CHAPTER TWO

Energy, Work, and Power of the body

By: Dr. Taki Ali Musa Al Musawi

Professor in Medical Physics

2.1: The Energy:

When he was young, the scientist James Watt (1736-1819) was watching a tea kettle on a fire, he noticed that the steam lifts the lid of the kettle. The lid of the kettle lifted by the steam against the earth's gravity where the steam done a work to lift the lid. This means that the steam has energy.

This observation probably led James Watt for the improvement of the steam energy uses.

The energy is defined as the capacity of the body to do a work. The more is the work done the more energy is used to do this work. The energy is a necessity of life.

Some of our organs are able to detect the presence of energy around us in various forms. For example; our ears detect sound energy, eyes respond to visible light, special nerves are sensitive to temperature which indicate heat energy, and other nerves respond to electric energy as nerve signals. Some other kinds of energies can be detected indirectly by our sense organs, for example we can sense the chemical, electrical, magnetic, gravitational, and nuclear energies. Also some special detecting and measuring instruments are developed to change some forms of energy that we cannot sense in something that we can sense. For example, we can sense the kinds of radiation like particles rays such as β rays (electrons $^{o}e_{1}$) and α rays (helium nucleon $^{4}{}_{2}He^{++}$) or electromagnetic radiations such as Rontgen rays (X-rays) and gamma rays, by using films or emulsion papers and other detectors. When these kinds of radiation incident on the film or emulsion paper, the energy of radiation will make a certain effect on them. Also we can sense ultraviolet and infrared radiation by feeling their heat when a large amount of them incident on our bodies.

There are other kinds of energies which can be sensed indirectly by our organs such as the chemical, gravitational, magnetic and nuclear energies.

The forms of energy are mutually interchangeable, i.e. one form of energy can be changed to another form of energy.

Our bodies require energy to live. We get this energy from the food, which is (plants, animals, where animals get their food from plants) oxygen and water, where oxygen and water are the source of life for all living things. We live in an integrated environment which we have to look after in order to stay healthy.

2.2: Forms of energies of the body:

There are several forms of energies of the body which are the potential, kinetic, chemical, heat, electrical, and nuclear energies.

The potential and kinetic energies are two general kinds of energy that all objects in the universe including our bodies may have.

The potential energy is the stored energy of the body due to the change of its position relative to a reference position of the body. It is gained by the body due to the gravity or other external forces on the body. There is no any relationship between the potential energy and the internal forces or energies of the body.

For example, when you are on a hill, your body has a potential energy (E_p) due to your position. This energy depends on your weight mg (where m=mass of the body and g=gravity constant =9.8 $m.s^{-2}$), and the height (h) of the hill from the surface of the earth. The potential energy is given by:

$E_p = mgh$ …………….. (2-1)

The kinetic energy is the energy due to the motion of the body or the organs inside the body. When you are walking, running, falling or jumping your body has a kinetic energy. Also when you are sitting in a moving object like a car, train, plane, ship, spaceship or riding a bicycle or a horse, your body has a kinetic energy.

Some of the organs in the body have kinetic energies such as the bones and muscles movements, heart beatings, blood circulating, and lungs and stomach movements.

In general, the kinetic energy E_k is dependent on the mass of the moving object and its velocity (v) where:

$E_k = \frac{1}{2}mv^2$ ……………. (2-2)

The other forms of body energy are discussed in the following articles of this chapter.

Several units are used in the measurement of energy of the body. The most widely used units are the meter kilogram second (MKS) system units such as Newton.meter (N.m) and dyne.centimeter (dyne.cm) and Joule (J). Also, centimeter, gram, second (cgs) system units are used in the measurement of energy of the body such as erg.

The English system unit, the foot.pound (ft.lb) is also used in the measurement of energy where:

$1J=10^7$ ergs = 0.737 ft.lb

2.3: Chemical energy of the body

The food is the fuel of our body, which is mostly carbohydrate, can be changed to glucose molecules ($C_6 H_{12} O_6$) by the digestive system. Also, some other kinds of food like fats and proteins can give energies but lower than that of the carbohydrate. (Table 2.1).

Glucose molecules are obtained either from the blood or by breakdown of glycogen stored in the liver, muscles or other organs of the body.

Table 2.1: Typical energy relationship for some foods and 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	4.8–5.0	—
Gasoline	—	11.4
Coal	—	8.0
Wood (pine)	—	4.5

The glucose molecules combine with oxygen in the cells of the body to supply chemical energy to these cells.

The body uses the chemical energy (food energy) to operate its various organs, do external work, and maintain a constant body temperature.

