Nutritional Assessment and Techniques

Topic 3

Module 3.3

Energy Balance

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Learning Objectives

- To know the components of energy expenditure in human beings;
- To understand the flow of energy in biosphere;
- To understand the concept of energy intake and expenditure in humans;
- To know the methods for measurement of energy expenditure;
- To be able to define how energy intake influences energy expenditure.

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6. Summary

Key Messages

- Energy demanding processes in humans are covered by energy from foodstuff or body energy reserve stores of carbohydrates, fat and protein;
- Total energy expenditure consists from resting energy expenditure (REE), diet induced energy expenditure (DEE), and energy spent for activity (AEE);
- Activity induced energy expenditure (AEE) - is the most variable part of energy expenditure;
- Indirect calorimetry is the most exact method to measure energy expenditure;
- REE is dependent mainly on fat-free body mass, but it is influences many factors such as disease or inflammatory activity, hormonal status or drug treatment;
- Positive energy balance is necessary condition for growth and development as well as for healing processes and muscle gain during rehabilitation;
- Positive energy balance is connected with development of obesity in an adult patient.

1. Definition of Energy Expenditure

All living organisms expend energy for their living activities. Probably the biggest part of energy on the Earth comes from the Sun. The energy, mainly UV light, is trapped in thilacoides of green plants and then transformed into chemical energy of carbohydrates, fats and proteins - photosynthesis.

Animals use energy from plants for their energy demanding processes. The energy is released from main energy substrates (carbohydrates, lipid and proteins) in the process of oxidation (mainly in mitochondria) and finally water, carbon dioxide and nitrogen compounds (urea) are released (Fig. 1).

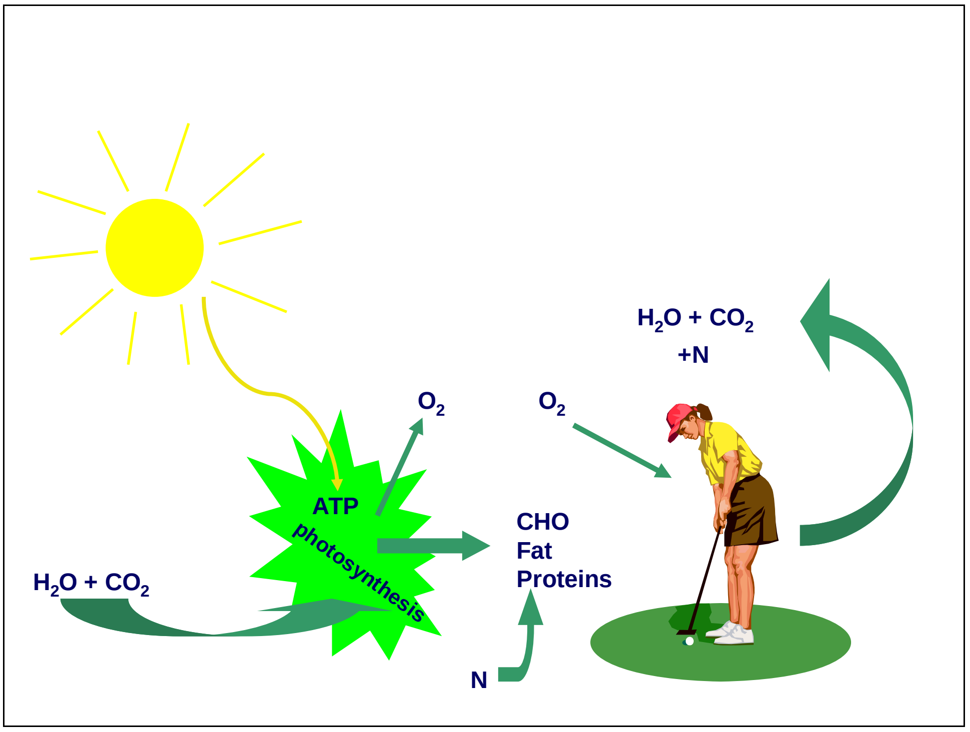


Figure 1 Flow of energy in biosphere

2. Components of Energy Expenditure

Total energy expenditure (TEE) consists of:
- resting energy expenditure (REE);
- diet induced energy expenditure (DEE);
- activity induced energy expenditure (AEE).

