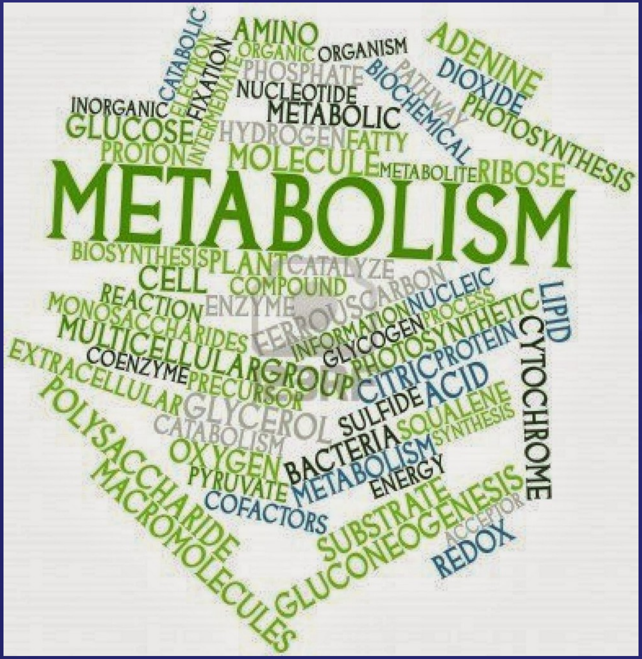
Volgograd State Medical University
Department of Normal Physiology

Physiology Of Metabolism



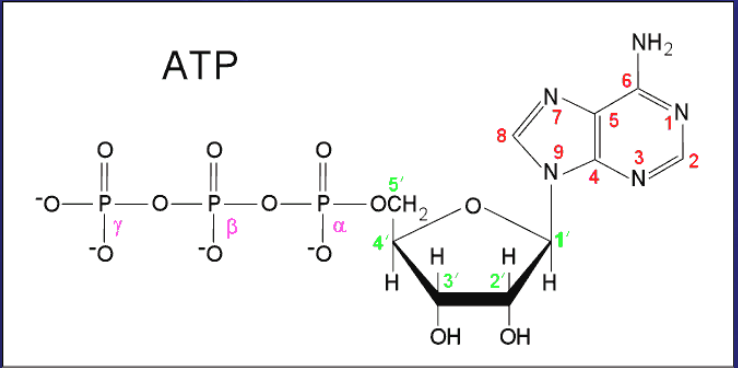
Introduction

Man, to remain alive, has to expend energy, even at rest. Thus, while he is at rest, heart continues to beat, respiration must occur and at cellular levels, $Na^+ K^+$ ATPase activity, active reabsorption in renal tubules, etc. must go on. These are some examples to illustrate that even a resting individual has to expend energy continuously.

When the individual begins to work, additional energy expenditure occurs.

Metabolic rate and energy expenditure

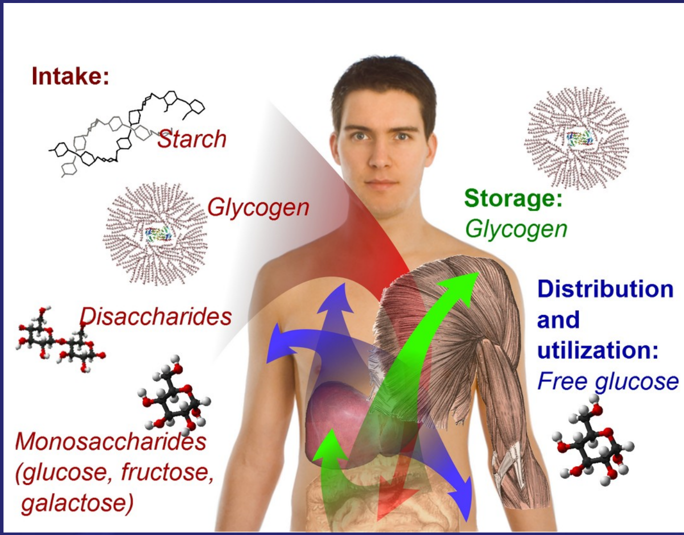
This energy comes from break down of ATP and other energy rich compounds. The ATP and related energy rich compounds are resynthesized by extracting energy which was potential in the food stuffs like carbohydrate, protein and fat, by catabolic processes.



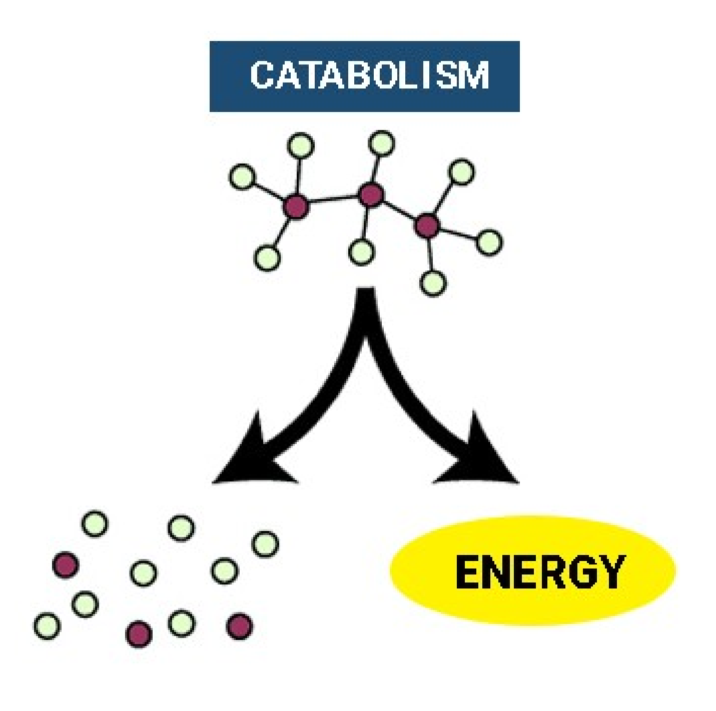
Metabolic rate and energy expenditure

Ultimately all energies must be provided from the food. If no food is available, the body will utilize its own reserve food (glycogen of the liver and muscle, and triglycerides of the adipose tissue) as well as break down its own muscle for nitrogen supply.

This state will continue as long as it is possible and then death will occur.



Catabolism



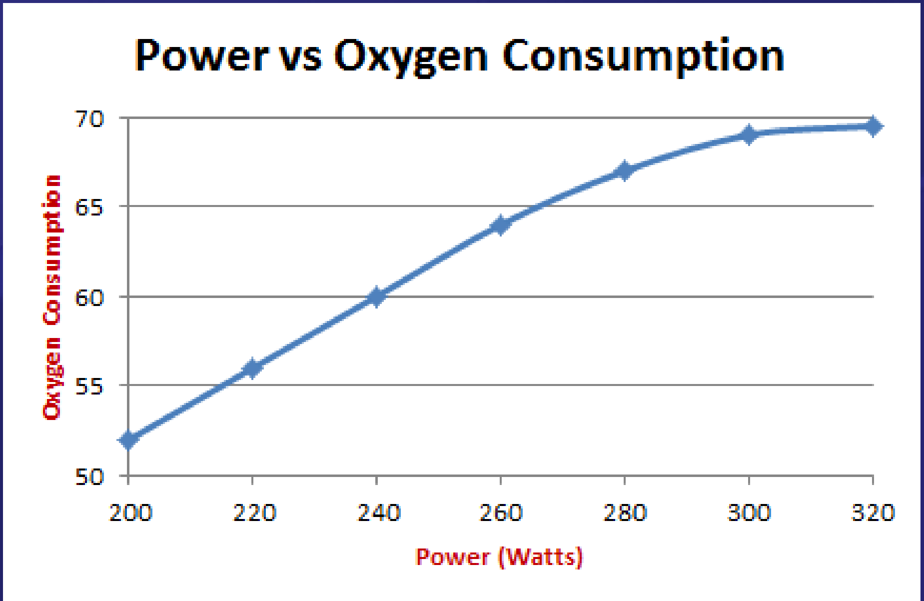
Catabolism of food stuff, ultimately speaking, requires oxygen supply.

Temporarily, even in absence of oxygen, partial catabolism and generation of little amount of ATP (***anaerobic oxidation***) can occur, but for long term purposes, O_2 must be supplied from the atmosphere.

Ultimately therefore, in a given subject, greater the O_2 utilization, greater is the intensity of metabolism.

Catabolism

Determination of oxygen consumption per unit time therefore will determine the metabolic rate as the two parameters are interrelated.

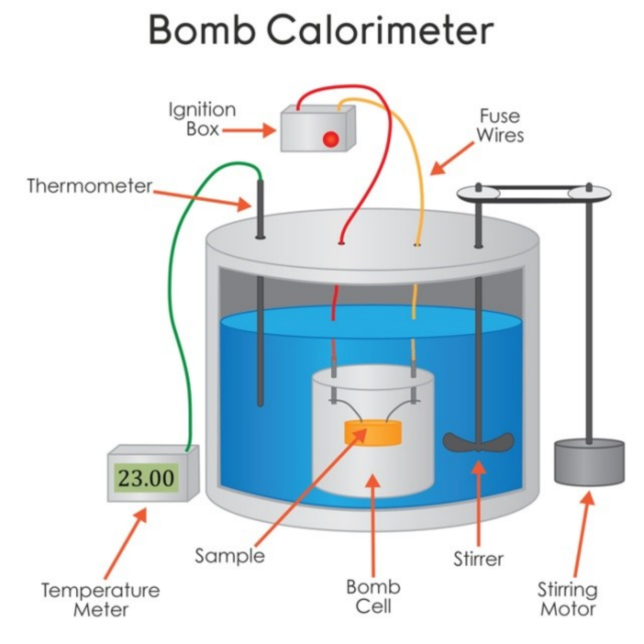


Bomb Calorimeter

This device, built by the great Ely Rubner of Germany, can determine the amount of energy that can be liberated when a food stuff is completely oxidized.

Bomb Calorimeter

An accurately weighted quantity of food is introduced into the *'bomb'* (a strong cylindrical container made up of steel), *completely* oxidized by igniting the food electrically in an atmosphere of oxygen and the heat produced (because of the oxidation) is measured by calorimetric principles.



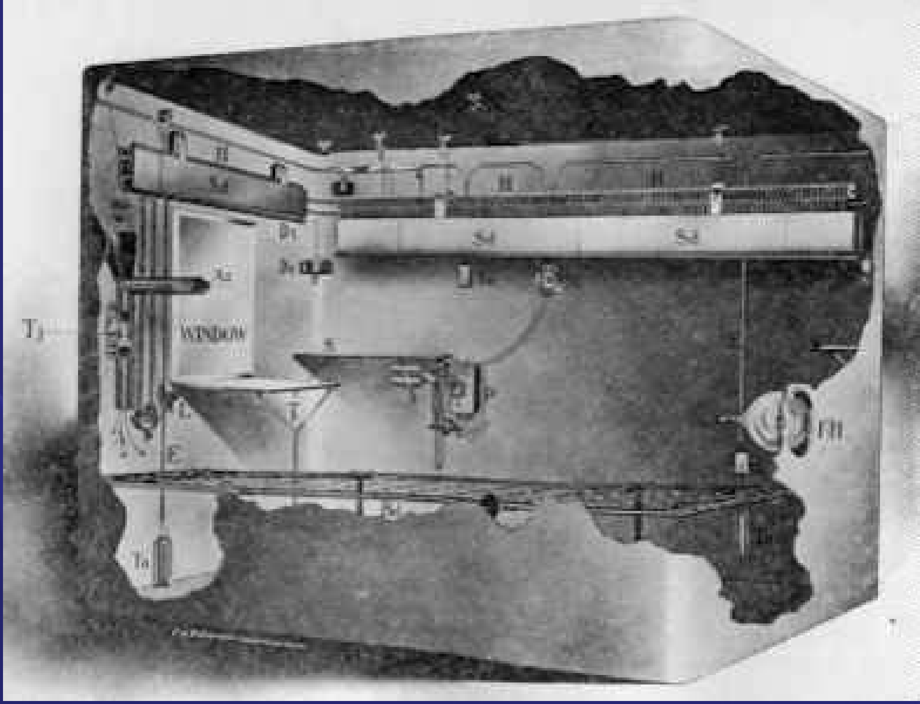
Bomb Calorimeter

The value obtained is the amount of energy hidden (i.e., potential energy) within the food.

Ely Rubner in the last part of the 19th century thus found out the ***calorific values of food stuffs in vitro***.

Metabolic rate and energy expenditure

Subsequently, the amount of energy liberated by the food stuffs when they are oxidized *within the body* (in vivo) were also measured, notably by Benedict and Atwater.



