Calorimetry

Calorimetry is the science, of measuring heat changes. It deals with physical, chemical and biological reactions while explaining the static systems using termophysics. It is based on the fact that all energy in human body is eventually changed into heat, so we can measure energy requirements of the body and determine the energy value of food using calorimetry units.

Units

The original unit of physiological caloric value of the nutrient content (burning heat) was calorie. Lately, however, it has been replaced with joules. Calorie (Cal) is defined as the amount of heat energy needed to raise the temperature of one gram of water by one degree Celsius from 14,5 up to 15,5°C. The exact temperature is placed in the definition due to the specific heat capacity, depending on the temperature and pressure. Calories represent a very small amount of energy, so we often use kilocalories (kcal) as a main unit. From the calorimetric equation $Q = mc\Delta T$ we can calculate the exact heat capacity of the water, which is 4185 J · kg-1 · K-1, 1 cal = 4.185 J (vv.: 1 J = 0.2389 cal)

Calorimetric measuring devices

According to the conditions they work in, we can divide calorimeters into two categories, adiabatic and isothermal.

- Adiabatic calorimetr - all heat is used to change the temperature of the calorimeter content which we can measure.
- Isothermal calorimetr - the temperature does not change throughout the whole experiment. The heat is converted to other form of energy, mostly chemical.

Measurement of energy in the food .

The energy is determined with the heat of combustion (the amount of heat released during the combustion of a specified amount of a substance - carbohydrates, fats, proteins), which is measured with the adiabatic bomb calorimeter.

Technical execution of calorimetry (theoretically)

First, we measure the usage of the oxygen and the production of the carbon dioxide. At the same time, we measure the portion of nitrogen in urine and stool. In hospital, these measurements are being made for 24 hours, but for the basic measurements, 30 minutes is far enough.

We use the measured readings of the released nitrogen for calculation of the amount of oxygen that was used for oxidation of proteins. (xO2* 5,92) and the amount of carbon dioxide that was released (xCO2* 4,75). The remaining amount of the measured oxygen (that was used) and carbon dioxide (that was released) is left for the oxidation of carbohydrates and fats.

We calculate the non-proteinous RQ in another phase, with the help of formula $RQ = VCO_2 / VO_2$. There is always one table value equivalent to the amount of carbohydrates and fats. Then you can calculate the whole amount of carbohydrates and fats by multiplying the table value and the amount of oxygen that was needed for the oxidation of the carbohydrates and the fats.

At the same time, we can calculate the amount of the proteins that were metabolised by using the amount of the released nitrogen. If we take the amount of every nitrogen substratum and also its physiological caloric value, we get the final amount of heat that was released when oxidating the nutrients.

Technical execution of an indirect calorimetry (practically)

In real life, automatic calorimetric devices are being used. The device is calculating the respiratory quotient. Based on the quotient, it calculates the actual metabollic need of a patient and the amount of utilised nutrients (in percents or in grams per day). After putting in the amount of nitrogen in patient's urine and basic antropometric indicators, the device calculates the patient's body surface and then calculates basic metabollic needs. Then, it gives us e.g. entry about the difference between the patient's BMI (Body Mass Index) and the actual metabolical need. The tests can be ran for example with a face mask or a with the accessories chosen to fit the patient's state and abilities.

Utilisation

By using this method, different types of diets or the amount and the intensity of training sessions can be set. Furthermore, this method offers wide range of options considering the clinical practice. It can be used for evaluation, diagnosis and monitoring of treatments. It allows to shape one's diet individually, so it prevents malnutrition or overfeeding. Usually, the patients get 110% of the calculated AEE (actual energetic need of the patient per day).

Normal metabollic needs: carbohydrates 50%, proteins 15%, fats 35%

Bigger amount of the consumption of proteins indicates a patological state.

·> 25% proteins → catabolism

·> 30% proteins → "catabolical" debacl

If the supplies of nitrogen are lowering in the human's body, the patient is in danger of the so-called „nitrogen death“. In conclusion, the patient looses muscle. Gradually, the amount of visceral proteins and transport proteins can lower and the immunity system is breaking down. Wound-healing is also worsening. In addition, the function of heart or hepar can change and be damaged.