The energy supplied by the food to our bodies is measured by a unit called kilo calorie (Kcal). It is defined as the amount of heat required to raise the temperature of one liter of water one degree Celsius where:

1 Kcal=4184J

The molecules of glucose cannot be used to energize body activities directly. The glucose molecules are normally combine with oxygen which result in the formation of chemical energy molecules called adenosine triphosphate (ATP) which is able to store and transport chemical energy within the cells.

ATP is the most useful form of energy in living system because it transports chemical energy within the cells for metabolism. The cells can use ATP like a battery.

The glucose is the pivotal fuel molecule in the oxidation via the reaction:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + 686 \text{ Kcal} \quad \ldots\ldots\ldots \ (2.3)$$

This reaction is reversible.

The rate of oxidation is called the metabolic rate.

In this reaction, one mole of glucose oxidized and energy of 686 Kcal is produced from which as much as 262 Kcal captured in ATP bonds and the rest liberate d as heat. Therefore, the above equation can be rewritten as a reversible reaction as follows:

$$C_6H_{12}O_6 + 6O_2 \leftrightarrow 6H_2O + 6CO_2 + 36ATP + heat \quad \ldots\ldots\ldots(2.4)$$

This corresponds to a cell energy capture of 38%, and a cell efficiency of 38%, while the man-made machines use only 10-30% of the energy available to them with efficiency of 10-30%. This means that the cells of our body are more efficient than any man made machine.

This energy is captured and stored as small packets of energy in the bonds of ATP. Actually ATP is a very unstable energy storing molecule and provide energy that is immediately usable by all of the body cells. These cells temporarily become more energetic and capable of performing some type of cellular work. During ATP hydrolysis, adenodiphosphate (ADP) and inorganic phosphate molecule are produced and energy released. The energy released corresponds closely to the amount of energy needed by the cells. This will protect the cells from excessive energy release which might damage the cells.

Most of ATP is manufactured to the cells by the mitochondria by a process that consumes O_2 and produce CO_2 to fuel all the activities of life.

The mitochondria (thread likes or sausage shaped and can change its shape almost continuously) are the manufacture of ATP to the cells and thus they are the factories of energy of the body cells which may called the power plant of the body.

Mitochondria are found throughout the cytoplasm. Large number of them as many as thousands are present in the cells that utilize large amount of energy like the kidney, liver and heart muscles whereas less active cells contain fewer mitochondria such as the skeletal muscles and unchallenged lymphocytes.

Example 2.1:

Calculate the energy liberated from consumption of 1 Lit of oxygen.

Solution:

From equation (2.3), the total energy liberated from the consumption of 6 moles of oxygen equals 686 Kcal.

The volume of each mole of O_2 equals 22.4 Lit.

Therefore, the total volume of 6 moles of O_2 equals:

6 x 22.4 = 134.4 Lit

Thus, the energy liberated by consumption of 1 Lit of O_2 equals:

686 / 134.4 = 5.1 Kcal.

2.4: Glucose level in the blood, as energy consumption indicator:

Glucose is a form of sugar in the blood comes from the food sources. The excess of glucose is stored in the liver as glycogen. The level of glucose in the blood is measured in America and some other countries (including Iraq) by the numbers of milligrams of glucose per deciliter of blood (mg/dL).

In some other countries like Britain and Canada it is measured by millimoles per liter (mmole/Lit) which can be countered to the American levels by multiplying the British or Canadian levels by 18. We use in this book the American levels.

Most of our food is broken down to glucose. The glucose is transported to the body cells by the blood stream, but it cannot enter the cells without insulin, which is a hormone produced automatically by the pancreas. The insulin helps the glucose molecules present in the blood to enter the cells of the body. The levels of glucose in the blood are reduced as soon as glucose enters the body cells.

The levels of glucose in the blood are getting very high when the pancreas is damaged and produced a little amount of insulin or does not produce insulin. In this case the body cells cannot get glucose or get little amounts for their essential energy and growth. The high level of glucose in the blood is called hyperglycemia which leads to diabetes mellitus and tends to dehydration and weight loss. It also affects eyes, liver, kidney, teeth and pregnancy. It can also lead to the hardening of blood vessels (atherosclerosis) which gives a heart risk.

The abnormal low level of glucose in the blood called hypoglycemia which can cause dizziness, confusion and fainting.

The level of glucose in the blood indicates the level of consumption of energy in the body. If the level of glucose is high in the blood this indicate a low level of energy consumption and vice versa.

The diabetes mellitus (commonly referred as diabetes) is a group of metabolic diseases in which there are high blood sugar levels (hyperglycemia) i.e. low level of energy consumption over a prolong time due to either the pancreas does not produce enough insulin, or the cells of the body does not respond properly to the insulin produced.

The symptoms of diabetes include frequent urination and increasing of thirst and hunger.