Metabolic rate and energy expenditure

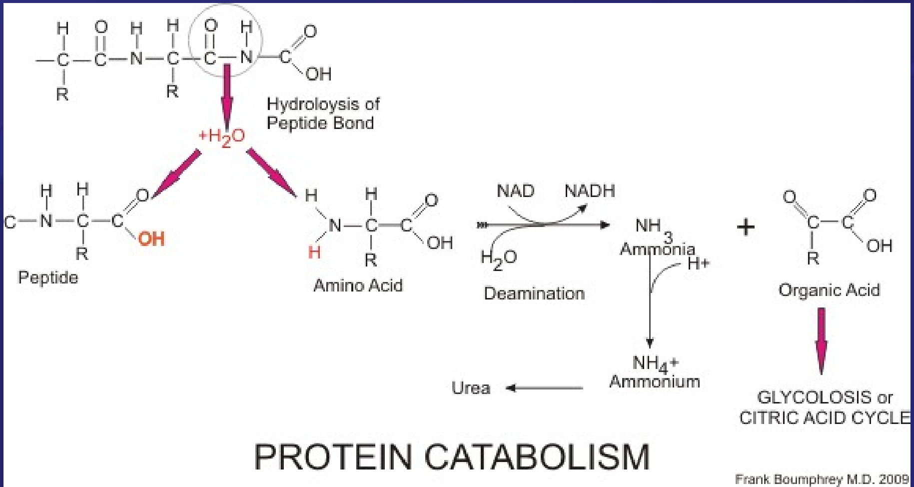
Calorific Values of foodstuffs

Food Stuff	Calorific Value (per gm)	
	In bomb calorimeter (in vitro)	Within the body (in vivo)
Carbohydrate	4 Kcal or 17KJ	4 Kcal or 17 KJ
Fat	9 Kcal or 38 KJ	9 Kcal or 38 KJ
Protein	5.5 Kcal or 23 KJ	4 Kcal or 17 KJ

Metabolic rate and energy expenditure

The values obtained so far as fat and carbohydrate are concerned, by the bomb calorimeter, are same as those obtained when they are catabolized within the body.

However, with the protein, the values differ. The bomb calorimeter gives higher values.

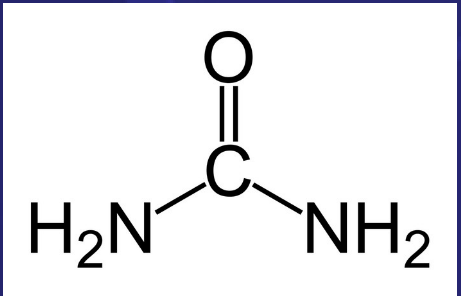


Metabolic rate and energy expenditure

Its explanation is as follows:

Carbohydrate and fat are completely oxidized within the body (by the biological processes) and therefore, for them, the values do not differ.

But in case of protein, in our body, a part of protein, viz, nitrogen, in the form of urea, is excreted out (via urine) without oxidation (that is, protein oxidation in our body is incomplete), whereas in the 'bomb' it is complete.



Units

The old unit for heat was calorie (= the amount of heat necessary to raise 1 gm of pure water's temperature from 14.5°C to 15.5°C).

In physiology, as calorie is too small an unit, Kcal or Cal is usually used (1 Kcal = 1000 cal).

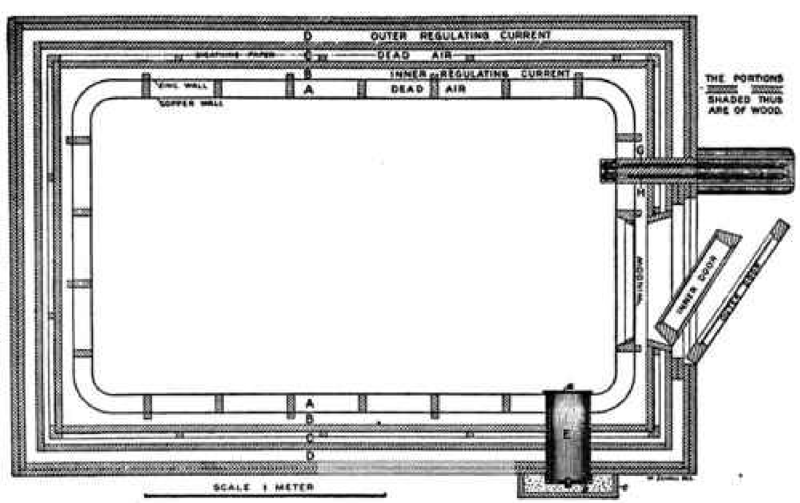
Modern unit is joule J or KJ (Kilo Joule). Thus, 1 cal = 4.184 J, hence 1 Kcal = 4.184 KJ.

Note : Kilo calorie can be written either as Kcal or as Cal, the C being capital.

Methods of determination of metabolic rate (direct method)

Aim of this method is to determine the heat given out by an individual in 24 hours.

The subject stays within a specially constructed chamber, called Benedict-Atwater chamber for a period of hours together. A pipe encircles the room and water circulates through the pipe.



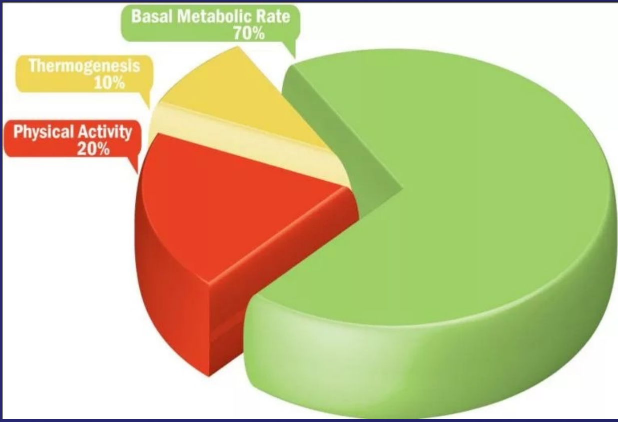
Methods of determination of metabolic rate (direct method)

The heat evolved by the subject escapes into the water of the pipe, so that by noting the

(i) initial (= where water enters the room) and final (= where water leaves the room) temperatures of the water, and

(ii) the volume of the water circulated during the period of observation, the total heat evolved by the subject during the period of observation can be found out.

Methods of determination of metabolic rate (direct method)



Next, the period of observation and total body surface of the subject, in square meter, are found out. From this, heat evolved/hr/sq m of body surface in Kcal can be expressed and is called the *metabolic rate.*

Metabolic rate is the amount of energy liberated by a subject per hour per sq. m of body surface area.

The room is made up of such material that does not cause loss or gain of heat to or from the exterior. The heat given out via the subject's excreta is also added.

This method is absolutely accurate but very expensive and cumbersome and unsuitable for routine use.

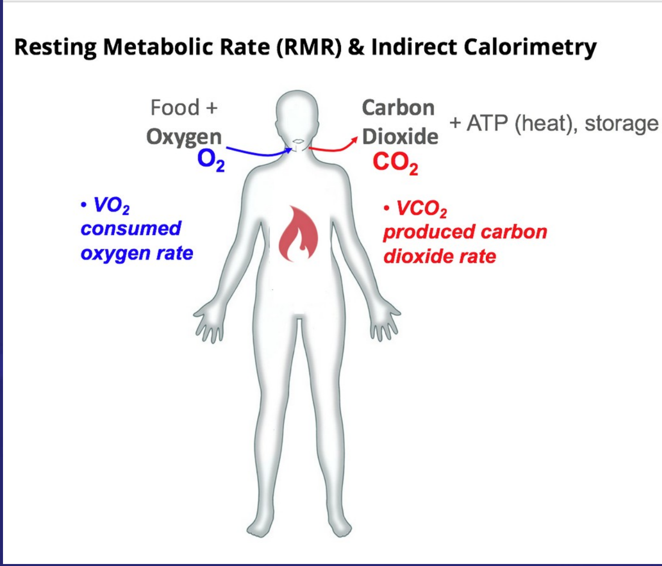
Methods of determination of metabolic rate (indirect method)

In indirect calorimetry, the heat evolved is not directly measured. Instead, two other parameters, viz,

(ii) the **respiratory quotient** (**RQ**), and

(ii) the **energy equivalent of oxygen utilized** in a specific period, are measured.

If these two data are known, energy expenditure can be calculated.

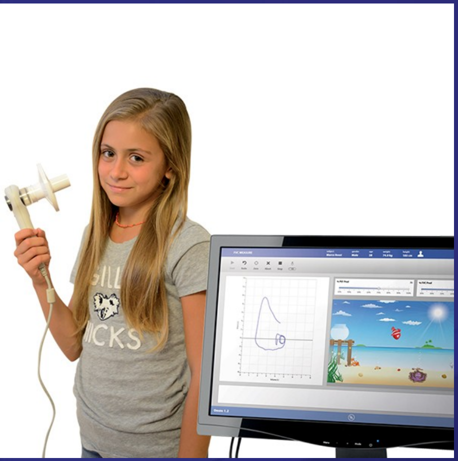


Methods of determination of metabolic rate (indirect method)

The principles involved in the indirect calorimetry (indirect method of determination of the metabolic rate) can be stated as follows:

1. At a given time, the body is utilizing a particular mixture of protein, carbohydrate and fat as a fuel. Oxidation of a fixed quantity of this mixture will produce an exact quantity of heat and will require an exact amount of oxygen.

Methods of determination of metabolic rate (indirect method)



Slated otherwise, when a particular fuel mixture is being used (oxidized) by the body, utilization of exactly one liter of oxygen will produce an exact quantity of heat [because one liter of O_2 can oxidize only a fixed quantity, not more, not less, of this fuel mixture and a fixed quantity of fuel mixture when oxidized can produce a fixed amount of heat].

What particular fuel mixture is burnt can be understood from the RQ. In practice, as stated below, one simply has to know the heat equivalent of 1 liter of O_2 at the given RQ.

Methods of determination of metabolic rate (indirect method)

2. The proportions of protein, carbohydrate and fat in the above mentioned fuel mixture varies from time to time, *but the proportion can be found out by determining the respiratory quotient* or RQ.

Thus, if the fuel mixture is known (which can be found out by the RQ) and volume of oxygen utilized in a given period be determined, **the heat produced by the body in that given period can be found out.** If now the surface area of the body is determined, the metabolic rate becomes known.

Calorific Value of Oxygen

SUBSTRATE	RQ
Fat	.70
Protein	.82
Carbohydrate	1.0
Mixed feeding	.85
Overfeeding	1.1. – 1.2

When the body is utilizing *purely glucose,* utilization of exactly one liter of oxygen produces oxidation of that much amount of fuel (glucose) which produces 5.04 Kcal (21.1 KJ) of energy (the *calorific value of (one liter) oxygen, when glucose (carbohydrate) is the fuel).*

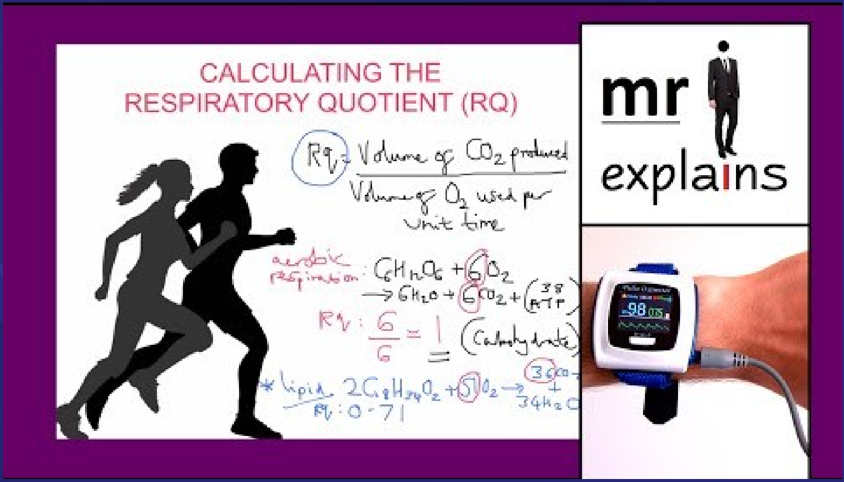
Similarly calorific value of O_2, when *protein or fat* are the fuels are *4.83 Kcal* (20.2 KJ) and *4.7 Kcal* (19.7 KJ) respectively.

However, human beings ordinarily utilize a mixture of carbohydrate, protein and fat. In such a mixed fuel, assuming the proportions are usual' (so that RQ is 0.85).

Respiratory quotient

The **respiratory quotient**, RQ is defined as *the volume* of CO_2 produced in a given time the *volume* of O_2 utilized in the same period.

For example, a resting man produces 200 ml of CO_2 and utilizes 250 ml O_2 per minute; his RQ will be 200/250 = 0.80.