Resting energy expenditure (REE) – is energy which is required for indispensable homeostatic functions:
- breathing;
- heart function;
- basic GI function;
- intermediary metabolism (e.g. continual proteosynthesis and breakdown);
- maintaining of ion gradients across cell membranes;
- thermogenesis.

During resting conditions almost 60% of REE is spent by heart, kidneys, brain and liver, although these organs account for only 5% of body weight (1) (see Module 18.1).

REE is dependent mainly on fat-free body mass. However, REE can be influenced by factors like:
- Hormonal status
  – thyroid hormones increase REE

– catecholamine increase REE
– combined secretion of glucagon epinephrine and cortisol (2)

- Disease process
  – disease or trauma increase REE (15-100%)
- Adaptation processes
  – prolonged starvation decreases REE
- Drugs
  – sympathomimetic drugs increase REE
  – opiates, barbiturates, sedatives, ß-blockers(3) and muscular relaxants decrease REE
- Age of subject
  – REE decreases with age of the subject, due mainly to loss of lean mass.

Diet induced energy expenditure (DEE) – Energy expenditure increases after meal ingestion or during administration of artificial nutrition (parenteral or enteral) in comparison with energy expenditure during fasting conditions. DEE is assumed to be 10% of TEE; however, its value is dependent on the thermic effect of specific substrates and on the rapidity of substrate administration. Especially high rates of artificial nutrition administration can lead to substantial increases in energy expenditure. This can have negative effects (e.g. cardiovascular function in patients with heart failure).
The thermic effect of nutrition (TEN) is defined as an increase in energy expenditure above basal fasting level divided by the energy content of the food ingested. It is usually expressed as a percentage of energy intake:

TEN = (REE after a meal - basic REE)/EI x 100

TEN - thermic effect of nutrition
REE – resting energy expenditure
EI – energy intake

Thermic effect of nutrition is dependent mainly on food composition and metabolic pathways of particular substrates(4). It usually lasts 5-10 hours after feeding.

Thermic effect of major energy substrates:

- Carbohydrates – 4-6%
- Lipids – 2-3%
- Proteins – 20-40%

Activity induced energy expenditure (AEE) - is the most variable part of energy expenditure. It is dependent on physical activity during the day and also on physical capacity of special subject.

Examples of energy expenditure through physical exercise, in kcal/ minute, for subjects of 60 kg and 80 kg are shown in Table1:

Table 1 Examples of energy expenditure through physical exercise (5, 6)

Body weight	60 kg	80 kg
Mountain climbing	9.4	12.7
Swimming (breast stroke)	9.6	13.0
Ice Hockey	9.1	12.5
Handball	8.5	11.5
Horse back riding (galloping)	8.1	11.0
Basketball (practice)	8.1	11.0
Soccer	8.1	10.9
Golf	5.0	6.8
Tennis (recreational)	6.4	8.7
Weight training	5.0	6.8
Running: 3 min/km	17.1	23.1
5 min/km	12.5	16.5
7 min/km	8.0	10.9
Cycling: Racing	10.0	13.5
15 km/h	5.9	8.0
9 km/h	3.8	5.1

3. Methods for Measurement of Energy Expenditure

Energy for metabolic processes is produced by oxidation of energy substrates (carbohydrates, lipids and proteins). Oxygen is consumed and carbon dioxide, water and nitrogen compounds (mainly urea) together with heat are released during this process.