Diabetes mellitus are Latin words where diabetes means siphon (referring to the excessive urination associated with the disease), and mellitus means like honey (referring to the sweet smell and taste of the patient's urine).

There are three types of diabetes: type 1, type 2 and gestation diabetes.

1- Type 1 diabetes:

Type 1 diabetes mellitus results from the failure of pancreas and very high level of glucose in blood and very low level of energy consumption. It often begins in child blood, for this it is used to be called Juvenile diabetes.

This type is also called insulin dependent diabetes, because its treatment is dependent on insulin injection.

2- Type 2 diabetes:

When the body cells do not consume the reliable amount of glucose because of the lack of exercises, this will result in insulin resistance by the cells, and increasing of glucose levels in the blood and decreasing of energy level consumption.

This case is called type 2 diabetes (diabetes mellitus type 2). It is a long term metabolic disorder characterized by high level of blood sugar, insulin resistance by cells of the body, and relative lack of insulin production by the pancreas.

There are five more general tests for glucose blood levels, to give indication if the patient is normal, prediabetes, or diabetic. Also it gives whether a person who has diabetes is successfully controlling his diabetes. These tests are:

1- Fasting plasma glucose (FPG) test:

It is a test of blood sugar levels in the plasma on fasting (not having any food or drink except water) for at least 8 hrs before the test.

2- Oral glucose tolerance (OGTT) test:

It is a test to indicate how the body processes glucose by giving the patient a special sweet drink of 75 gm of glucose. The glucose level in the blood is measured before and after 2 hrs after taking the drink because the peaks of blood glucose levels are mostly occurred around 2 hrs after starting meals.

3- Hemoglobin A1e (Hb A1c or A1e) test:

This test gives the average level of blood sugar over the past two or three months. It measures how much glucose is bound to the hemoglobin in the red blood cells.

Because the red blood cells live normally for about three months, therefore, the test shows the average level of glucose in the blood for the past two to three months. When the glucose level in the blood is higher than hemoglobin A1c test is higher.

This test is also called (average blood sugar test or reported as eAG).

It is a test to indicate the glucose level in the hemoglobin without fasting and without drinking or eating anything. But it is not recommended for everyone.

4- Post prandial (2 hrs. post meal) test:

It is a blood test to measure the glucose level in the blood after 2 hrs of having a meal from the starting of the meal, while the glucose level in the blood is at its peak.

5- Random plasma glucose test:

It is a blood test to measure the glucose level in the blood at any time of the day for the patients who have severe diabetes symptoms.

The American Diabetes Association (ADA) recommended a diabetes test criterion, (Table 2.2).

Table 2.2: Diabetes test criteria (American Diabetes Association).

The test	Normal values mg/dL	Prediabetes mg/dL	Diabetes mg/dL
1-Fasting plasma of glucose (FPG) test	Less than 100	100 - 125	126 and more
2- Oral glucose tolerance test (OGTT)	Less than 140	140 - 199	200 and more
3- Hb A1e test	Less than 5.7%	5.7 - 6.4%	6.5% and more
4- 2hr post pradial test	90 - 130	131 - 139	140 and more
5- Random plasma test.	79 - 139	140 - 200	200 and more

A diet combined with exercise and medication can reduce the level of glucose in the blood.

2.5: Electrical Energy:

The electrical energy in our body results from the movements of the ions in the body. It is similar to the energy of electricity moved as a current (flow of electrons) in the electricity wiring.

In our body there are three big examples of electrical energy which are:

1- Electrical currents which are generated when the ions move along or across the cell membrane.

2- Nerve impulses generated in the nervous system which are electrical currents used to transmit messages from one part of the body to another.

3- Electrical currents traveling across the heart to stimulate the heart beats and pump the blood from the ventricles of the heart.

2.6: Energy of muscles contraction:

ATP is the only source of energy used directly for contractile activities of the muscles which store amounts of ATP relative to their activities.

The time for contraction of the muscle is very small, about 4 – 6 sec. During the muscle contraction, the ATP must be supplied to the muscle as fast as it is possible.

Energy is usually liberated from ATP in the cell by a reaction that removes one of the phosphate – oxygen groups producing adinodiphosphate ADP and the phosphate group. This reaction is reversible:

$$ATP + H_2O \leftrightarrow ADP + energy$$

Fortunately, after ATP is hydrolyzed to ADP and inorganic phosphate it is regenerated within a fraction of a second. This procedure can be done by three paths which are:

1- Interaction of ADP with creatine phosphate:

Creatine phosphate (CP) is a unique high energy molecule stored in the muscles more than the ATP. When we have a vigorous exercise, the ATP stored in the muscles is consumed within breaking down of glucose which is called glycolysis (from the Greek language, glycose means sugar and lysis means break down)

When there is a sudden higher demand. For ATP in the muscles, like in muscle twitches (involuntary tightening of muscle), the CP will couple with ADP and result of instant transfer of energy to form ATP, as follows:

$$CP + ADP \rightarrow C + ATP \quad \ldots.. (2.5)$$

Thus ATP can be regenerated again by the reaction of ADP with the phosphate oxygen group which allows ATP to store energy like rechargeable battery.

