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Medical Physics

Energy, Work and power of the body

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Energy, Work and Power of the Body

Considering the body as an energy converter. All activities of the body, including thinking involve energy changes. The conversion of energy into work such as lifting a weight or riding a bicycle represents only a small fraction of total energy conversions of the body.

Under resting conditions the body energy is being used as follows.
1. 27% by the liver and spleen.
2. 25% by the skeletal muscles.
3. 19% by the brain.
4. 10% by the kidney.

The body's basic energy (fuel) source is food; the food must be chemically changed by the body molecules that can combine with oxygen in the body.

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.

Conservation of energy in the body

The conservation of energy in the body undergo to first law of thermodynamics, Can be written as a simple equation:-

[Change in stored energy] = [Heat lost from the body] + [Work done]

** Change in stored energy= food energy= body fat=body heat
There are a continuous energy changes in the body both when is doing work and when it is not.
The first law of thermodynamic equation is:

$$\Delta U = \Delta Q + \Delta W \text{ .... (1)}$$

Where **ΔU** is the change in stored energy
ΔQ is the heat lost or gain

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

If a body no work (**ΔW = 0**) and at a constant temperature to lose heat to its surroundings, and **ΔQ** is ***negative*** .**ΔU** is also ***negative***, indicating a decrease in stored energy.

The change of **ΔU**, **ΔQ** and Δ**W** in a short interval of time Δ t, equation (1) becomes:

$$\Delta U / \Delta t = \Delta Q/\Delta t - \Delta W/\Delta t \quad ..... \quad (2)$$

Where **ΔU/Δt** is the rate of change of stored energy

ΔQ/Δt is rate of change of heat loss or gain,

ΔW/Δt is the rate of doing work that is mechanical work.

Energy Changes in the Body

Several energy and power units are used in relation to the body. Physiologists usually use kilocalories (Kcal) for food energy and kilocalories per minute for the rate of heat production .

The ***energy*** unit is the newton.meter or ***joule*** (J), ***erg***.

The units are joule or calorie

1cal= 4.184J

1Kcal=4184J and

1J=10^7 ergs

The ***power*** is defined as energy or work per unit time =***J/s***=***watt***.

1Kcal/min=69.7Watt, 100Watt=1.43kcal/min

Met: is defined as the rate of energy consumption of the body, 50 Kcal/m² of body surface are per hour = 50 ***Kcal/m².h***.

Metabolic rate (MR): Metabolic rate is define as the rate of oxidation. In oxidation process within the body heat is released as energy of metabolism.

Basal metabolic rate (BMR)

The lowest rate of energy consumption, which is the amount of energy needed to perform minimal body functions (such as breathing and pumping the blood through the arteries) under resting conditions.

BMR depends on ***sex, age, height, and weight***; it depends primarily on ***thyroid function***, overactive thyroid gives higher BMR. Since the energy used for basal metabolism becomes heat which is mainly dissipated from the skin, so the basal rate is not related to the surface area but on the mass of the body.

The BMR depends to large extent on the body 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 temperature drops 3°C below normal, the metabolic rate decreases by about 30%. For this reason hibernating animals at low body temperature will reduce the metabolic rate very much.

Example1:

The oxidation for one mole of glucose

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

1 mole	6 mole	6 mole	6 mole	releasing (heat energy)
(180 g)	6(32 g)	6(18 g)	6(44 g)	
180g	192g	108g	264g	

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

Solution:

Kcal of energy released per gram of fuel (glucose) =686/180=3.80

Kcal of energy released per liter of O_2 used=686/ (22.4×6) =5.1

Liters of O_2 used per gram of fuel glucose = (22.4×6)/180=0.75

Liters of CO_2 produced per gram of fuel glucose= (22.4×6)/180=0.75

The ratio of moles of CO_2 produced to moles of O_2 used, called the (***respiratory quotient***) R=1

Example2:

Suppose you wish to lose 4.54 kg either through physical activity or by dieting. How long would you have to work at an activity of 15 kcal/ min to lose 4.54 of fat? Knowing that energy release for 1 gm of fat is 9.3 kcal/g. If you work for T minutes.