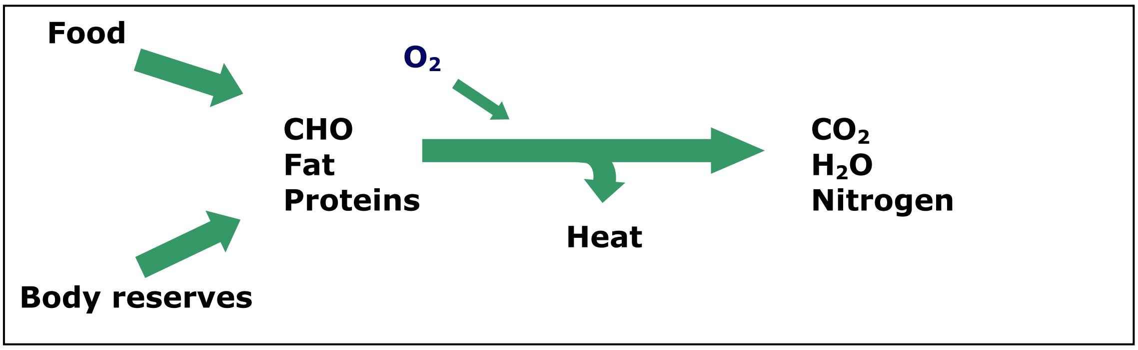


Figure 2 Oxidative processes in organism

3.1 Direct Calorimetry

Direct calorimetry is method based on measurement of the heat production. Heat released from the body can be measured in special devices (e.g. whole body compartment) such as whole body calorimeter:

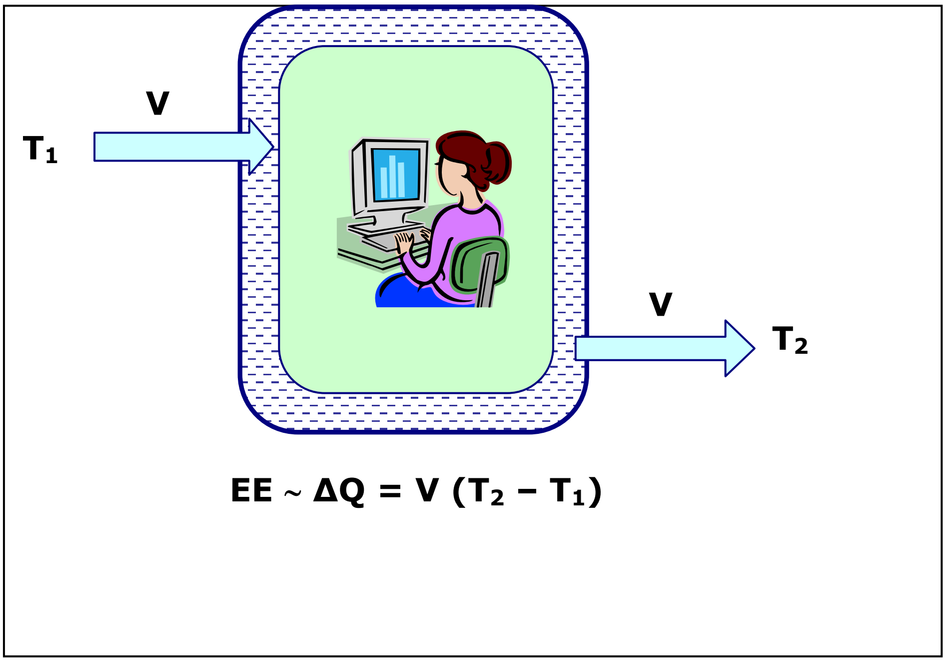
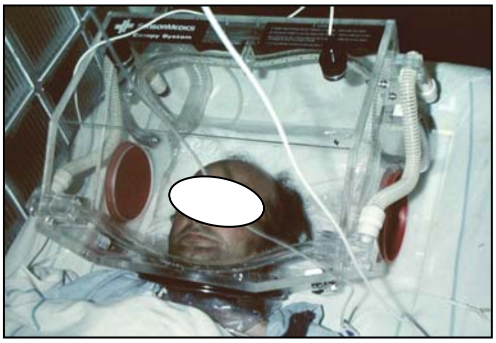


Figure 3 Principle of direct calorimetry

3.2 Indirect Calorimetry

In indirect calorimetry, energy production is based on knowledge of oxidative pathways of particular substrates. Energy expenditure is calculated from oxygen consumption and carbon dioxide production. Analyzers are connected to ventilated hood, mouthpiece or special whole body chambers.