This couple reaction is reversible to keep CP reserved in the muscles.

Both stored ATP and CP provide power to the muscles for 10 to 15 seconds maximum. The short time heavy exercises such as weight lifting, diving and sprinting (short and very fast race) which require a sudden and great increase of energy but last only for few seconds rely entirely on the energy stored in the ATP and CP.

2- Anaerobic mechanism:

When the muscle contracting activity reaches about 70% of its maximum possible contraction, the glucose is breaking down without oxygen releasing enough energy to form 2ATP per each glucose molecule.

Anaerobic path way produces ATP about 2½ times faster and can provide most of the ATP needed for moderate periods of strenuous (great effort) muscle activity (30-40 sec) as long as the fuel and enzymes are available.

When the body performs a hard effort, this activity can be supported for nearly a minute.

The hard exercises such as tennis, soccer and 100 m swimming which are on and off or burst like activities appear to be fueled almost entirely by anaerobic glycolysis.

3- Aerobic respiration:

Aerobic respiration means the breaking down of glucose in the presence of oxygen. It includes glycolysis and reactions that take place in the mitochondria, where glucose molecule is broken down by the reaction with O_2 yielding water, CO_2, 36 ATP and heat (eq. 2.5).

Aerobic respiration provides 95% of the ATP used for muscles activity during rest and light to moderate exercises that continue for several hours in well condition individuals. Aerobic respiration is relatively slow because of its many steps and requires delivery of O_2 and nutrient continuously.

The prolong exercises such as marathon runs and jogging depend mainly on the aerobic respiration.

The cardiac muscles have greater dependence on oxygen for its energy metabolism, than the skeletal muscles because the cardiac muscles have more mitochonderia rely almost exclusively on aerobic respiration. While skeletal muscles can rely on anaerobic respiration and contract for prolong time even during oxygen defects.

Cardiac muscles use multiple fuel molecules like glucose and fatty acids and lactic acids produced from skeletal muscles. Thus the real danger of an inadequate blood supply to the myocardium is the lack of oxygen supply and it is not the nutrient fuel.

2.7: Effect of lack of energy and oxygen on the muscle's contraction:

The lack of energy and oxygen provided to the muscle result in muscle fatigue

where the muscle contract is decreased or the muscle unable to contract even when the muscle still receiving stimuli.

There are three characteristics of fatigued muscle which are:

1- Decline in muscle tension as a result of previous contractile activity.

2- Decrease in shortening velocity i.e. the muscle doesn't contract as fast as when it was normal.

3- Slower rate of relaxation i.e. the muscle flexibility is decreased.

When oxygen in the muscle is limited and ATP production is less than ATP used, the muscle contraction is less and less effective until muscle fatigue sets in.

Note that muscle fatigue results from a slightly lower concentration of ATP in the fatigued muscle than in a resting muscle.

If contractile activity continues without fatigue, the ATP concentration will decrease to the point that it will be very damaging to the muscle fibers. Thus muscle fatigue is a mechanism to prevent damage to the muscle fibers.

The muscle fatigue relative to the lack of ATP is quite different from other fatigues of muscles such as the psychological fatigue in which the flesh is still able to perform but we feel tired, and the central command fatigue in which the appropriate regions of the cerebral cortex fail to send excitory signals to the muscles.

2.8: Work of the body:

From the definition of energy (the capacity of doing work), we can conclude that wherever energy exists, there is a capability of doing work. Therefore, because cells of the body store energy, they are capable to do a work. Also when 0there is a consumption of energy there should be a work done.

The internal energy liberated (ΔE) during break down of a (fuel) molecule can perform a work (ΔW) and liberate a heat (ΔH) which can be given according to the first law of thermodynamics as follows:

$$\Delta E = \Delta W + \Delta H \qquad \text{……………………. (2.6)}$$

During the body metabolism there is, about 38% of the energy released from the fuel molecules is used as a work and the rest appears immediately as a heat.

The heat released in the body cannot be changed to work because our body is not a heat engine, but the heat is used to maintain the temperature of the body and the rest is dissipated outside of the body.

The units of measuring work are standard units, the same standard units of measuring energy such as Joule and erg.

There are two kinds of work can be performed by our body, the external work and the internal work.

1- The external work:

The external work is done when a force exerted on the body (or an object in the body) causing it to move in the direction of the applied force.