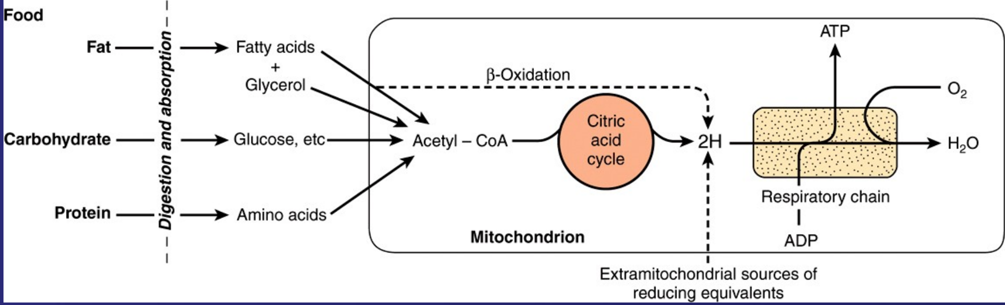
Respiratory quotient

1. **Fuel (food) utilized**. When pure carbohydrate is being oxidized, the RQ is 1. With protein and fat, it is 0.8 and 0.7 respectively. With a *'mixed' diet, the RQ is about 0.85.*

Take the case of carbohydrate. Inside the body, the only form of carbohydrate is glucose ($C_6H_{12}O_6$).

$$RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$$

Respiratory quotient



Now,

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + \text{Energy}$$

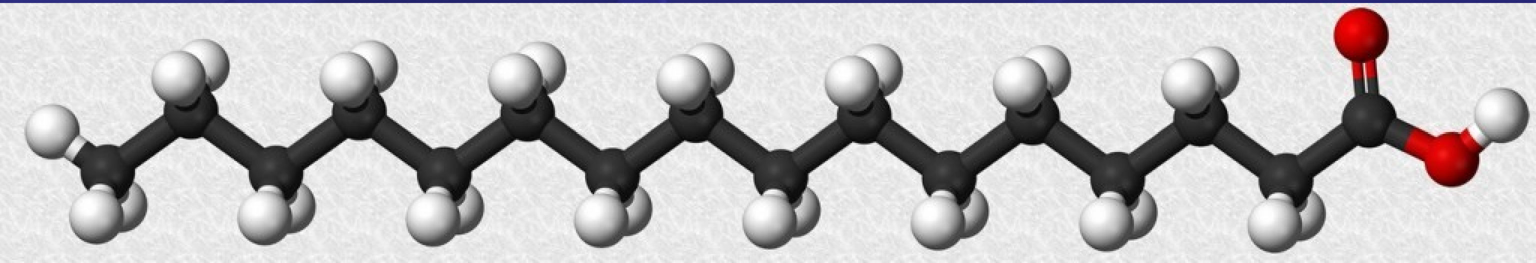
that is, when six molecules of CO_2 are evolving and glucose is the fuel, then six molecule of oxygen must have been utilized.

According to *Avogadro's hypothesis,* equal number of molecules under same temperature and pressure must have same volume. Therefore, 6 molecules of CO_2 and 6 molecules of O_2 must have same volumes. So we have, for glucose, the *RQ to be 1.*

Respiratory quotient

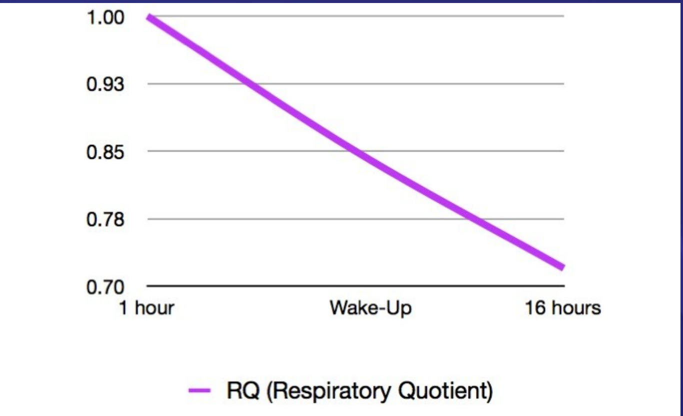
If the structural formula of a long chain fatty acid is examined (e.g. palmitic acid) it will be seen that the ratio between C and O is very high in the molecule (with glucose it was 1 : 1).

Therefore, complete oxidation of a fatty acid requires greater amount of O_2 so that the value of the RQ, when fat is the fuel, becomes low, about 0.7.



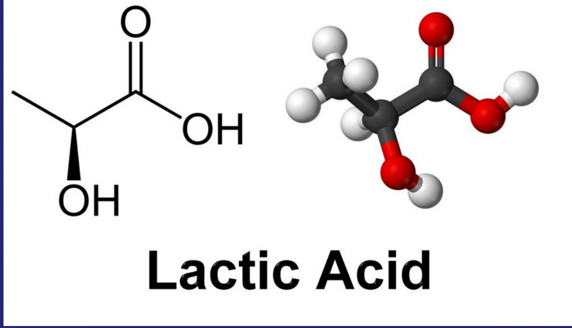
Respiratory quotient

It has been found out by experimental works that about *14 hours after last meal, if there is mental and physical rest, the value of RQ is about 0.8.*



The reason is, 14 hours after the last meal, the body uses a fuel at which RQ becomes 0.8. [if the fasting be prolonged, the RQ will move closer to 0.7 as there will be more and more higher proportions of body reserve fat in the fuel],

Respiratory quotient

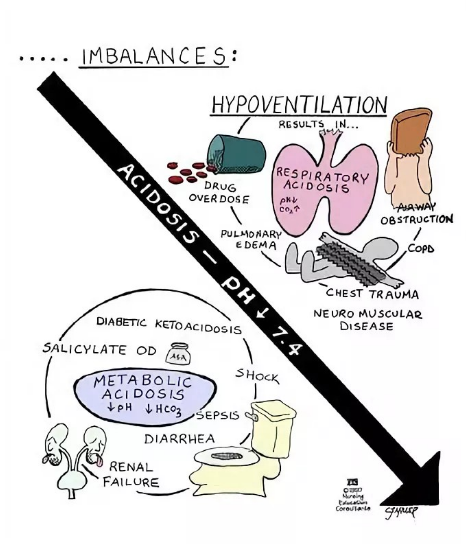


2. **Exercise**. During *severe* exercise, lactic acid concentration of blood rises (from about 5 mg/100 ml at rest to such figures like 120 mg/100 ml). Lactic acid of blood reacts with plasma bicarbonate according to the equation.

The H_2CO_3 is then broken down to form $H_2O + CO_2$ and the CO_2 escapes via the lungs. This causes a rise of RQ and during *violent exercise* values of RQ may become over 1.5.

During recovery the RQ falls (may be as low as 0.5).

Respiratory quotient



3. **Altered V_E**. Alteration of the ventilatory volume (V_E), (other parameters remaining constant), can cause alteration of RQ. Thus, during ***voluntary hypoventilation***, CO_2 is retained and the value of the RQ falls. Reverse occurs in voluntary hyperpnea. Hyperpnea due to even acidosis also should cause rise of RQ. But in diabetic acidosis, two opposing factors work:

(i) the attendent hyperpnea tends to increase the RQ, but

(ii) the associated combustion of fatty acids tend to decrease the RQ.

The actual RQ, therefore, will be the resultant of these two opposing factors.

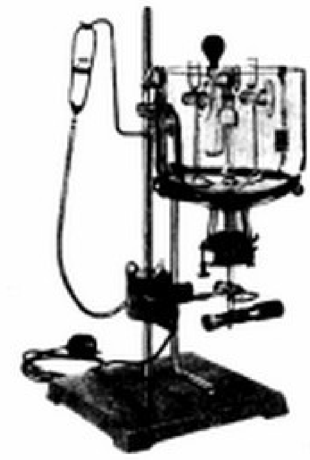
Measurement of respiratory quotient

Douglas bag and gas analysis. Expired air is collected by a Douglas bag and its O_2 and CO_2 concentrations as well as the ventilation volume/minute are found out

Measurement of respiratory quotient

From these values the values of CO_2 evolved and O_2 utilized in ml/min under NTP can be found out and thus the RQ can be determined.

O_2 and CO_2 concentrations of the sample of air from the Douglas bag can, alternatively, be determined by the Scholander's gas analyzer.

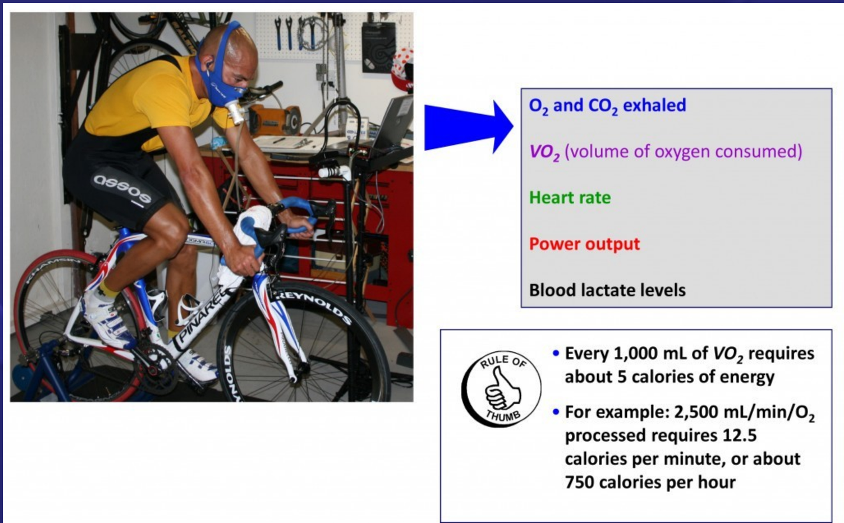


▲
Micro Scholander

Very reliable and swift method of estimating oxygen, carbon dioxide and nitrogen in small gas samples (0.5 ml). Accuracy 0.02 volume %.
Stopcocks on all three arms of the reaction chambers. A complete estimation can be made in less than ten minutes. The apparatus comprises all necessary glass components and micrometer. They are mounted on a metal support.
The side chambers for the absorption liquids have stopcocks.
At request a motorshaker and bubble pump are available as accessories.

Measurement of respiratory quotient

In modern laboratories, RQ can be measured by using modern computerized electronic gadgets where the subject merely breathes in the atmospheric air but exhales into the instrument and the printed result comes out of the instrument.



Measurement of respiratory quotient

Within the instrument O_2 is analyzed by paramagnetic O_2 analyzer and CO_2 by infrared CO_2 analyzer.

Measurement of respiratory quotient

Can RQ go above 1?

NO

Time (min)	VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	RER	RQ
0.5	4.7	0.80	
4.0	10.7	0.84	
7.5	15.1	0.88	
10.5	21.1	0.94	
13.0	24.2	0.99	
15.0	31.6	1.00	
17.0	37.5	1.07	
18.5	41.3	1.12	
20.0	49.0	1.15	

The value of the RQ depends upon the nature of the fuel utilized by the body. Again the nature of the fuel (hence the value of the RQ) determines how much energy will be liberated when exactly one liter of O_2 is used.

Conclusion *therefore is, if the value of the RQ is known, how much energy liberation occurs ('energy equivalent of the O_2 utilized') per liter of O_2 utilized, can be found out.*

Stated in another way if the RQ and the volume of O_2 utilized are known, the energy expenditure can be found out.

Measurement of respiratory quotient

Thus at RQ values of 0.85,1.0 and 0.7, the energy equivalents of one liter of O_2 are 4.875 Kcal, 5.04 Kcal and 4.7 Kcal respectively.

At an RQ of 0.8 the value is about 4.83 Kcal/liter (= 20.2 KJ/liter).

Respiratory Quotient =

Amount of Co2 that leaves every minute

Divided by the amount of O2 that enters every minute

$$\frac{200ml}{250ml} = 0.8$$

Common procedures for indirect calorimetry

Benedict-Roth Spirometer is the classical instrument for determination of BMR (basal metabolic rate), used in clinical laboratories.

For determination of metabolic rate (MR) during outdoor activities like sports, mountaineering or any other form of activities, this instrument is unsuitable.

Common procedures for indirect calorimetry

Preparation of the subject. The subject is tested about 12 to 14 hours after the last meal. The subject must desist all works after the last meal.

Any condition which alters the BMR *(e.g., fever)* makes the subject unsuitable for testing.

In the ***luteal*** **(*secretive*)** ***phase of menstrual cycle***, there is usually an elevation of basal body temperature (BBT).