Adiabatic bomb calorimetr

The sample is placed in a hermetically sealed pressure vessel, called a *calorimetric bomb* that is put into a bigger container filled with water, and connected to ignition wires. Subsequently, the measured substance is electrically ignited and burned. The water is heated and the additional mixing tool distributes heat evenly in the area. The purpose of the study is to determine the temperature elevation of the water, respectively the value of the heat of combustion of the sample. The name comes from the ability of the calorimetr to withstand high pressures, while having constant volume.

In the human body, energy from food is stored as chemical energy (most often as ATP, GTP), and if needed converted into other forms of energy. From the macro-energetic bonds in given molecules, energy is released by oxidation. This process is important for measuring energy of food. We think of the energy slowly released in body the same way as of quick burning in one of the calorimetric measuring kit. But we have to realise that the human body is not a 100% efficient machine and therefore it cannot use all the heat of the combustion. The calorific values measured in the calorimeter and the true physiological caloric values (the amount of energy actually released and used in the body) are therefore slightly different (see the table).

	Heat of combustion [kJ/g]	**Physiological caloric value [kJ/g]**
Saccharides	17.2	17.2
Lipids	39.1	38.9
Proteins	23.4	17.2

However, these physiological caloric values are unrealistic and may differ in each and every type of nutritional substrates.

Carbohydrates

Carbohydrates are burned in order to produce carbon dioxide and water. The energy content of the individual compounds depends on the structure of the substance (carbohydrates / maltodextrins / polysaccharides). For example, when glucose burns there is only 15.7 kJ/g released.

Fats

Oxidation of fats also leads to the formation of carbon dioxide and water, but the energy stored in fats is much more difficult to use than in carbohydrates because fats are more complex molecules and their breakdown in human body is not complete. For precise and accurate measuring of energy in lipid, we have to count with different fatty acid structure. Medium-chain fatty acids (8 carbons) release about 36 kJ/g. Long-chain FAs can release up to 40.2 kJ/g. The amonia released in protein catabolism is removed through the urea cycle and excreted in the form of urea in urine as well as other substances (hydrogen kation etc.).

Proteins

The energy potential of proteins depends on the nitrogen content, because nitrogen cannot be used in heat combustion. Its concentration in individual protein substrates fluctuates from approximately 15% to 19%. The energy potential of proteins is also affected by many other factors, such as the proportion of protein in total energy intake or physical activity of the patient.

Energy expenditure measurement

We can measure the released energy of a patient through direct or indirect calorimetry. Due to technical and financial difficulties of direct calorimetry we often use indirect method.

- **Direct calorimetry**-the proces is similar to the one with adiabatic calorimetr. The examined person is left in a closed chamber flowing in a water tank. The heat produced by the organism is measured on water temperature in the tank surrounding it while we monitor the oxygen intake; carbon dioxide; nitrogen excretion via breath, urine and faeces.
- **Indirect calorimetry**- the basic principle of this method is to measure the consumption of nutrient substrates and gas exchange at a given time and to determine the respiratory coefficient.

Respiratory Quotient

Respiratory quotient is calculated from the ratio of carbon dioxide produced by the body divided by oxygen consumed by the body using respirometr in undirect calorimetry. Its values depend on the proportional oxidation of individual nutritional substrates (lipids, carbohydrates, proteins) due to the different pathways of every macronutrient. Some of the other factors that may affect the respiratory quotient are energy balance, circulating insulin, and insulin sensitivity. RQ for ordinary mixed diet is around 0.85. RQ values for oxidation of essential nutritional components and RQ of some metabolic processes are listed in the table below:

Substrate/metabolic action	RQ
glycogen, carbohydrates	1
lipids	0.7
proteins	0.9
glucogenesis	0.4
lipolysis	0.7
lipogenesis	2.75

Basically, molecules containing more oxygen require less inhaled oxygen to be fully broken down, therefore, have higher respiratory quotiens.

Fatty acid molecules of fats contain little oxygen compared to the total carbon content, so they use more oxygen during their metabolism. That is the reason why the lipogenesis is the most influential process on RQ value. Therefore, RQ> 1 indicates lipogenesis and excessive unused amount of glucose (building fat storage). Value <0,7 is an indicator of inability to oxidize glucose, fasting, the lipolysis and gluconeogenesis. Situation is more complicated with proteins, because of their incomplete catabolism. Firstly, we tried to find RQ for a number of metabolized proteins, but for further research we work with the so-called non-protein RQ. The non-protein RQ is based on the fact that 1 gram of nitrogen in urine equals the amount of proteins requiring 5.92 liters of oxygen for its oxidation and creating 4.75 liters of carbon dioxide.