The amount of external work W equals to the product of the force F applied on an object times the displacement Δd of the object, where the force must be in the same opposite direction of the displacement. Therefore:

$$W = F\Delta d \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.7)$$

In MKS system, the force is measured in newton (N), the distance is measured in meter (m) thus the work is measured in N.m which is called joule (J). Thus, one joule is defined as the work done by a force of one newton acting through a distance of one meter.

Obviously external work is done when you are climbing a hill or walking upstairs. The external work you done can be calculated by multiplying your weight mg (where m=mass of the body, g= gravity constant) by the vertical distance h moved by your body. Therefore, in this case external work done by your body is given by:

$$W = mgh \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2.8)$$

This work equals to the potential energy gained by your body when you move your body to another position of height h.

2- The internal work of the body:

When you are running, walking or sliding on a horizontal level surface with a constant speed, most of the forces act are perpendicular to your motion (displacement). Thus the external work done by your body equals about zero. But your muscles consumed energy therefore, they performed internal work and liberated heat in the muscles which caused a rise in its temperature.

The internal work can be defined as the work done by the internal cells tissues, or organs of the body. For example, during cardiac contraction the internal work is performed. But because of the friction of the blood flow with the blood vesicles, energy appears as heat generated by this friction.

2.9: Work of the heart:

The function of the heart is just to apply a force on the blood to eject the blood out of the ventricles.

When the heart contracts, the blood will be forced out of the left and right ventricle chambers in the systemic and pulmonary circles. The ventricles contraction and blood ejection are called systole.

Then the heart relaxes allowing its chambers to refill with blood.

The period of ventricular relaxation and blood filling is called diastole. All events associated with the blood cardiac flow through the heart during one complete heart beat is called cardiac cycle. In each cardiac cycle the atrium systole and diastole are followed by ventricle systole and diastole.

The blood circulates endlessly and an arbitrary starting point should be selected for one turn of the cardiac cycle. Each cardiac cycle lasts for approximately 0.8 sec with 0.3 sec (about one third of the cycle) is systole and 0.5 sec (about two third of the cycle) is diastole.

In each cardiac cycle there is a succession of pressure and volume changes in the heart. The volume of blood ejected from each ventricle during systole is called the stroke volume.

For an adult at rest, the stroke volume for each ventricle equals about 70 ml. Notice that not all the blood in the ventricle is ejected during the heartbeat. The systolic volume of the blood in each ventricle equals about 135ml from which about 70 ml are ejected as a stroke volume and about 65ml stay in the ventricles as diastolic volume.

The volume of blood pumped by each ventricle per minute i.e. the volume of blood flowing through either the systemic or the pulmonary circuit per minute is called the cardiac output. The cardiac output (CO) is the product of the heart rate (HR) which is the number of heart beats/min by the stroke volume (SV). Thus:

$$CO = HR \times SV \quad \text{……………(2.9)}$$

The work of the heart can be calculated when we consider each ventricle as a pump with certain volume and a pressure. The work of the pump (W) is equal to the product of the pressure (p) multiplied by the pumped volume $\Delta \upsilon$. Thus:

$$W = p\Delta v \quad \text{……….. (2.10)}$$

The resistance of blood vessels in the pulmonary circle is small therefore the pressure of right ventricle is small as well. While the resistance of systematic circle is large and thus the pressure of the left ventricle is large too. Typical pulmonary artery systolic and diastolic pressures are 24 and 8 mmHg respectively compared to systemic arterial pressure of 120 and 70 mmHg. Thus the work done by the heart in the systolic and diastolic of the system in blood circle is much more than that of the pulmonary circle.

Example 2.2:

Calculate:

1- the total work done by the normal heart?

2- The cardiac output of the normal heart?

Solution:

1- Calculation of the work of the heart:

The work of each ventricle of the heart can be calculated by multiplying the average pressure of the systolic and diastolic pressures by the volume of the pumped blood. For normal heart at rest, the systolic pressure of the left ventricle equals about 120 mmHg, and its diastolic pressure equals about 70 mmHg. Therefore:

The average pressure of the left ventricle = $\frac{120+70}{2} = 95 mmHg = 95x1.33x10^3 dyne/cm^2$; Where: 1mmHg=1.33x10^3 dyne/cm^2.

The work of the left ventricle = P $\Delta\upsilon$ = 95x 1.33x10^3 dyne/cm^2 x70cm^3

= 8900000 dyne.cm = 0.89 N.m = 0.89 N.m = 0.89 J;

where: 1 dyne.cm = 10^{-7} N.m

Thus the work of the left ventricle = 0.89 J.

