mole of a gas at normal temperature and pressure has a volume of 22.4 liter.

Using the information above we can compute several useful quantities in metabolism

Kilocalories of energy released per gram of fuel= $\frac{686}{180} = 3.8$

Kilocalories released per liter of $O2$ used= $\frac{686}{22.6 \times 6} = 5.1$

Liters of $O2$ used per gram of fuel= $\frac{22.4 \times 6}{180} = 0.75$

▪ Liters of $CO2$ produced per gram of fuel= $\frac{22.4 \times 6}{180} = 0.75$

Ratio of moles of $CO2$ produced to moles of $O2$ used is

called ***respiratory quotient (R)=1***

Similar calculations can be done for fats, proteins, and other carbohydrates. This table shows the caloric values of some food types, energy released per liter of oxygen, and common fuels

Food or fuel	Energy released per liter of O_2 used (kcal/liter)	Caloric value (kcal/g)
carbohydrates	5.3	4.1
Proteins	4.3	4.1
fats	4.7	9.3
Typical diet	4.8-5	----------
Gasoline	------	11.4
coal	------	8.0
Wood (pine)	-----	4.5

Energy requirements

1. Male need 2500 kcal/day

2. Females need 2000 kcal /day

■ Loss of 500 kcal/day will lose weight 0.5Kg/week.

■ No Cal intake at all will lose weight 2kg/week.

The energy consumption

■ The amount of daily energy each body depends on an individual daily energy consumption and metabolic energy requirements which can be estimated by body weight and activity level.

■ The basic energy consumption of the body is 4 kJ/kilogram of body weight and daily hour so to calculate an individual's basic energy consumption.
The energy consumption

■ Total energy consumption = body weight x 4 kJ x 24 hour/day /4.18kJ.

■ The total energy consumption value is divided by 4.18kJ in order to convert the value into kilocalories.

■ Excess food intake that is not used as energy can be stored in the body as fat.

■ Excessive fat storage can lead to a high body mass index.

Basal Metabolic Rate (BMR)

■ The rate in which the body use food energy to sustain life and to do different activity is called the Metabolic Rate.

■ When the body is completely at rest, it will have the lowest rate of energy consumption this is called the basal metabolic rate (BMR).

■ Also, it is known as metabolism, which is the amount of energy needed to perform minimal body functions (such as breathing and pumping the blood through the arteries) under resting.

■ For typical person 1 met is about 92kcal/hror 107 W or 1 met =50 Kcal /hour per m^2 = 58 watts/m^2.

■ **m^2**: Body surface area.

■ The children have high value of BMR because for the energy required for growing, while men have slightly higher values than woman because the man have less body fat, therefore use more energy to maintain body temperature.

BMR depends upon

1. Sex, age, height, and weight.

2. Thyroid function

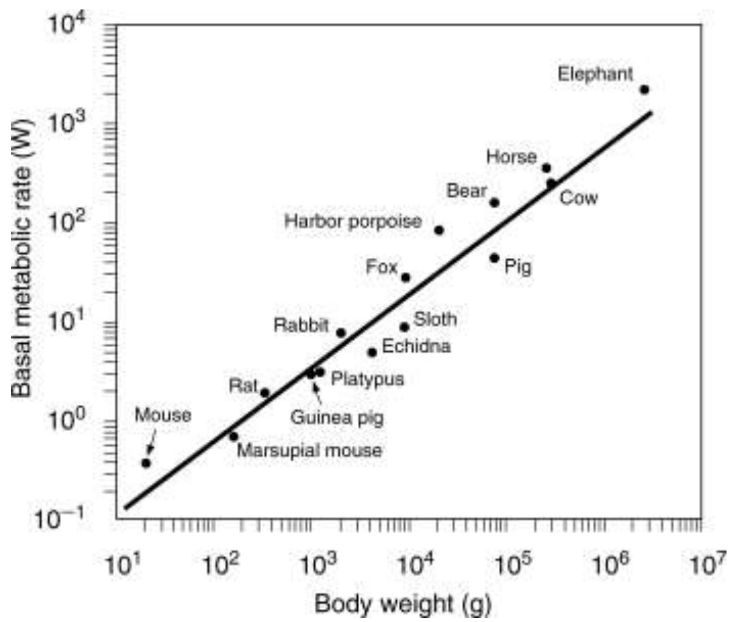
▪ A person with an over active thyroid has a higher BMR than a person with normal thyroid function and vice versa.

3. The mass

- ➢ As animals get larger or have larger mass, their BMR increases faster.
- ➢ In figure 1 the graph represents the change between BMR (kcal/day) and the mass of different animals, the slope of the graph indicates that the BMR is proportional to mass.

4. Temperature

- *For an increase of 1°C it will change by 10% in the metabolic rate, so for 3°C the change will be 30% greater than normal.*
- *Similarly, if the body temp. drops 3°C below normal, the metabolic rate decreases by about 30%.*
- *For this reason, hibernating animals at low body temp. will reduce the metabolic rate very much.*



WORK AND POWER

Chemical energy stored in the body is converted into external mechanical work as well as into life –preserving functions.

External work ΔW: is the force (F) moved through a distance ΔX.

$\Delta W = F\ \Delta X$

$where\ \Delta W$ = external work, F = force, and

ΔX = distance

Power (P): is the rate of doing work. Thus for a constant force

$P = \frac{\Delta W}{\Delta t} = \frac{F \Delta X}{\Delta t} = Fv$

Where

$\frac{\Delta X}{\Delta t} = v \text{ is the velocity}$

External work is done when a person is climbing a hill or walking upstairs. We can calculate the work done by multiplying the persons weight (mg) by the vertical distance (h) moved. When a man is walking or running at a constant speed on a level surface, most of the forces act in the direction perpendicular to his motion. Thus the external work done by him appears to be zero. The person muscles are doing internal work which appears as heat in the muscle and causes a rise in its temperature. This additional heat in the muscle is removed by blood flowing through the muscle, by conduction to the skin, and by sweating.

The efficiency of the human body

The efficiency of the human body as a machine can be obtained from the used definition of the efficiency ∈

$$\in = \frac{\text{work done}}{\text{energy consumed}} \times 100\%$$

Efficiency is usually lowest at low power but can increase to 20% for trained individuals' activities such as cycling and rowing. The max. work capacity of the body is variable. For short periods of time, the body can perform at very high power levels; but for long term efforts it's more limited and proportional to the maximum rate of oxygen consumption in working muscles. For a healthy man, the consumptions is typically (50 ml/kg) of body weight each minute.

HEAT LOSSES FROM THE BODY

Birds and mammals are referred to as *homoeothermic* (warm blooded).

Other animals considered *poikilothermic* (cold blooded). Poikilothermic animal will have a higher body temp. on a hot day than a homoeothermic animal. Homoeothermic animals have mechanisms to keep their body temp. constant despite fluctuation in the environment temp. The normal body contains stored heat and constant temp. 37 ± 0.5 C°.

The body temperature depends upon

▪ The time of the day (lower in the morning).

▪ The temp. of the environment.

▪ The amount of the physical activities.

▪ The amount of clothing.1

▪ The health of the individual.

The body should have certain mechanisms to keep this temperature constant despite of the fluctuations in the environment temperature, these mechanisms are

1- Radiation.

2- Convection.

3- Evaporation of sweat (perspiration).

4- Respiration.

The actual amount of heat that is lost by the (above 4 mechanisms) depends on a number of factors:

1. The temperature of the surroundings.
2. Humidity.
3. Motion of the air.
4. The physical activity of the body.
5. The amount of the body that is exposed.
6. The amount of isolation on the body (clothes and fat).