Lecture (3)

Medical Physics

Fourth Stage

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Medical Physics

Conservation of Energy in the body:

Energy is a capacity to do work. Under resting (basal) condition the percentage of energy of the body used by:

- 25 % of body’s energy used by skeleton, muscle and heart.
- 10 % of body’s energy used by kidneys.
- 19% of body’s energy used by brain.
- 27 % of bodies energy used by liver and spleen.
- 19 % of bodies energy used by other work cycle such as walking, … riding etc.

The body uses the food energy to:

1. Operate its various organs.
2. Maintain a constant body temperature.
3. Do external work e.g. lifting.

- A small percentage (~5%) of the food is excreted in the feces and urine.
- Any energy that is left over is stored as body fat.
- The energy used to operate the organs appears as body heat.

- Basic energy source (fuel) is the food. Which is chemical conversion into molecules which is combined with oxygen in body cell.
- Body uses food energy to maintain temperature and do external work.

$$\begin{bmatrix} \boldsymbol{Change\ in\ stored\ energy\ in\ the\ body} \\ \boldsymbol{(food\ energy, body\ fat\ and\ body\ heat)} \end{bmatrix} = \begin{bmatrix} \boldsymbol{Heat\ lost} \\ \boldsymbol{from\ the\ body} \end{bmatrix} + \begin{bmatrix} \boldsymbol{Wrk} \\ \boldsymbol{Done} \end{bmatrix}$$

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

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

This is the first law of thermodynamics.

There are continues energy changes both when it is doing work and when it is not. The energy is conserved in all processes.

$$\Delta U \text{ is change in stored energy}$$

$$\Delta W \text{ is the work done by body}$$

$$\Delta Q \text{ is heat loss or gain}$$

If the body doing no work ($\Delta W = 0$) and the constant temperature continuous to lose heat to its surroundings and ΔQ is negative indicating decrease in stored energy.

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

Where $\frac{\Delta W}{\Delta t}$ is called mechanical power.

Energy change in the body:

- Physiologist use kilocalories for food energy (Nutrionist used cal).
- Diet= 2500 kcal/day.
- Energy is Newton.meter or Joules. 1 cal = 4.184 J or kcal= 4184 J
- Power is given in joules per second =watts.
- Rate of energy consumption of body is measured in (met).
- The met is defined as 50 kcal$/m^2$ of body surface area per unit hour.
- **Consider example of Glucose:**

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

- 1 mole of glucose (180 g) combines with 6 moles of O_2 (192 g) to produce 6 moles each of H_2O (108 g) and CO_2 (246 g), releasing 686 kcal of heat energy in the reaction.

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- Using this information we can compute a number of useful quantities for glucose metabolism. (Remember that 1 mole of a gas at normal temperature and pressure has a volume of 22.4 liters.)

- Kilocalories released per gram of fuel $= 686/180 \ = \ 3.80$

- Kilocalories released per liter of O_2 used $= \frac{686}{22.4 \times 6} = 5.1$

- Liters of O_2 used per gram of fuel $= \frac{6 \times 22.4}{180} = 0.75$

- Liters of CO_2 produced per gram of fuel $= \frac{6 \times 22.4}{180} = 0.75$

- Ratio of moles of CO_2 produced to mole of O_2 used = Respiratory Quotient (R) = 1

- Similar calculation can be done for **fats**, **proteins** and **carbohydrates**.

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- **BMR (Basat Metabolic Rate)**
- It is lowest rate of energy consumption. For a person at rest required about 92 kcal/hr or 107 w for breathing and heart functioning, this energy called 1 met.
- BMR depends on mass of body and temperature of body. If temperature of body changed 1 C^o BMR change by 10 %.

Problem 1: A person wants to lose 4.54 kg by dieting or exercises

(a) how long would you have to work at an activity 15 kcal/min to lose 4.54 kg of fat? (1 gm of fat gives 9.3kcal/g).

(b) If you normally use 2500 kcal/day, how long you must diet at 2000 kcal/day to lose 4.54 kg weight of fat?

Sol.

(a) 1 gm = 9.3 kcal

$$4.54 \times 10^3\ gm = 4.54 \times 10^3 \times 9.3\ kcal = 4.2 \times 10^4\ kcal$$

$$T_{min} = \frac{4.2 \times 10^4}{15} = 2800\ min$$

$$T_{hr} = 46.6\ hr$$

(b)

Food give 2500 kcal/day

Per day saving of 500 kcal

Then to lose 4.2×10^4 kcal

$$day\ required = \frac{4.2 \times 10^4}{500} = 84\ days.$$

Problem 2: (a)what is the energy required to walk 20 km at 5 km/hr (heat production while walking = 3.8 kcal/min). (b) Assuming 5 kcal/gm of food, calculategram of food needed for the walk.