The work of the right ventricle can be calculated as follows:

The average pressure of the right ventricle = $\frac{24+8}{2} = 16 mmHg = 16x1.33x\frac{10^3 dyne}{cm^2}$

Therefore, the work of the right ventricle = pΔv = 16x1.33x10^3 dyne/cm^2 x70 cm^3 = 1489600 dyne/cm = 1.5x10^6 dyne.cm = 0.15 J

The total work of the heart = work of the left ventricle + work of right ventricle = 0.89J + 0.15J= 1.04J

Because of the values of stroke volume, systole pressure and diastole pressure are all approximated, therefore we can approximate the value of the work of the heart during one cardiac cycle to about 1J.

During exercise and some cardiovascular diseases, the work of the heart increases because of the increase of the stroke volume and systolic and diastolic pressures of the ventricles.

2- Calculations of the cardiac output:

From eq. 2.9: CO = HR x SV

For normal adult heart at rest, the heart rate equals 72 beat/min, and the stroke volume at each beat equal 70 ml (0.07 lit), therefore:

CO = 72 beats/min x 0.07 L/beat = 5 L/min.

The entire volume of the blood in the body equals approximately 5 lit therefore, all the blood is pumped around the circuit in the body one time each minute.

During heavy exercise in a well-trained athlete, the cardiac output may reach 35 lit/min which means that the entire blood volume is pumped around the circuit of the blood in the body about 7 times/min.

2.10: Power of the body:

The power (P) is defined as the time rate (Δt) for doing work. Therefore

$$P = \frac{W}{\Delta t} \qquad \text{………….. (2.11)}$$

Note that you do the same amount of work when you climb the stairs of a building in 2 min or 6 min, but your power output is not the same because it depends on the time interval of doing works.

The units of power are the units of work divided by the unit of time Δt. For example, if the work is measured in Joule and the time is measured in second, therefore the power unit is J/sec = Watt.

Thus the power of the heart can be calculated from equation (2.11) as follows:

$$P = \frac{W}{\Delta t} = \frac{1J}{sec} = 1 \text{ Watt}$$

Also, the power of the cell for breaking glucose molecule at one second can be calculated from equation (2.11) where energy of ATP which converted to work= 262 Kcal, therefore:

$P = \frac{262\ Kcal}{1\ sec}$; Since 1 Kcal = 4184 J, therefore P=262x4184 J/sec= $1.1\text{x}10^6$ J/sec = 1.1 MW. Hence the cell is very big power plant.

2.11: Efficiency of the body:

The efficiency is defined as the rate of the useful work output to the total input work. Therefore:

$$\text{Efficiency} = \frac{\text{output work}}{\text{input work}}$$

$\text{eff} = \frac{W_o}{W_i}$.................. (2.12)

Because the output work is always less than the input work, therefore the efficiency of all machine is less than 100%.

Each cell in the body is a machine which consume energy and it has a power and efficiency. As it is clear from equation (2.11) that the total energy supplied by glucose molecule is 686 Kcal which corresponds to the work input from which only 262 Kcal are used as an output work. Therefore, the efficiency of human cell which can be calculated from equation (2.11) equals to:

$$\text{eff} = \frac{W_o}{W_i} = \frac{262\ \text{Kcal}}{686\ \text{Kcal}} = 38\%$$

The efficiency of human made machine does not exceed 30% until now, which means that the cell of the body is more efficient than any human made machine.

Example 2.3:

Suppose your mass=60 kg, you climbed a hill of 20 m height and consumed 3 lit of oxygen, calculate:

1- External work done by your body.
2- Power of your body.
3- Energy consumed in climbing the hill.
4- Efficiency of your body to climb the hill.

Solution:

1- $w = F.\Delta d$

$F = mg = 60\text{kg}x9.8\frac{m}{sec^2} = 588\ N$

$\Delta W = 588N.20m = 11760\ J$

2- $P = \frac{W}{\Delta t}$

$\Delta t = 5min = 5x60sec = 300sec$

$P = \frac{11760 \text{ J}}{300\text{sec}} = 39.2 \text{ W}$

3- Since 1 Lit of O_2 consumed liberates energy of 5.1 Kcal.

Therefore: energy consumed = 3 x 5.1 Kcal = 15.3 Kcal = 15.3 Kcal x 4184= 64015.2 J

4- $\text{Efficiency} = \frac{W_o}{W_i}$

The output work, W_o = 11760 J

The input work, W_i = 64015.2 J

Therefore:

$\text{eff} = \frac{W_o}{W_i} = \frac{11760 \text{ J}}{64015.2 \text{ J}} = 18.37\%$

The work, power and efficiency of the cell for prediabetic or diabetic person are less than that of the healthy persons. This is relative to the number of glucose molecules that can enter from the blood to the cell.

It is clear from table (2.2) that the number of glucose molecules enter the cells of the healthy person is more than that of the prediabetic person which is more than that of diabetic person.