Common procedures for indirect calorimetry

$$RQ = \frac{VCO_2}{VO_2}$$

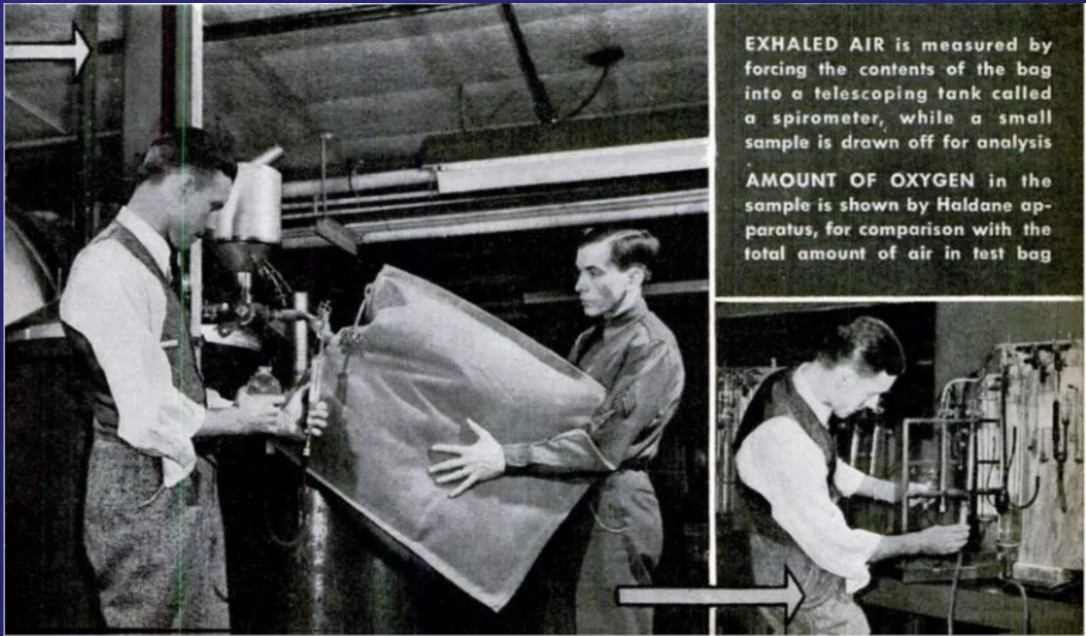
Principle. 12 to 14 hours after the last meal, the subject's RQ is presumed to be 0.8, as stated earlier. Therefore, ***the CO_2 need not be determined*****, as the RQ** is **already known.**

Further, as stated earlier, metabolic rate is determined from the principle that if the RQ is known, the energy expenditure can be determined from the volume of O_2 utilized.

All that is required, is to estimate the O_2 consumption in a specified period of time (six minutes). At this RQ, the calorific value of O_2 is 4.83 Kcal or 20.2 KJ per liter of O_2 utilized.

Common procedures for indirect calorimetry

Douglas bag (open circuit method). Here the RQ has to be found out. The great advantage of this method is that it can be used in determination of **BMR** as well as **MR** in non basal conditions.



Common procedures for indirect calorimetry

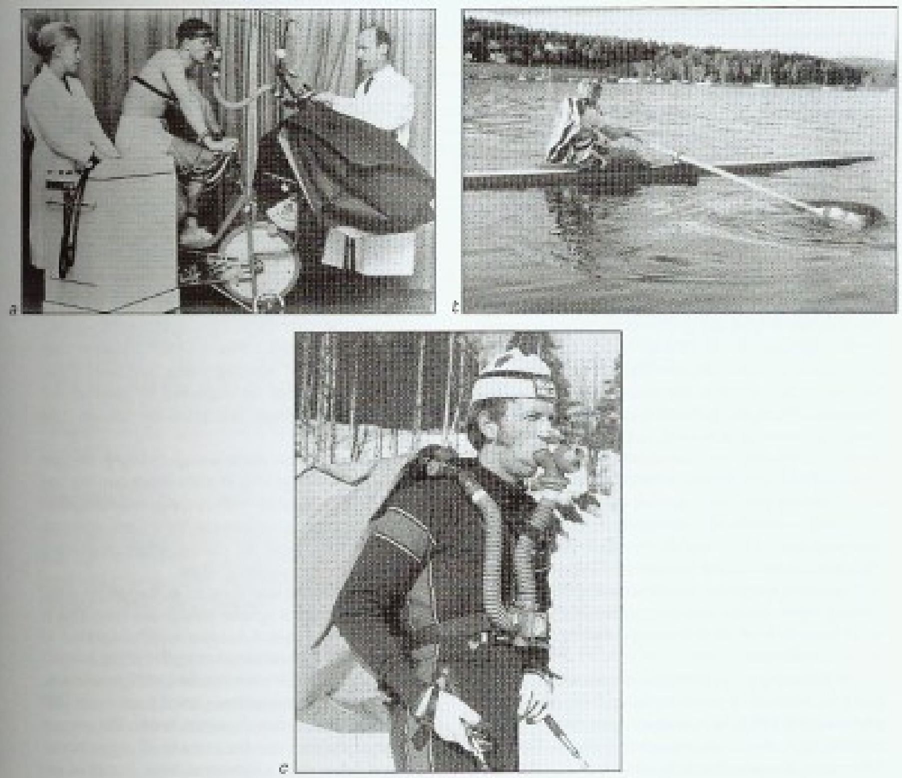


Figure 82 Application of the classic Douglas bag method for measuring aerobic energy output during different types of exercise. The skier shown in (c) carries a three-way stopcock and a stopwatch on his chest to record the time during which the expired air is collected in the Douglas bag. The stopwatch automatically starts and stops when the stopcock is turned.

Common procedures for indirect calorimetry

Determination of surface area. The surface area **of** the body can be determined by **Dubois formula**

$$S = W^{0.425} \times H^{0.725} \times 7.184 \times 10^{-3}$$

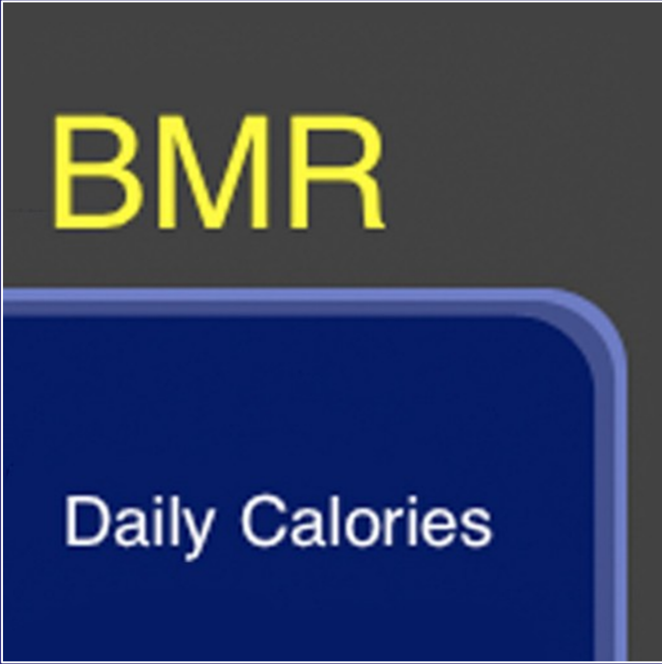
where **S, W and H** stand for surface area (in sq m), body weight (in Kg) and height (in cm) respectively. [In practice, the surface area is determined from the height and weight of the subject and referring the data to standard tables given in practical books.]

Basal metabolic rate

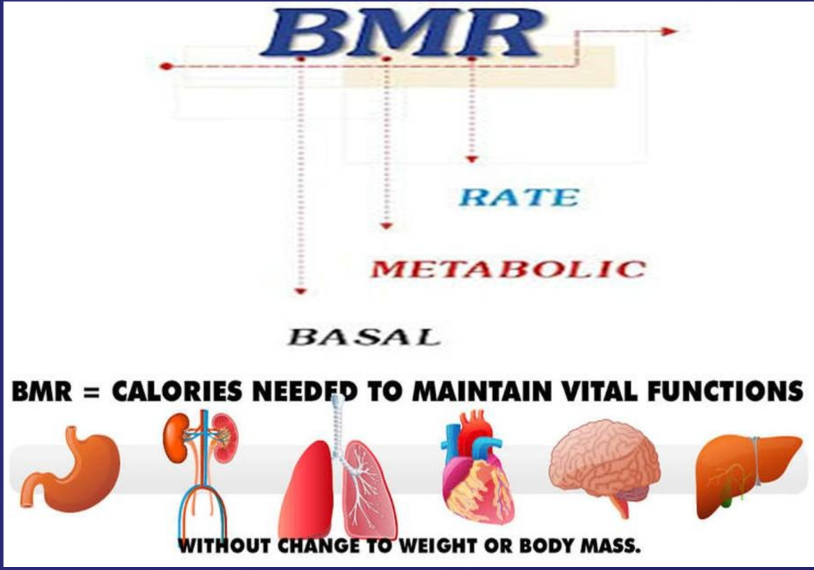
BASAL METABOLIC RATE (BMR)

Definition. It is the metabolic rate at basal conditions.

Basal condition is a condition when the subject is at complete mental and physical rest (but not sleeping) 12 to 14 hours after the last meal, at an ambient temperature of about 25°C and free from all illness.



Basal metabolic rate

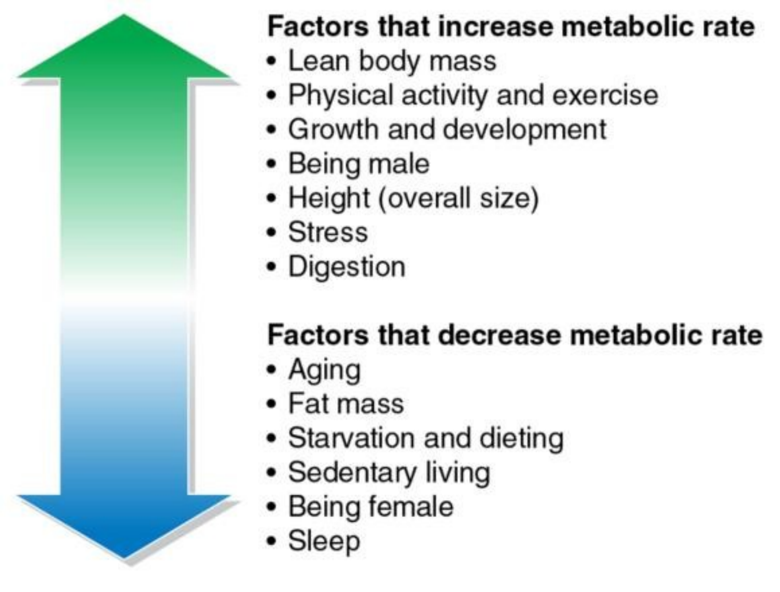


Normal values. Values are expressed as Kcal (or KJ) per square meter of body surface per hour.

In adults, BMR for *healthy males is 40 Kcal (about 168 KJ)/sq m/hr and in healthy females, it is 37 Kcal (155 KJ)/ sq m/hr.*

This means, that the total caloric expenditure in 24 hours, at *complete basal state* is, ***1,800 Kcal (7,500 KJ)* for males and *1400 Kcal (5859 KJ)* for female assuming the total body surface areas are 1.8 sq m and 1.6 sq m respectively**.

Basal metabolic rate



The values for old age and childhood have been given below.

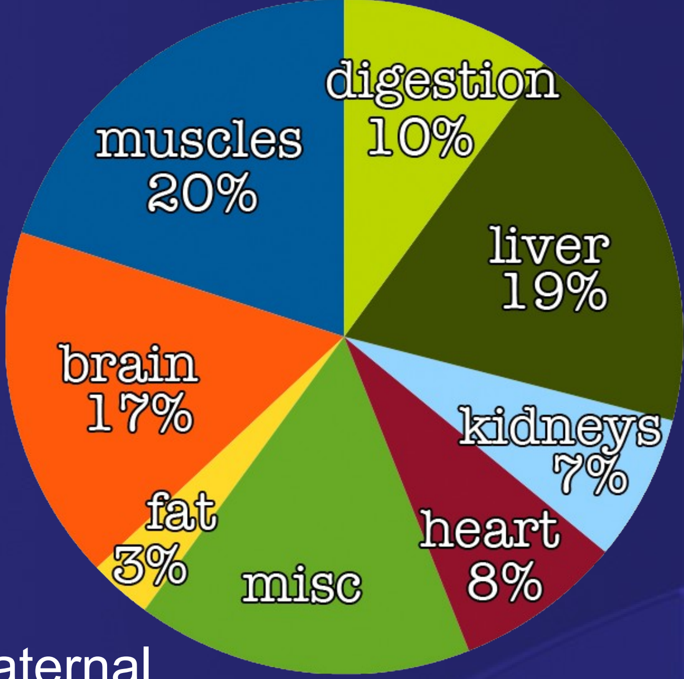
Factors influencing BMR value

Age. In childhood it is high. In old age (after 60) the BMR tends to fall.

Sex. Throughout life, BMR is somewhat lower in the females. But if the BMR values be taken for fat free *lean* body tissue mass, the difference due to sex disappears.

Food. If the food contains excess protein, the BMR value rises. This is due to the *high specific dynamic action* of the food (mostly protein).

Basal metabolic rate

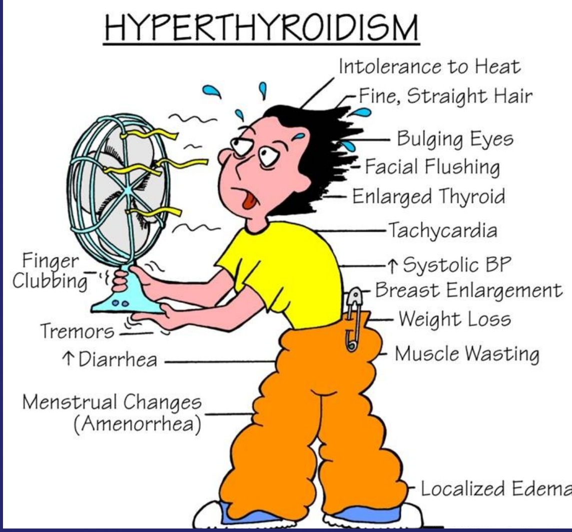


Climate. Colder the climate higher is the BMR and vice versa.