Ventilated hood (canopy)

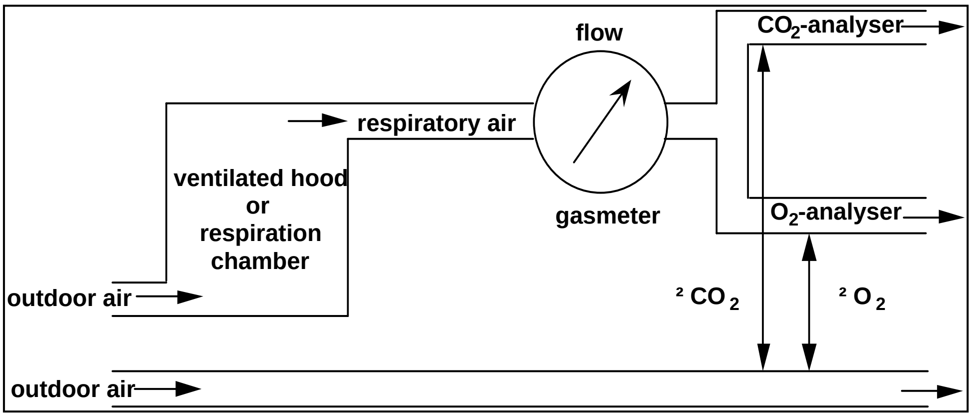


Figure 4 Principle of indirect calorimetry

Using indirect calorimetry we can measure:

- Oxygen consumption - VO_2
- Carbon dioxide production - VCO_2

The energy equivalent of VO_2 and VCO_2 is dependent on quantities of carbohydrate (C), protein (P) and fat (F) oxidized. Protein oxidation (g) is calculated from nitrogen lost in urine and subsequently the following formula can be used for calculation of energy expenditure (7):

$$EE\ (MJ) = 16.20\ VO_2 + 5.00\ VCO_2 - 0.95\ P$$

Energy expenditure can be also calculated either from oxygen consumption or carbon dioxide production.

Carbon dioxide production can be measured during long term period utilising **doubly labelled water method** (7, 8).
The doubly labelled water method is a method of indirect calorimetry. The principle of the method is that after a loading dose of water labelled with the stable isotopes of ^2H and ^{18}O, ^2H is eliminated as water, while ^{18}O is eliminated as both water and carbon dioxide. The difference between the two elimination rates is therefore a measure of carbon dioxide production. This method is used for long-term measurement of energy expenditure (usually 14 days).
Reverse Fick method is used to measure oxygen consumption in ICU. This method is based on measurement of cardiac output (thermodilution) and difference in oxygen concentration between arterial and mixed venous blood.

3.3 Estimation of Energy Expenditure

The most common approach to predict REE for an individual in clinical practice is to apply the Harris-Benedict equations.

- Male: REE = 66.5 + (13.8 x weight) + (5.0 x height) - (6.8 x age)
- Female: REE = 655.1 + (9.6 x weight) + (1.8 x height) - (4.7 x age)

These equations are based on sex, age, height and body mass, but do not take body composition into account.