Sol.

(a)

For walking 20 km , 4 hours are needed

$$4 \times 60\, min = 240\, min$$

Kcal produced in 4 $hr = 240 \times 3.8 = 912\, kcal$

(b)

Gram of food needed to walk $= \frac{912}{5} = 182\, gm.$

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Problem 3: A 50 kg person jumping from a height of 1 m is traveling at 4.5 m/s just prior to landing. Suppose he lands on a pad and stops in 0.2 s what is the maximum force experience?

Sol.

$$F = \frac{\Delta p}{\Delta t} = \frac{\Delta(mv)}{\Delta t} = \frac{50 \times 4.5}{0.2} = 1125\ N$$

Problem 4: suppose the elevator (lift) is broken in the building in which you work and you have to climb 9 stories, a height 45 m above ground level, how many extra calories with this external work cost you if your mass is 70 kg and your body work at 15% efficiency?

Sol.

$$work\ done = mgh = 70 \times 9.8 \times 45 = 30870\ J$$

$$work\ done = \frac{30870\ J}{4.2 \times 10^3\ J} = 7.35\ kcal$$

$$extra\ calories\ needed = \frac{7.3}{efficinicy} = \frac{7.3}{0.15} = 49\ kcal$$

Heat losses from the body

- Birds and mammals are referred to as homeothermic (warm blooded). While other animals are considered poikilothermic (cold blooded). The terms warm blooded and cold blooded are misleading, for a poikilothermic animal such as a frog or a snake will have a higher body temperature on a hot day than a mammal. Bird and mammals both have mechanisms to keep their body temperature constant. Because the body is at a constant temperature is contains stored heat energy that is essentially constant as long as we are alive.

- The healthy human body maintains its internal temperature around 37°C. Variations, usually of less than 1°C, occur with the time of the day, level of physical activity or emotional state. A change of body temperature of more than 1°C occurs only during illness or when environmental conditions are more than the body's ability to cope with extreme heat.

- As the environment warms-up, the body tends to warm-up as well. The body's internal "thermostat" maintains a constant inner body temperature by pumping more blood to the skin and by increasing sweat production. In this way, the body increases the rate of heat loss to balance the heat burden. In a very hot environment, the rate of "heat gain" is more than the rate of "heat loss" and the body temperature begins to rise. A rise in the body temperature results in heat illnesses.

- **In body heat is removed by processes taking place on skin:**

- Radiation
- Convection
- Evaporation (perspiration)

- The temperature of body is close to its normal value $37\ C^{o}$ or 98 f.

Heat lose in the body depends on:

- Temperature of the surrounding
- Humidity
- Motion of air
- Physical activity of body
- Amount of body exposed
- Amount of insulation of body

• The amount of energy emitted by the body is proportional to the absolute temperature raised to the fourth power (amount of emitted heat by body $\propto T^4$).

• $rate\ of\ energy\ gain\ or\ loss\ due\ to\ radiation = H_r = k_r A_r e^{(T_s - T_w)}$

Where

- H_r = rate of energy loss (or gain) due to radiation
- A_r = effective body surface area
- T_s = temperature of skin in C°
- T_w = temperature of surrounding wall
- k_r = constant $= 5\frac{kcal}{m^2}hr\ C°$
- e = emissive power

• Under normal condition the heat loss is due to radiation only 54 %.

Heat loss due to Convection (H_c)

$$H_c = k_c A_c \, (T_s - T_a)$$

- k_c = constant depending on amount of air $\approx 2.3 \, kcal/m^2 \;\; hr \;\; C^{\circ}$
- T_a = temperature of air
- A_c = effective surface area

At 25^{o} C we find:

$H_c = 2.3 \times 1.2 \; (34 - 25)$

$H_c = 2.3 \times 1.2 \times 9 = 25 \; kcal/hr$

25 % bodies heat loss

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Heat loss due to evaporation:

- Evaporation of sweat
- Perspiration (7 % of body heat loss)
- Evaporation of moisture in lungs
- Respiratory heat loss (14 %)
- Counter-current heat exchange (due to returning blood from hands and legs).