Pregnancy. In later months of pregnancy, the BMR rises, because at this stage, the maternal BMR includes that of the fetus which is considerable.

In early stage of pregnancy also, there is some rise of BMR. This is perhaps due to HCG (human chorionic gonadotropin) which might have a TSH like action.

Basal metabolic rate

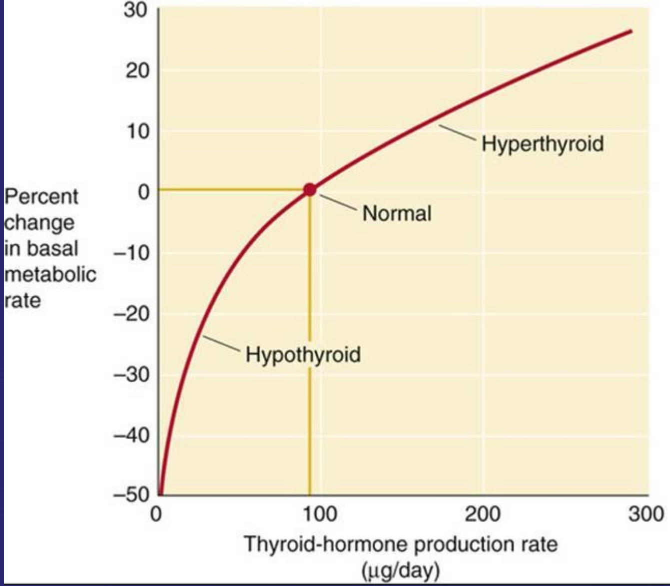


Endocrine factors. BMR is related to *thyroid activity.* In *thyrotoxicosis* BMR rises whereas in *hypothyroidism* the BMR falls. Prior to the advent of modern methods like radio immunoassay (RIA), *thyroid disorders used to be diagnosed by BMR estimation.*

A value of BMR over 40 % than normal (i.e., more than + 40 %) or less than —20 % (i.e., less than – 20 %) used to be usually regarded as diagnostic of thyrotoxicosis and myxedema respectively.

BMR and Na^+ K^+ ATPase. Ultimately speaking a major part of our BMR is due to the action of this enzyme.

Basal metabolic rate



Applied Physiology

BMR estimation used to be a diagnostic tool for disorders of thyroid. In less developed countries where RIA facilities are not freely available, this may be still of considerable help.

However, *routine* estimation of BMR, for all practical purposes, in clinical medicine, is obsolete.

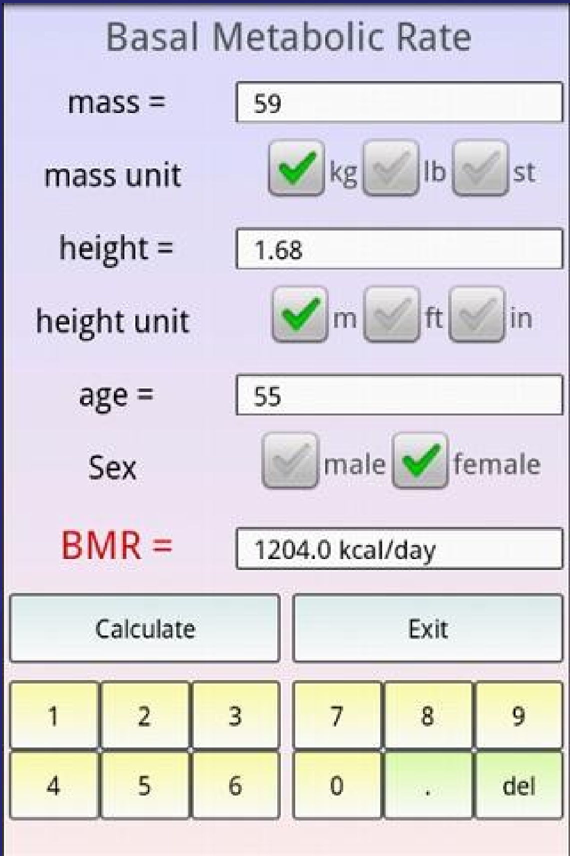
BMR gives an idea about the food requirement of the subject. Thus for subjects, lying in bed, the attending physician can formulate his diet.

Summary & highlights

In our body 1 gm of carbohydrate, protein and fat yields, 4, 4 & 9 Kcal respectively.

BMR is the metabolic rate at basal conditions (12 to 14 hrs after meal, complete mental and physical rest, environmental temperature about 25°C, freedom from disease) and its value is 40 Kcal/sq m/hr (male) or 37 Kcal/sq m/hr (female).

Usually the surface area of an 'average' man is around 1.8 sq m and an average woman is 1.6 sq m.

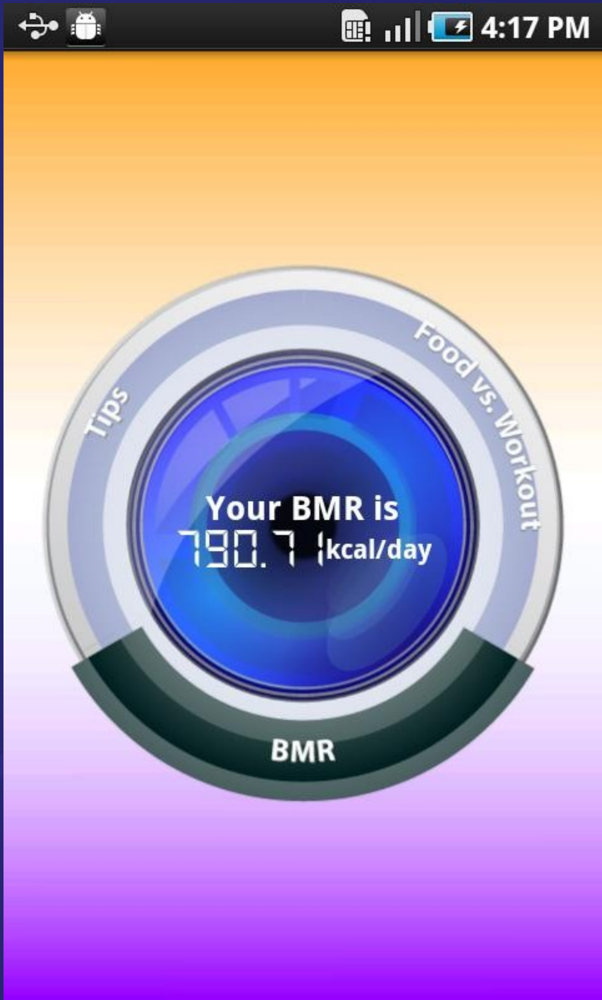


Summary & highlights

In Benedict Roth method, the patient is so prepared that only oxygen consumption for six minutes is all that is to be determined.

Moreover, the instrument is so designed that rise of the writer through 1 mm is equivalent to 1 Kcal per hr.

In Douglas bag, the RQ and the O_2 consumption values are to be determined.



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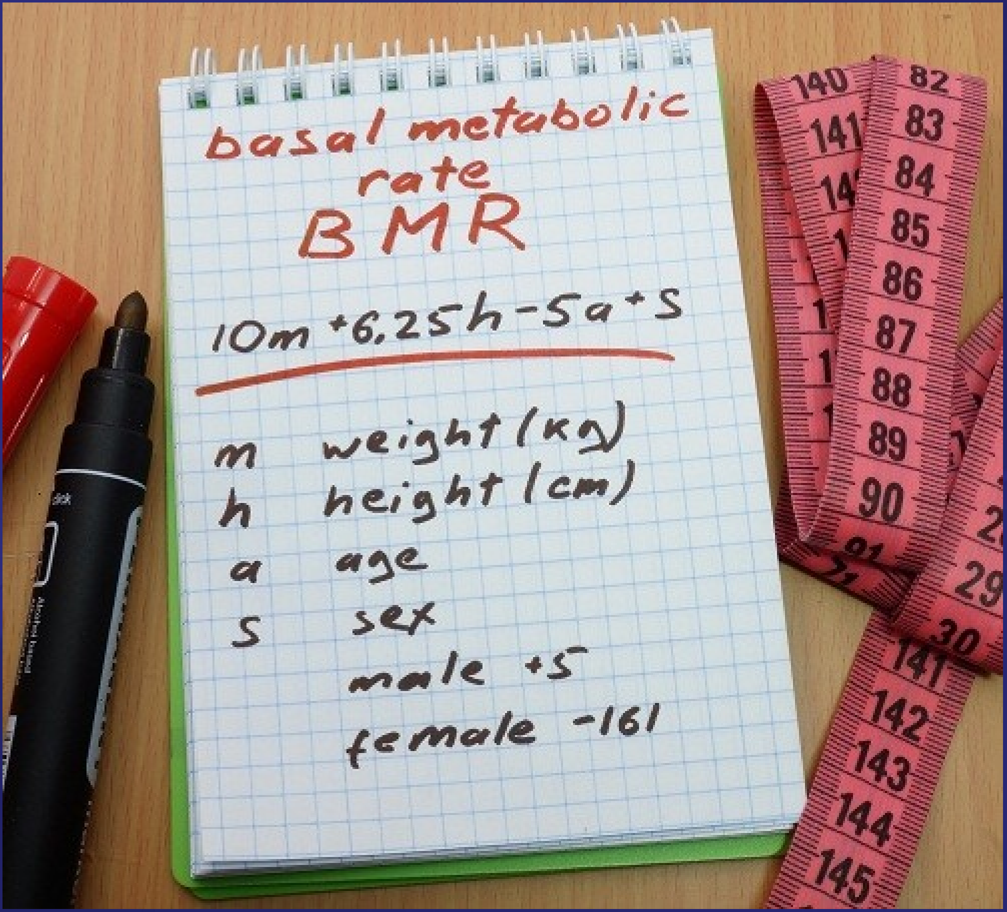


Volgograd State Medical University
Department of Normal Physiology

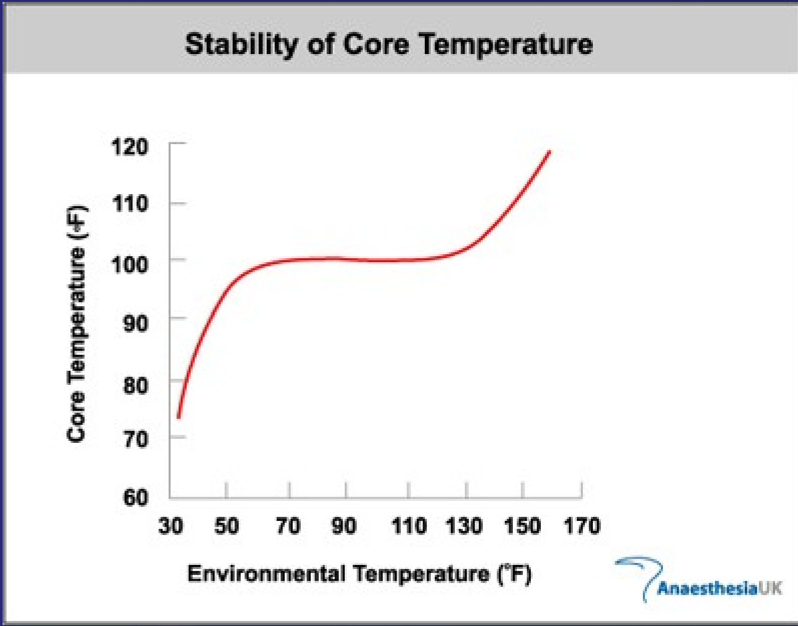
Physiology Of Thermoregulation

Normal body temperature

The temperature of the deep tissues of the body – the "core" temperature – remains almost exactly constant, within ±0.6°C, day in and day out except when a person develops a febrile illness. The skin temperature, in contrast to the core temperature, rises and falls with the temperature of the surroundings.

Normal body temperature

When the rate of heat production in the body is greater than the rate at which heat is being lost, heat builds up in the body and the body temperature rises. Conversely, when heat loss is greater, both the body heat and body temperature decrease.