A. Through physical activity then,

$$(T\ min)(15kcal/min) = (4.54\times10^3\ g) \times (9.3kcal/g) = 4.2\times10^4\ kcal$$

$$T = 2810\ min \approx 47hr$$

B. It is much easier to lose weight by reducing your food intake. If you normally use 2500 kcal/day, how long must you diet at 2000kcal/day to lose 4.54kg of fat?

$$T = \frac{energy\ of\ 4.54\ kg\ fat}{energy\ deficit\ per\ day} = \frac{4.2\times10^4\ kcal}{5\times10^2\ kcal/day} \approx 84\ day$$

Work and power

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

The Internal work: is the force (F) moved through a distance Δx.

$$\Delta W = F\ \Delta x \text{ .... (3)}$$

The force and the motion Δx must be in the same direction.

Power: is the rate of work done.

$$P = \Delta w/\Delta t = F\ \Delta x / \Delta t = F\ v \text{.....(4)}$$

External work: is done when a person is climbing hill or walking up stairs.

We can calculate the work by:

Multiplying the person weight (mg) by the vertical distance (h) moved.

$$W = mg*h \text{ .... (5)}$$

We can also measure the oxygen consumed during any activity:

The total food consumed can be calculated since 4.8 kcal are produced for each 1 liter of oxygen consumed. The efficiency of the human body as machine can be obtained from the following:

ε (Efficiency) = work done / energy consumed

Example3:

Compare the energy required to travel 20 km on a bicycle to that needed by an auto for the same trip. Gasoline has 11.4 kcal/g and a density of 0.68 kg/litter. Assume that the auto can travel 8.5 km on a litter (1) of gasoline. The auto required 2.35 litters to travel the 20 km?

Solution:

(2.35 litters) (0.68 kg/litter)= 1.6 kg of gasoline

($1.6\ x10^3$ g) (11.4 kcal/g)= $1.8\ x10^4$ kcal for 20 km

(1 litter) (0.68 kg/litter) = 0.6 kg of gasoline

($0.6\ x10^3$ g) (11.4 kcal/g) = $0.68\ x10^4$ kcal for 20 km

Heat losses from the body

Birds and mammals are referred to as homeothermic (Warm-blooded) while other animals are considered poikilothermic (cold-blooded) such as frog and snake, will have a higher body temperature on a hot day than mammals, birds and mammals both have mechanisms to keep their body temperature constant despite fluctuations in the environmental temperature Constant body temperature .

The temperature of the body depends on the:

1. Time of the day (lower in the morning).
2. Environment temperature.
3. The amount of clothing.
4. Health of the person.
5. On his recent physical activity.

The heat losses depends on many 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 exposed.
6. The amount of the insulation of the body (like clothes and fat).

In Body heat is removed by processes taking place on skin:

1. Radiation.
2. Convection.
3. Evaporation.

The temperature of body is close to its normal value 37°C or 98 F.

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

The rate of energy loss or gain due to radiation

$$\boldsymbol{H_r = K_r A_r e^{(T_s - T_w)}} \text{ ..... (6)}$$

Hr is the rate of heat energy loss or gain
Kr is a constant depends upon various physical parameters and it's about =5Kcal/m^2 hr C° for man
Ar effective body surface area emitting radiation
(e) is the emissivity of the surface which is nearly=1, independent on the color of the skin indicating that the skin at this wavelength is almost a perfect emitter and absorber of radiation.
T_S is the skin temp. in C°
T_W is the temp of the surrounding walls
Under normal condition that heat loss due to radiation only 54%

***Heat Loss by convection

Heat losses by convection (H_C)

$H_C = K_C A_C (T_S-T_a)$ ...... (7)

H_C is the amount of heat gained or lost be convection

A_C is the effective surface area

Ta is air temp.

K_C is a constant that depends on the movement of the air, for a resting body and no apparent wind K_C is about 2.3kcal/ m^2 hr °C.

25% bodies heat loss

***Heat Loss by 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)