4. The Influence of Disease on Energy Expenditure

Acute and chronic illnesses frequently increase energy expenditure (9). This is due to the inflammatory reaction, increase in body temperature, shivering or increase substrate cycling (futile cycles). The increase in body temperature leads to a rise in energy expenditure by 10-15% per degree C. The increase in energy expenditure during disease processes is also a result of increased sympathetic activity. Disease related increase in energy expenditure can be partially abolished by sympathetic blockade. The increase in energy expenditure after severe burns can be reduced by higher ambient temperature (thermo-neutral zone for burn patients is over 30°C, compared to 28°C for normal subjects). Also energy intake influences energy expenditure during disease, showing that diet induced thermogenesis also operates during illness (10). Thermo-neutral environment also decreases energy expenditure in ICU patients. The influence of critical illness on energy expenditure is described in module 18.1.

Note: our thermoneutral zone is the ambient temperature at which we need to expend no additional energy in order to maintain our body temperature i.e. the ambient temperature at which our basal metabolic expenditure is minimal.

5. Energy Intake and Energy Balance

In stable non-growing organism the energy intake should balance energy expenditure. However as energy expenditure is relatively continual process (with constant REE part and DEE and AEE bouts according to food intake and body activity) energy intake is intermittent process. Therefore, over short periods the energy balance of free living subject may vary from positive to negative. However energy intake should be equivalent to energy expenditure over the long-term.

The main energy substrates:

- **Carbohydrates** – 4 kcal/g (glucose, maltodextrin, starch, glycogen);
- **Lipids** – 9 kcal/g (fat, lipid emulsion);
- **Proteins** – 4 kcal/g (meat, casein, whey protein, plant proteins).

Positive energy balance is associated with:
- Synthesis of glycogen (liver and muscle glycogen);
- Fat storage in adipose tissue – fat is also partially stored in non-adipose tissue;
- Storage of proteins - physical activity is a necessary condition for protein synthesis in skeletal muscles in adult patients.

Negative energy balance is associated with:
- Breakdown and oxidation of glycogen stores – body glycogen stores are exhausted within 24 hours;
- Lipolysis, release and oxidation of fatty acids;
- Protein breakdown and oxidation – a degree of protein breakdown is dependent on concomitant inflammatory process.

In growing organism (neonates, infants and children) a large part of ingested energy is devoted to growth. The most positive energy balance is apparent in neonates. Their daily energy expenditure is 50-60 $kcal \cdot kg^{-1} \cdot day^{-1}$, whereas recommended energy intake is 110-120 $kcal \cdot kg^{-1} \cdot day^{-1}$. This difference is due to the energy cost of growth (accretion) - 30-40 $kcal \cdot kg^{-1} \cdot day^{-1}$(11).
Positive energy balance is also necessary for "catch up" growth after a period of malnutrition in children or during rehabilitation of adults or children from severe illness. Muscle proteosynthesis also requires positive energy balance.

In conclusion positive nitrogen balance is necessary for:
- growth;
- wound healing;
- rehabilitation after severe disease;
- exercise and muscle gain.

However, long term positive energy balance due to excess intake and/or too little exercise leads to gain of fat tissue, overweight and obesity.

6. Summary

All living organisms expend energy for their living activities. Animals use energy generated in plants in the form of carbohydrates, lipids and proteins. These substrates are oxidised to water, carbon dioxide and nitrogen, the quantity of oxygen consumed and carbon dioxide produced being equivalent to energy expenditure. Energy expenditure is usually measured using direct or (more frequently) indirect calorimetry. Indirect calorimetry is based on measurement of oxygen consumption or/and carbon dioxide production.

Total energy expenditure consists of resting energy expenditure (REE), diet induced energy expenditure (DEE) and activity induced energy expenditure (AEE). Loss of energy stores is the result of negative energy balance, the character of tissue substrate loss depending on conditions during which negative energy balance occurs. Pure starvation, at least in its early stages, leads mainly to loss of fat, whereas injury induces a proportionally greater loss of lean mass, Positive energy balance is necessary for growth, wound healing and muscle gain, but if large and prolonged, can lead to overweight and obesity.

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