Human Core & Environmental Temperature

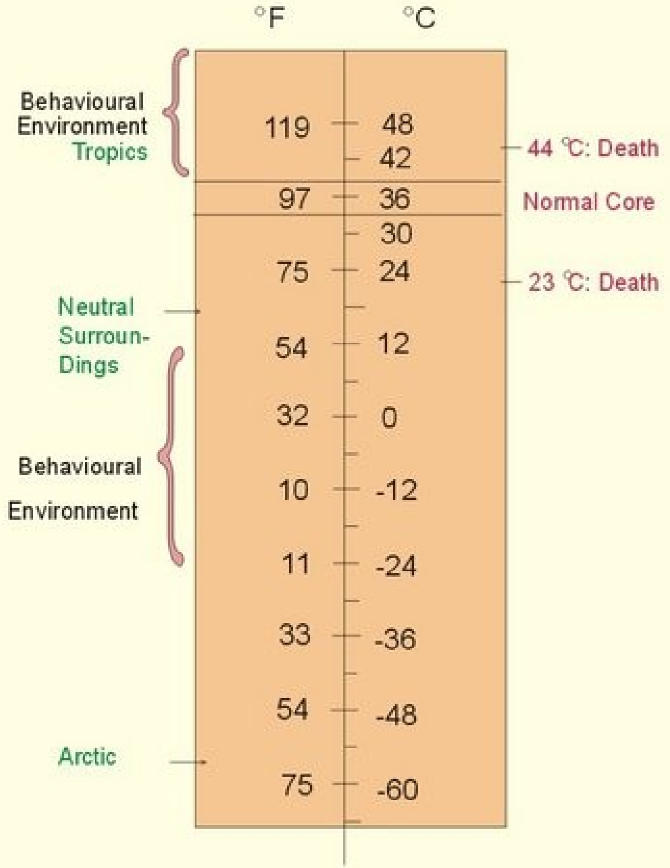


Fig. 21-7

Kmc

Heat Production

The most important factors that determine the rate of heat production are:

1) **basal rate of metabolism** of all the cells of the body;
2) **extra rate of metabolism caused by muscle activity**, including muscle contractions caused by shivering;
3) **extra metabolism caused by the effect of thyroxine** (and to a less extent other hormones, such as growth hormone and testosterone) on the cells;

Heat Production

4) **extra metabolism caused by the effect of epinephrine, norepinephrine and sympathetic stimulation on the cells**;

5) **extra metabolism caused by increased chemical activity** in the cells themselves, especially when the cell temperature increases.

Heat Loss

Most of the heat produced in the body is generated in the deep organs, especially in the liver, brain, heart, and the skeletal muscles during exercise. Then this heat is transferred from the deeper organs and tissues to the skin, where it is lost to the air and other surroundings.

Heat Loss

Therefore, the rate at which heat is lost is determined almost entirely by two factors:

1) how rapidly heat can be conducted from where it is produced in the body core to the skin and;

2) how rapidly heat can then be transferred from the skin to the surroundings.

Insular System of the Body

The skin, the subcutaneous tissues, and especially the fat of the subcutaneous tissues are a heat insulator for the body. The fat is important because it conducts heat only one third as readily as other tissues.

When no blood is flowing from the heated internal organs to the skin, the insulating properties of the normal male body are about equal to three quarters the insulating properties of a usual suit of clothes. In women, this insulation is still better.

Insular System of the Body

The insulation beneath the skin is an effective means of maintaining normal internal core temperature, even though it allows the temperature of the skin to approach the temperature of the surroundings.

The system of heat transfer

Blood flow to the skin from the body core provides heat transfer. Blood vessels penetrate the fatty subcutaneous insulator tissues and are distributed profusely immediately beneath the skin. Especially important is a continuous venous plexus that is supplied by inflow of blood from the skin capillaries. In the most exposed areas of the body - the hands, feet, and ears - blood is also supplied to the plexus directly from the small arteries through highly muscular arteriovenous anastomoses.

The system of heat transfer

The rate of blood flow into the venous plexus can vary tremendously - from barely above zero to as great as 30 per cent of the total cardiac output. A high rate of blood flow causes heat to be conducted from the core of the body to the skin with great efficiency, whereas reduction in the rate of blood flow decreases the heat conduction from the core.

The system of heat transfer

Therefore, the skin is an effective controlled "heat radiator" system – and the flow of blood to the skin is a most effective mechanism of heat transfer from the body core to the skin.

The system of heat transfer

Heat conduction to the skin by the blood is controlled by the degree of vasoconstriction of the arterioles and artenovenous anastomoses that supply blood to the venous plexus of the skin. This vasoconstriction in turn is controlled almost entirely by the sympathetic nervous system in response to changes in the body core temperature and changes in the environmental temperature.

Basic principles of the heat lost from the skin surface

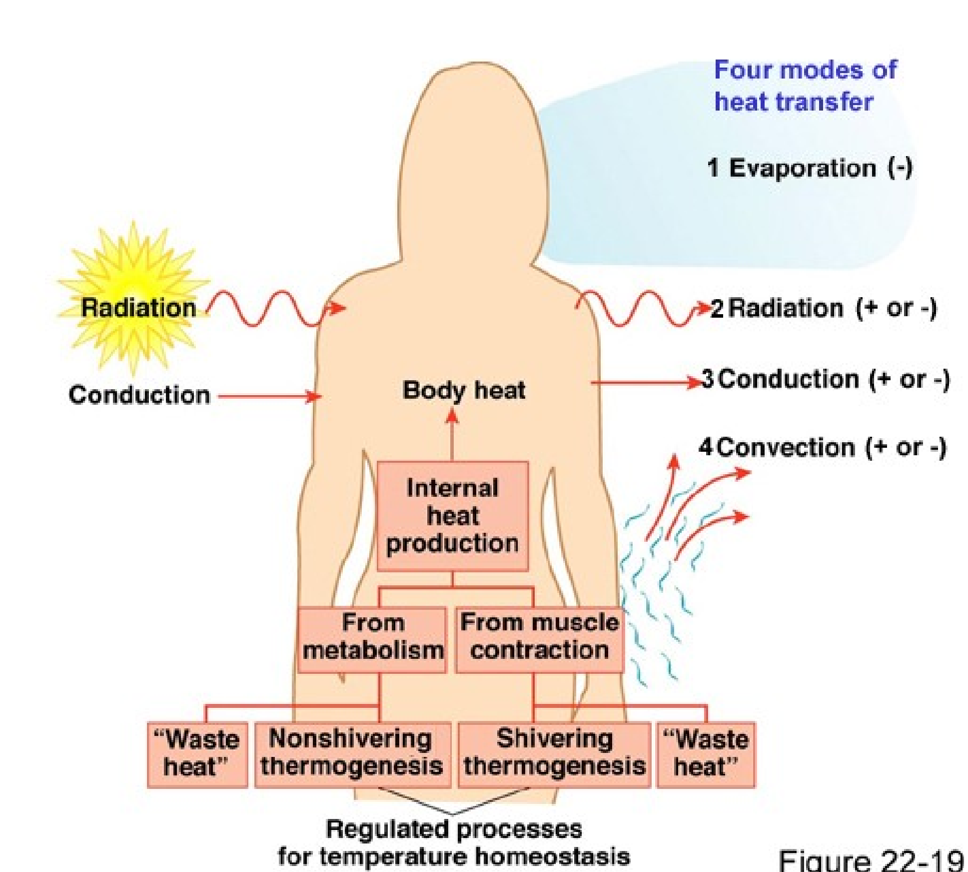


Figure 22-19

Basic principles of the heat lost from the skin surface

The main ways by which heat is lost from the skin to the surroundings are include radiation, conduction, convection and evaporation.

RADIATION. A nude person in a room at normal room temperature loses about 60% of the total heat loss - about 15% by radiation.

Loss of heat by radiation means loss in the form of infrared heat rays. Most infrared heat rays that radiate from the body have wavelengths of 5 to 20 micrometers, 10 to 30 times the wavelengths of light rays.

Basic principles of the heat lost from the skin surface

All objects that are not at absolute zero temperature radiate such rays. The human body radiates heat rays in all directions. Heat rays are also being radiated from the walls and other objects toward the body. If the temperature of the body is greater than the temperature of the surroundings, a greater quantity of heat is radiated from the body than is radiated to the body.

Basic principles of the heat lost from the skin surface

CONDUCTION. Only minute quantities of heat are normally lost from the body by direct conduction from the surface of the body to other objects, such as a chair or a bed. On the other hand, loss of heat by conduction to air does represent a sizable proportion of the body's heat loss (about 15 per cent) even under normal conditions. The conduction of heat from the body to the air is self-limited unless the heated air moves away from the skin, so that new, unheated air is continually brought in contact with the skin, a phenomenon called air convection.

Basic principles of the heat lost from the skin surface

CONVECTION. The removal of heat from the body by convection air currents is commonly called heat loss by convection. Actually, the heat must first be conducted to the air and then carried away by the convection currents. Therefore, a nude person seated in a comfortable room without gross air movement still loses about 15 per cent of his or her heat by conduction to the air and then by air convection away from the body.

Basic principles of the heat lost from the skin surface

When the body is exposed to wind, the layer of air immediately adjacent to the skin is replaced by new air much more rapidly than normally and heat loss by convection increases accordingly. Water has a specific heat several thousand times as great as that of air, so that each unit portion of water adjacent to the skin can absorb far greater quantities of heat than can air.

Basic principles of the heat lost from the skin surface

Also, the conductivity of water for heat is marked in comparison with that of air. Therefore, the rate of heat loss to water at moderately low temperatures is many times as great as the rate of heat loss to air of the same temperature.

Basic principles of the heat lost from the skin surface

EVAPORATION. When water evaporates from the body surface, 0.58 Calorie (kilocalorie) of heat is lost for each gram of water that evaporates. Even when a person is not sweating, water still evaporates insensibly from the skin and lungs at a rate of about 450 to 600 ml/day. This causes continual heat loss at a rate of 12 to 16 Calories per hour.

Basic principles of the heat lost from the skin surface

This insensible evaporation through the skin and lungs cannot be controlled for purposes of temperature regulation because it results from continual diffusion of water molecules through the skin and respiratory surfaces. However, loss of heat by evaporation of sweat can be controlled by regulating the rate of sweating.

Basic principles of the heat lost from the skin surface

As long as skin temperature is greater than the temperature of the surroundings, heat can be lost by radiation and conduction. But when the temperature of the surroundings is greater than that of the skin, instead of losing heat, the body gains heat by both radiation and conduction. Under these conditions, the only means by which the body can rid itself of heat is evaporation.

Basic principles of the heat lost from the skin surface

Therefore, anything that prevents adequate evaporation when the surrounding temperatures are higher than skin temperature will cause the body temperature to rise. This occurs occasionally in human being, who are born with congenital absence of sweat glands. These people can stand cold temperatures as well as can normal people, but they are likely to die of heatstroke in tropical zones because without the evaporative refrigeration system, they cannot prevent a rise in body temperature when the air temperature is above that of the body.

Heat Transfer

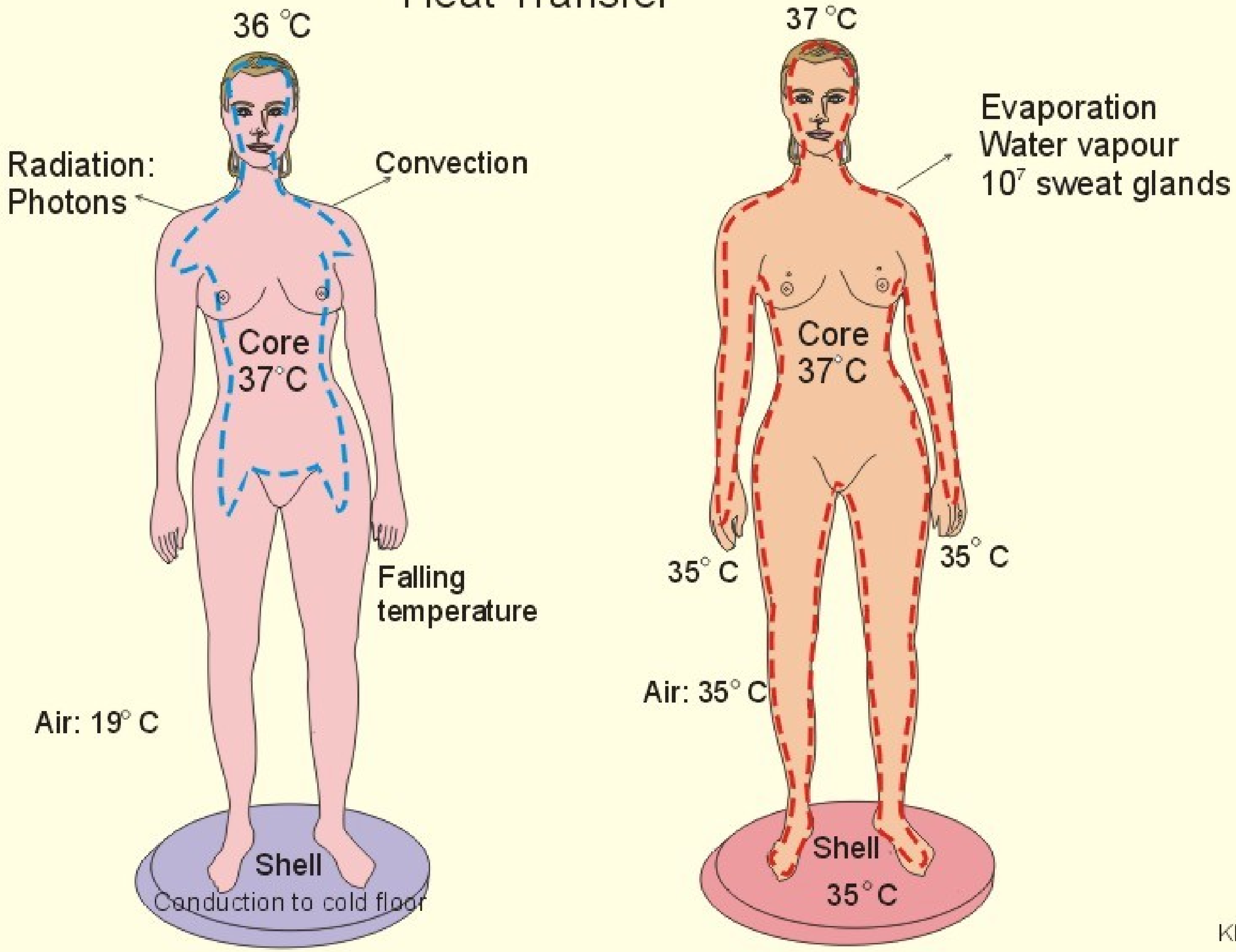


Fig. 21-1

KMc

THE EFFECT OF CLOTHING ON CONDUCTIVE HEAT LOSS

Clothing entraps air next to the skin and in the weave of the cloth, thereby increasing the thickness of the so-called private zone of air adjacent to the skin and also decreasing the flow of convection air currents. Consequently, the rate of heat loss from the body by conduction and convection is greatly depressed. A usual suit of clothes decreases the rate of heat loss to about half that from a nude body, whereas arctic-type clothing can decrease this heat loss to as little as one sixth.