From this table we expect that the work and power of the healthy person is not more than 25% than that of the prediabetic person, and 25% or more than that of the diabetic person.

Note that the work, power and efficiency of the braking down of the glucose molecule in the cell in the healthy, prediabetic and diabetic person are the same.

2.12: The heat and temperature of the body:

The heat is a thermal energy which is like any other energy can't be created or destroyed. It can be transferred from one point to another and converted to or from other kind of energy.

In medicine and biology, the internal energy liberated during breaking down fuel molecules (ΔE) can perform a work (ΔW) and release a heat (ΔH). This represents the first law of thermodynamics which is an application of the law of conservation of energy (eq 2.6).

The heat is defined as the thermal energy in the process of being added to, or removed from a substance or transferred from one material to another.

The heat is added to the body from the internal energy consumption of fuel molecules and from the outer surroundings of the body. Also, heat is removed from the body to outer surroundings by breathing and heat losses from the skin.

The total heat produced by all the chemical reactions and mechanical work of the body is called metabolic rate. It is the body rate of energy output. The skeletal muscle activity can alter the metabolic rate. A small increase in skeletal muscle contraction can cause a significant increase in the metabolic rate and may rise heat production more than 15 times.

At rest, all body tissues produce heat, and the most heat generated when the body at rest is by the liver, heart, brain, skeletal muscles and endocrine organs.

The skeletal muscles at rest account for 20-30 % of the heat production, but during vigorous exercise, heat product by the skeletal muscles increases to about 30 to 40 times more than that of the other parts of the body. This means that the change in a muscle activity is one of the most important modifying factors of body heat.

The indicator of the amount of heat contained in a system and in the human body is called temperature. Every reaction in human body occurs at certain levels of energy and temperature.

The normal range of the body temperature requires a precise regulation mechanism by the body. The temperature of a healthy individual fluctuates approximately 1 $^{\circ}$C (1.8 $^{\circ}$F) in 24 hours where the lowest temperature occurs in early morning and the highest in late afternoon or early evening.

The rise in body temperature leads to increase of the enzyme catalyst and accelerate the chemical reactions. A rise of 1 °C increases the rate of chemical reactions about 10%. Most adults go into convulsions when body temperature reaches 41 °C (106 °F). It seems that the absolute limit of life is at 43 °C (about 110 °F).

Low body temperature reduces the metabolic rate of the body tissues which can withstand a reduction in temperature if other conditions are carefully controlled. Thus the body cooling can be used in cryosurgery (surgery under low temperature) during open heart surgery when the heart must be stopped. Also, cryosurgery can be used during the treatment of Parkinson's disease (shaking palsy) by cooling the appropriate region of the brain.

There are two regions in the body have different resting temperatures which are:

1- The body core regions which include organs within the skull, thoracic, and abdominal cavities.

Normal core temperature is exact temperature at which all the functions of the human body system can operate with optimal efficiency.

The ideal core temperature is considered to be 37 ^{O} C (98.6 ^{O} F) which is the average of variation of the normal temperature in the range of minimum temperature of 36.5 ^{O} C (97.7 ^{O} F) to a maximum temperature of 37.5 ^{O} C (99.5 ^{O} F). Any temperature below or above this range is regarded as abnormal temperature.

The good indicator of core temperature is the under tongue in the mouth. Therefore, the measurement of the under tongue mouth temperature gives a good estimation of the core temperature. For this the thermometer is usually put under the tongue in the mouth to measure the core temperature. The core temperature is precisely regulated by the blood, breathing, skin, and the external environment.

2- The shell region which is essentially the skin where the temperature of the skin changes with the surroundings.

The internal heat which is produced by chemical reactions of the cells transferred from the cell to the blood in the capillary vessel tubes. The warm blood returned back to the heart where some of it, is driven to the lungs for oxygen exchange. The heat transferred from the blood to the air in the alveoli. During expiration this air is driven outside the body. Breathing get rid of about 10% of internal heat of the body.

Most of the heat in the blood is transported by the blood to the blood vessels in the skin to be lost to the external environment. The blood vessels reduce the skin insulating capacity of heat by carrying heat to the skin surface.

2.13: Obesity (over weight):

Obesity is a medical condition in which excess body fat has accumulated to the extent that it may have a negative effect on health. Obesity is caused mostly by a combination of three reasons, the excessive food intake, lack of physical activity and genetic reasons. A few cases of obesity are caused by medications, endocrine disorders, or mental illness.

Obesity results in a variety of diseases, such as hypertension, heart disease, stroke diabetes type 2, and high blood cholesterol. It is also a major cause of gallstones, osteoarthritis and respiratory problems.

Body mass can tell little about body composition because dense bones and well developed muscles can make a person technically over weighted.