REGULATION OF THE SWEATING

Stimulation of the anterior hypothalamus-preoptic area either electrically or by excess heat causes sweating. The impulses from this area that cause sweating are transmitted in the autonomic pathways to the spinal cord and then through the sympathetic outflow to the skin everywhere in the body.

REGULATION OF THE SWEATING

The sweat glands are innervated by sympathetic cholinergic nerve fibers (i.e. are stimulated by acetylcholine). These glands can also be stimulated by epinephrine or norepinephrine circulating in the blood, even though the glands themselves do not have adrenergic innervation. This is important during exercise, when these hormones are secreted by the adrenal medullae and the body needs to lose the extra heat produced by the active muscles.

REGULATION OF THE SWEATING

Mechanism of sweat secretion. The sweat gland has a tubular structure consisting of two parts:
1) a deep subdermal coiled portion that secretes the sweat and
2) a duct portion that passes outward through the dermis and epidermis of the skin. As is true of so many other glands, the secretory portion of the sweat gland secretes a fluid called the primary secretion or precursor secretion; then the concentrations of the constituents in the fluid are modified as the fluid flows through the duct.

REGULATION OF THE SWEATING

The precursor secretion is an active secretory product of the epithelial cells lining the coiled portion of the sweat gland. Cholinergic sympathetic nerve fibers ending on or near the glandular cells elicit the secretion.

Human Thermocontrol

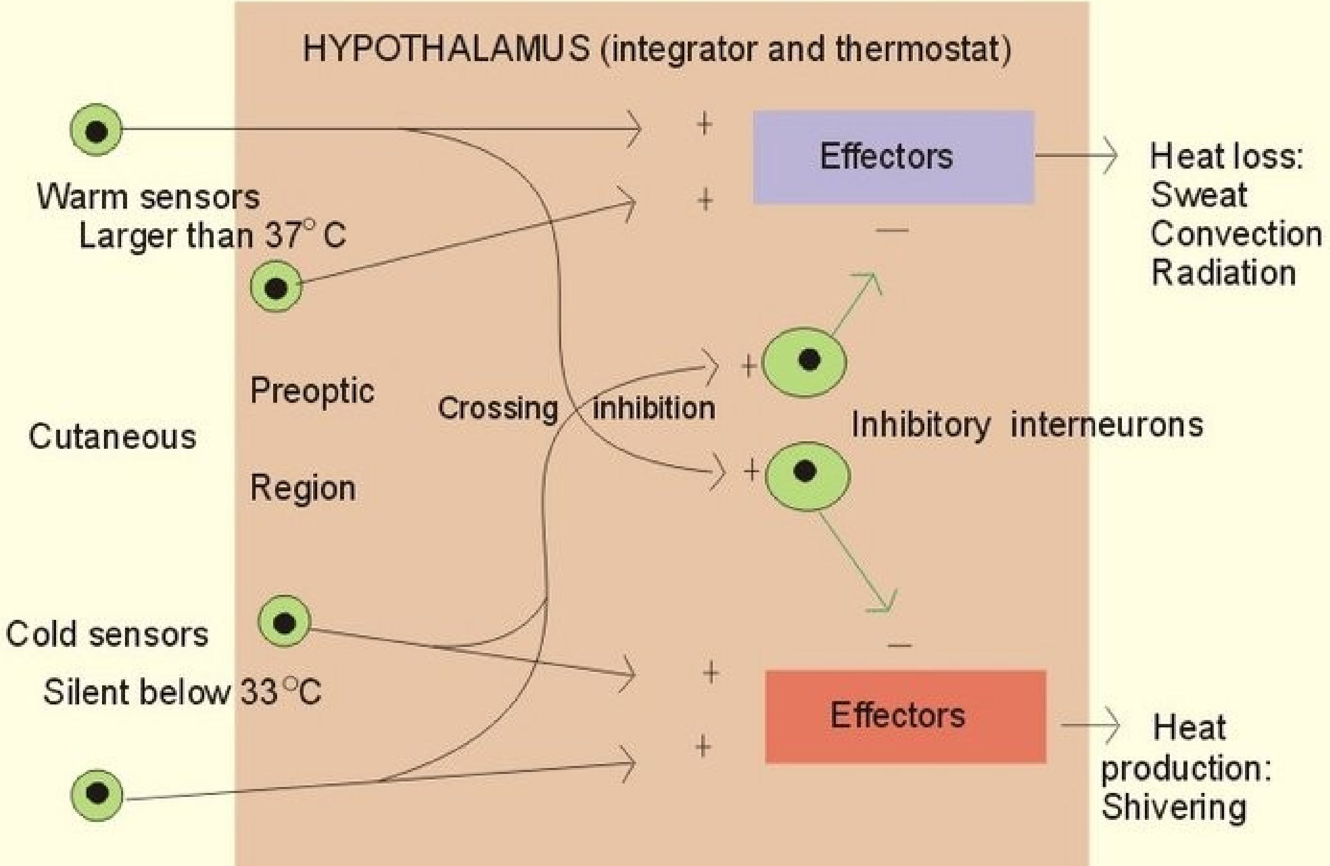


Fig. 21-12

KMc

Regulation of body temperature by preoptic and anterior hypothalamic nuclei

The temperature of the body is regulated almost entirely by nervous feedback mechanisms, and almost all these operate through temperature-regulating centers located in the hypothalamus. For these feedback mechanisms to operate, there must also exist temperature detectors to determine when the body temperature becomes either too hot or too cold.

Regulation of body temperature by preoptic and anterior hypothalamic nuclei

The principal area in the brain in which body temperature is controlled consists of the preoptic and anterior hypothalamic nuclei of the hypothalamus. This area has been found to contain large numbers of heat-sensitive neurons as well as about one third as many cold-sensitive neurons. These neurons are believed to function as temperature sensors for controlling body temperature.

Regulation of body temperature by preoptic and anterior hypothalamic nuclei

The heat-sensitive neurons increase their firing rate as the temperature rises, 2- to 10-fold with an increase in body temperature of 10°C. Cold-sensitive neurons, by contrast, increase their firing rate when the body temperature falls.

Regulation of body temperature by preoptic and anterior hypothalamic nuclei

When the preoptic area is heated, the skin everywhere over the body immediately breaks out into a profuse sweat while at the same time the skin blood vessels over the entire body become greatly vasodilated. Thus, this is an immediate reaction to cause the body to lose heat, thereby helping to return the body temperature toward the normal level. In addition, excess body heat production is inhibited. Therefore, the preoptic area of the hypothalamus has the capability of serving as a thermostatic body temperature control center.

Somatomotor & Sympathetic Nervous System

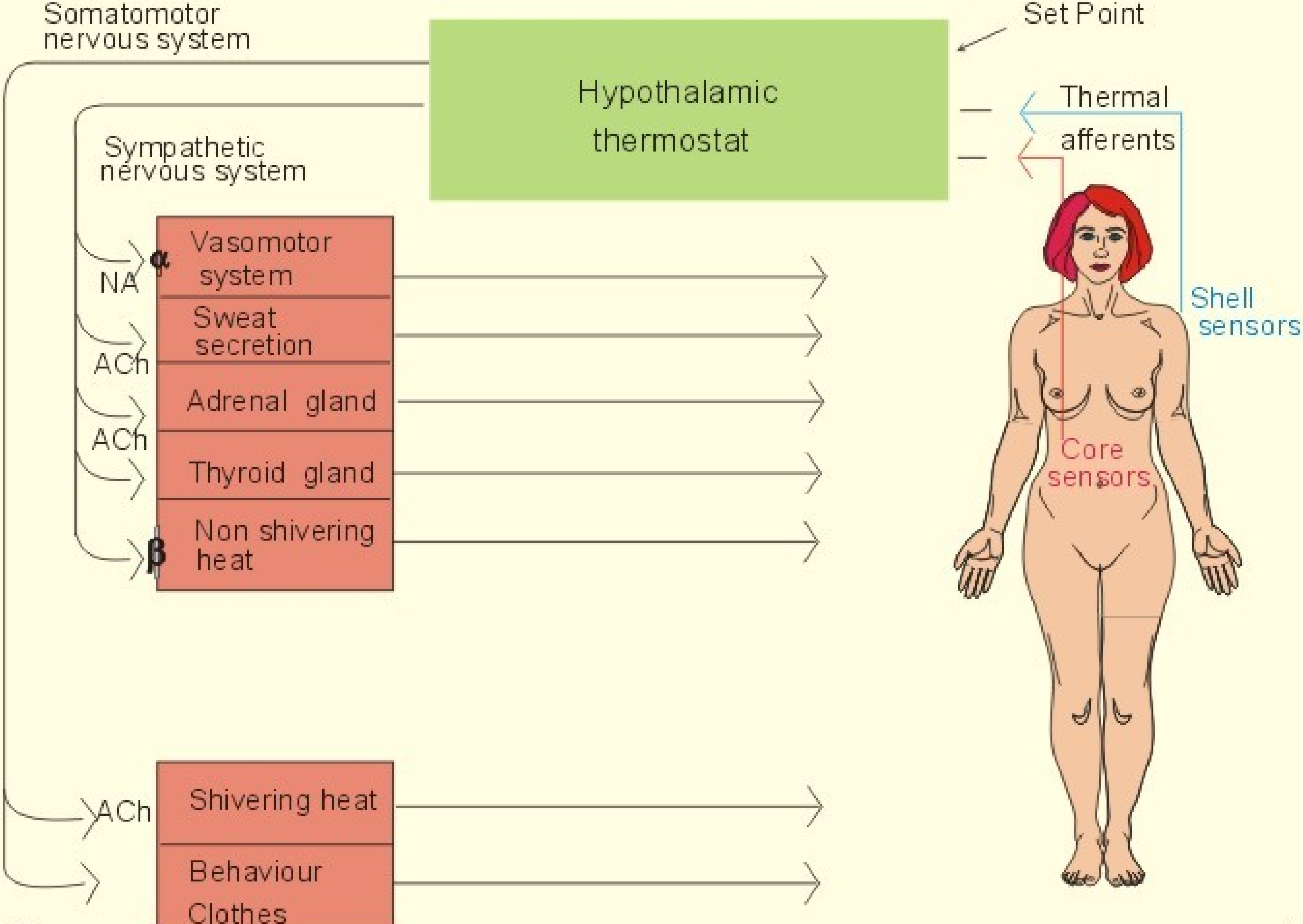


Fig. 21-14

KMc

Detection of temperature by receptors in the skin and deep body tissues

Although the signals generated by the temperature receptors of the hypothalamus are extremely powerful in controlling body temperature, receptors in other parts of the body also play important roles in temperature regulation. This is especially true of temperature receptors in the skin and in a few specific deep tissues of the body. The skin has both cold and warmth receptors.

Detection of temperature by receptors in the skin and deep body tissues

There are far more cold receptors than warmth receptors, in fact, 10 times as many in many parts of the skin. Therefore, peripheral detection of temperature mainly concerns detecting cool and cold instead of warm temperatures.

Detection of temperature by receptors in the skin and deep body tissues

When the skin is chilled over the entire body, immediate reflex effects are invoked to increase the temperature of the body in several ways:

1) by providing a strong stimulus to cause shivering, with resultant increase in the rate of body heat production;

2) by inhibiting the process of sweating if this should be occurring;

3) by promoting skin vasoconstriction to diminish the transfer of body heat to the skin.

Heat and Cold Adaptation

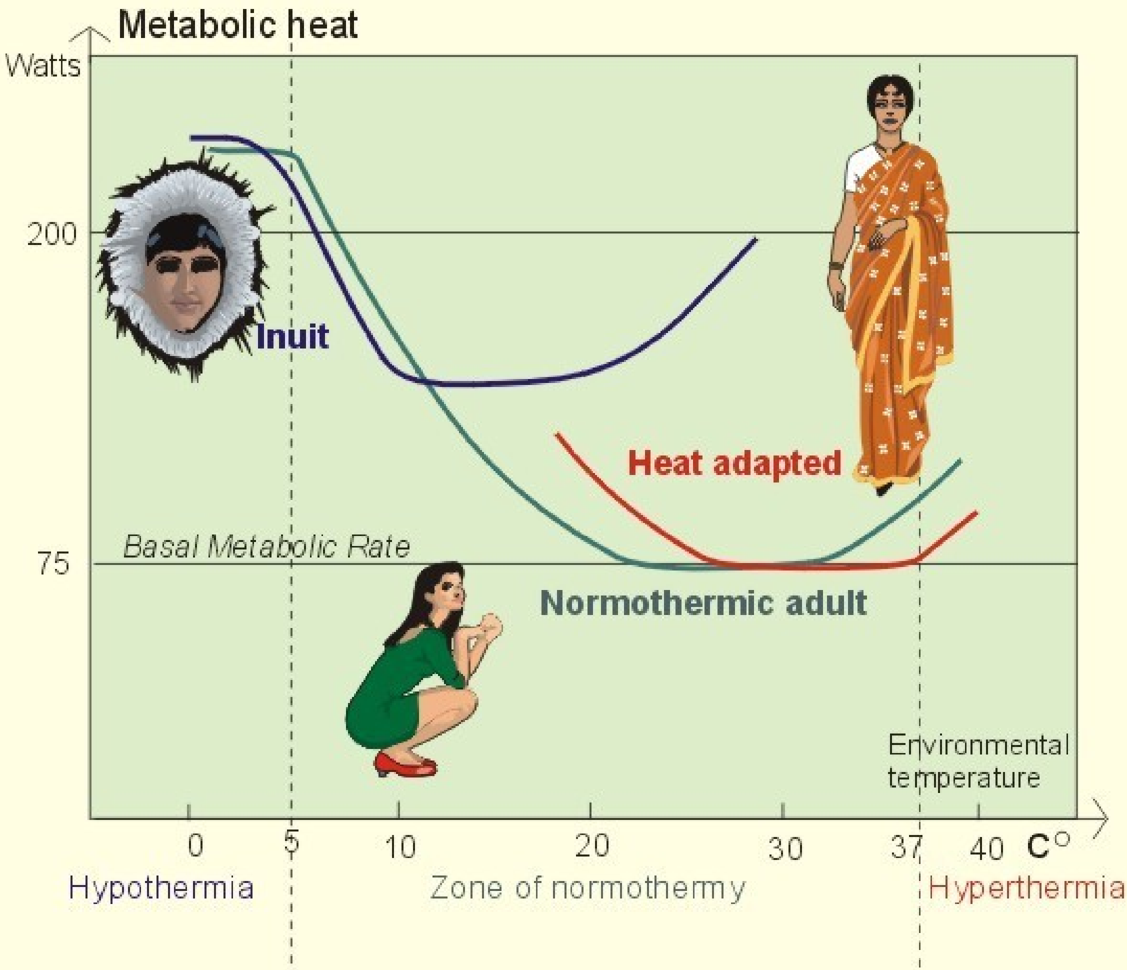


Fig. 21-15

KMc

TEMPERATURE-DECREASING MECHANISMS

The temperature control system uses three important mechanisms to reduce body heat when the body temperature becomes too great:

1. **Vasodilatation**. In almost all areas of the body, the skin blood vessels become intensely dilated. This is caused by inhibition of the sympathetic centers in the posterior hypothalamus that cause vasoconstriction. Full vasodilatation can increase the rate of heat transfer to the skin as much as eightfold.

TEMPERATURE-DECREASING MECHANISMS

2. **Sweating**. There is sharp increase in the rate of evaporative heat loss resulting from sweating, when the body core temperature rises above the critical temperature level of 37°C. An additional 1°C increase in body temperature causes enough sweating to remove 10 times the basal rate of body heat production.

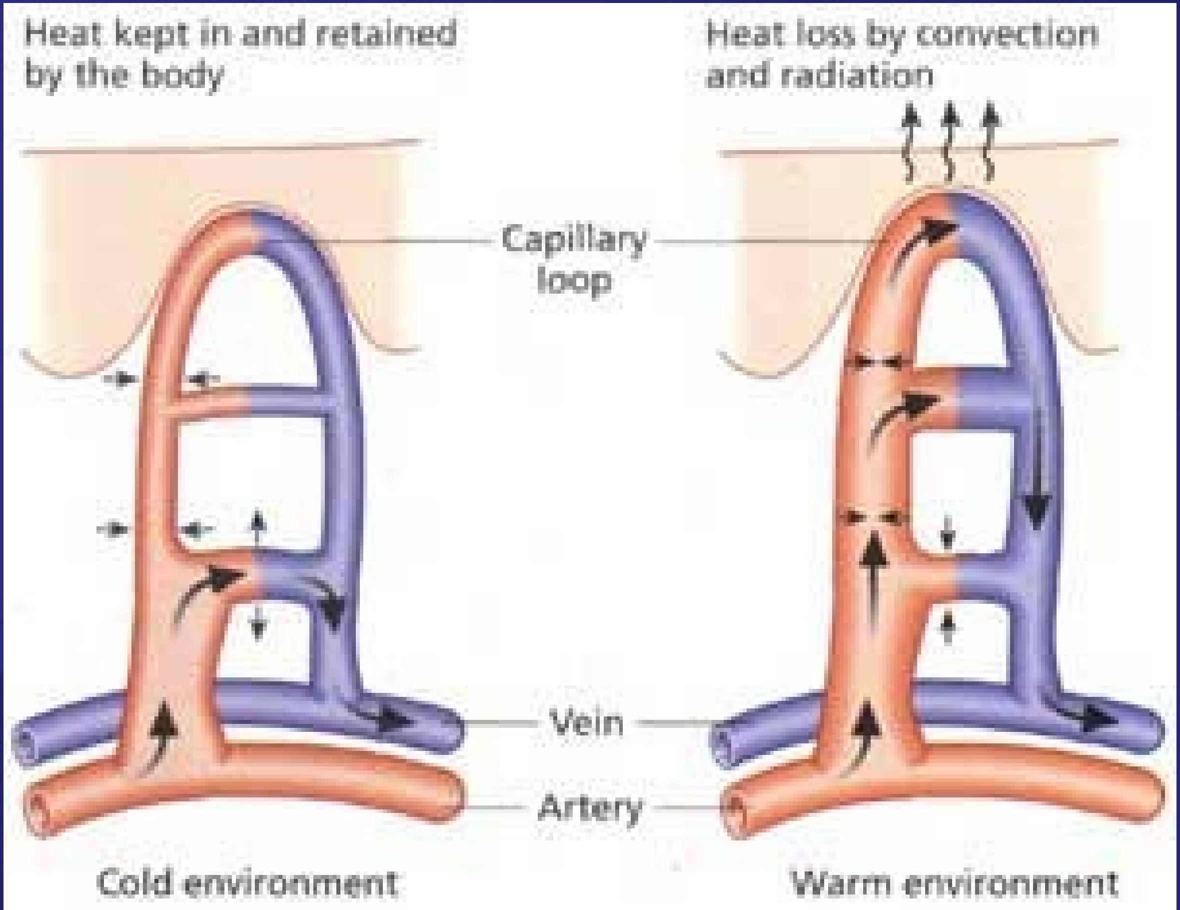
3. **Decrease in heat production**. The mechanisms that cause excess heat production, such as shivering and chemical thermogenesis, are strongly inhibited.

TEMPERATURE-INCREASING MECHANISMS

When the body is too cold, the temperature control system institutes exactly opposite procedures. They are:

1. **Skin vasoconstriction throughout the body**. This is caused by stimulation of the posterior hypothalamic sympathetic centers.

TEMPERATURE-INCREASING MECHANISMS



TEMPERATURE-INCREASING MECHANISMS

2. **Piloerection**. Piloerection means hairs "standing on end." Sympathetic stimulation causes the arrector pili muscles attached to the hair follicles to contract, which brings the hairs to an upright stance. This is not important in the human being, but in lower animals, upright projection of the hairs allows them to entrap a thick layer of "insulator air" next to the skin, so that the transfer of heat to the surroundings is greatly depressed.

TEMPERATURE-INCREASING MECHANISMS

3. **Increase in heat production**. Heat production by the metabolic systems is increased by promoting:

a) shivering;

b) sympathetic excitation of heat production;

c) thyroxine secretion.

Counter Current Exchange

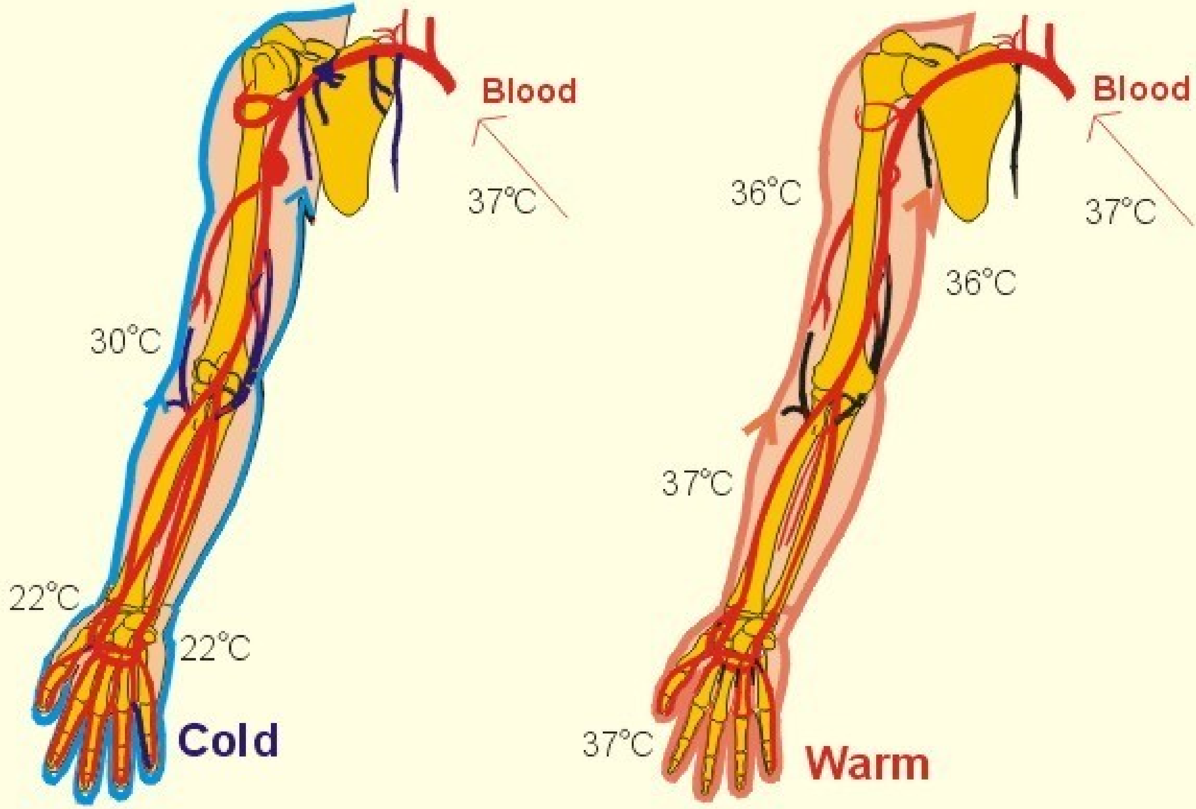


Fig. 21-5

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CONCEPT OF A "SET-POINT" FOR TEMPERATURE CONTROL

A critical body core temperature, at a level of almost exactly 37.1°C, changes occur in the rates of both heat loss and heat production. At temperatures above this level, the rate of heat loss is greater than that of heat production, so that the body temperature falls and reapproaches the 37.1°C level.

CONCEPT OF A "SET-POINT" FOR TEMPERATURE CONTROL

At temperatures below this level, the rate of heat production is greater than heat loss, so that now the body temperature rises and again approaches the 37.1°C level. This crucial temperature level is called the "set-point" of the temperature control mechanism. That is, all the temperature control mechanisms continually attempt to bring the body temperature back to this set-point level.

BEHAVIORAL CONTROL OF BODY TEMPERATURE

Aside from the subconscious mechanisms for body temperature control, the body has still another temperature-controlling mechanism that is even more potent. This is behavioral control of temperature. Whenever the internal body temperature becomes too high, signals from the brain temperature-controlling areas give the person a psychic sensation of being overheated. Conversely, whenever the body becomes too cold, signals from the skin and probably from the deep body receptors elicit the feeling of cold discomfort.

BEHAVIORAL CONTROL OF BODY TEMPERATURE

Therefore, the person makes appropriate environmental adjustments to reestablish comfort - such as moving into a heated room in freezing weather. This is a much more powerful system of body temperature control than most physiologists. Indeed, this is the only really effective mechanism for body heat control in severely cold environs.

Thanks for your attention!