The official medical measure of obesity and body fitness is the body mass index (BMI). BMI is the weight (physically means the mass) of a person (in Kg) divided by the square of his height (in meter). Thus:

$$BMI = \frac{weight}{(height)^2} \quad \text{..................} \quad (2.13)$$

The unit of BMI is Kg/m^2

The National Institutes of Health and the American Health Foundation issued on 1995 a guideline which defined the healthy weight of a person as follows:

i- Healthy when his BMI is below 25 kg/m^2.

ii- Overweight when his BMI is between 25 to 30 kg/m^2, and

iii- Obesity when his BMI is more than 30 kg/m^2. For adult males and females, a body fat contents of 18% and 20% respectively is regarded normal. To lose a certain amount of weight we should lose a certain weight of fats where each gram of fat loses about 9 kcal, in addition to that, the adipose (fatty) tissues lose 10% of that weight as a water lose.

<u>Example 2.4:</u>

A person of height 160 cm and a weight of 90 kg:

1- Show if this person is normal, overweight or obese and how much fat he should loose if it is necessary.
2- If he wants to lose 1000 kcal/day how much weight he should loose and how long time required until he gets his proper weight.

Solution:

1) $BMI = \frac{weight}{(height)^2} = \frac{90}{(1.6)^2} = 35.2$ kg/m^2

Therefore, this person is obese, because BMI should be less than 30 to avoid risk of obesity.

The proper weight of the patient means that the patient will not have overload or obesity; and we should take BMI = 25.

The proper weight of this person can be calculated from equation (2.13) where:

Weight= BMI (height)^2

For this person:

Weight= $25 \times (1.6)^2 = 64$ Kg

Access weight to be loosed = 90 – 64 = 26 kg.

Therefore, this person should lose 26 kg of fat.

Each 1 gm of fat liberate 9 kcal, therefore:

The mount of Kcal to be loosed = 26 x 1000 x 9 kcal= 2.34×10^5 kcal

2) Each gram of fat can liberate 9 kcal of energy and therefore, to lose 1000 kcal/day this corresponds to 1000/9 = 111 gm of fat/day.
   Also there is a 10% lose of weight as water from the adipose tissue (=11.1 gm) therefore:
   The total weight he should lose/day is:

   111+11.1 =122.1 gm = 0.12 kg.

The time required to lose all the excess weight:

$$total\ time = \frac{26}{0.12} = 216.7\ days$$

Which is approximately equals 117 days.

We should warn here that some of the so called treatments for obesity are more dangerous than the obesity itself. For example

i) The diuretics (water pills) prompt the kidney to excrete more water to lose few kilograms of weight at few hours which can cause serious dehydration and electrolyte imbalance.
ii) Diets nutrient which consider high protein, and low carbohydrate regimens.
iii) Surgery which may involve stomach stapling (see figure 2.1) and intestinal bypass surgery. It carries all the risks of surgery as fat adipose depots are overfilled elsewhere in the body, in addition to a probability of eating habit change.
iv) Diet pills where some of them has serious health problems depending on the pill structure.

The best way to lose weight is to take a few fat calories in your food and increase your physical activity. We must take in account the fact that there is an equation of energy balance of two sides: the caloric intake and the energy output. This is the only way to keep the obesity and the overweight away of your body.

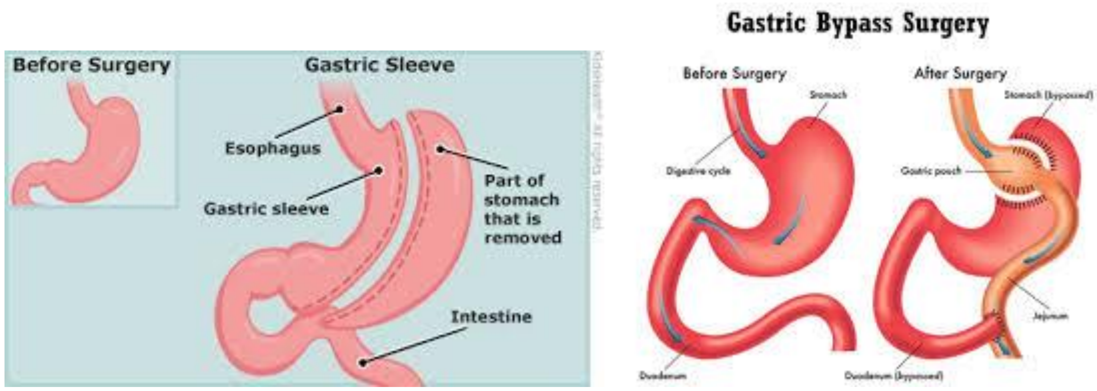

Figure 2.1: The technique used to eliminate the stomach volume by a stapling method.

END OF THE CHAPTER