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Energy Expenditure at Rest and During Exercise

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ENERGY METABOLISM

Alactacid Energy Metabolism—Adenosine Triphosphate

The immediate source for muscle contraction is delivered from splitting of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) and a 'free' phosphate ion (P). This reaction is very fast and does not normally limit energy turnover and muscle performance. However, the ATP stores in the muscles are very limited. The whole ATP pool would be emptied in only a few seconds of muscle contraction. Therefore ATP has to be continuously regenerated through other energy systems.

These supporting energy systems are very effective and can keep the ATP concentration unchanged or only marginally lowered, even during heavy exercise. In essence, there are four such systems, with different speeds of reaction and capacities, which release energy for active phosphorylation of ADP to restore the ATP pool. They are (1) creative phosphate, (2) lactacid anaerobic metabolism, (3) aerobic metabolism and (4) adenylate kinase reactions.

Creatine Phosphate

The most immediate energy system to restore ATP from rephosphorylation of ADP is creatine phosphate (CrP). CrP is stored in the muscle for immediate use, but it can also be regarded as an energy transport system between the mitochondria and the myofibrillar system as well as an 'energy buffer' for phosphorylation of ATP, when the capacity and speed of the other energy regeneration systems cannot keep up with an acceptable ATP concentration in the myofibrillar system. Phosphorylation of ADP from CrP (CrP + ADP to Cr + ATP) is fast. The total CrP pool can be used up by several seconds of heavy exercise.

At rest and during light submaximal exercise the CrP concentration is not different from resting concentration due to continuous rephosphorylation of Cr in the mitochondria. During normal dynamic heavy exercise the CrP pool may be lowered to 50% or less of resting and completely emptied during extreme exercise conditions.

The amount of CrP in the muscle as well as ATP and ADP concentrations can only be measured by sophisticated laboratory methods.

Lactacid Anaerobic Metabolism

In this energy pathway the chemically bound energy in carbohydrates, mainly muscle glycogen, can be utilized for ATP regeneration during stepwise degradation of glycogen or glucose to lactate (Hla) and hydrogen ions. No oxygen is used. This reaction is fairly fast but normally limited by the

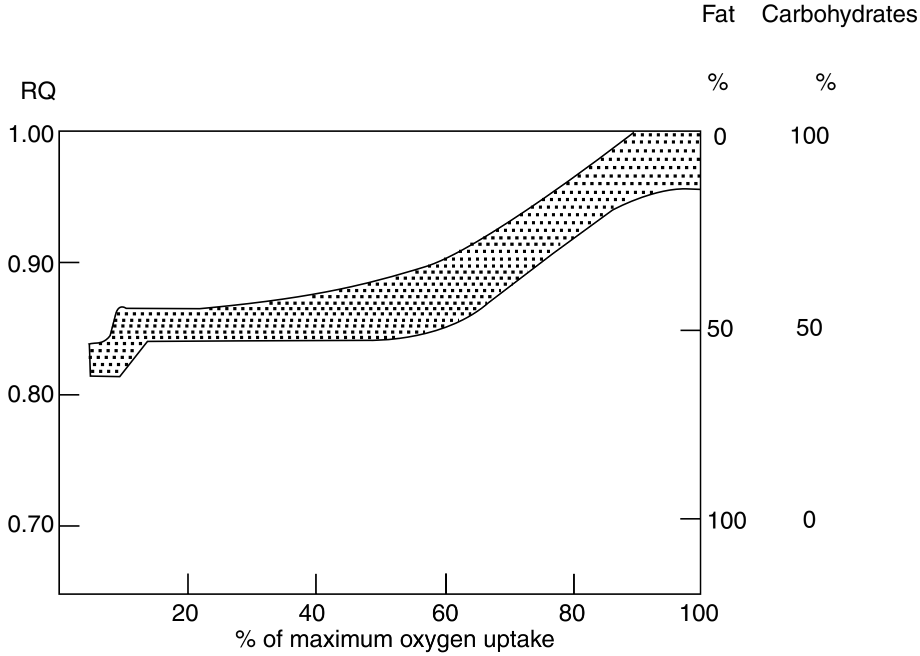

Figure 11.1 Metabolism of fat and carbohydrate at rest and during submaximal exercise, and during heavy exercise

formation of hydrogen ions which decrease the muscle pH and impair muscle performance in several ways.

If muscle glycogen stores are more or less empty this anaerobic energy system is impaired due to the reduced substrate availability. For each molecule of glucose or glycogen two and three ATP, respectively, are formed. This energy system is activated only during heavy exercise. Measurements of lactate concentration in blood are only able to indicate a qualitative involvement of this anaerobic energy system during physical stress. It is not possible to make quantitative calculations of the lactacid anaerobic energy yield during exercise from measurements of lactate concentrations in the blood due to dilution and transport of lactate in different water compartments in the body, elimination of lactate in the metabolism and other factors.

Aerobic Metabolism

Quantitatively the most important energy system during exercise is the breakdown and splitting of the energy-rich fat and carbohydrate molecules. Fat is stored in large amounts in fat cells all over the body but also in the muscle, which is very important. Glucose is stored as glycogen in the liver and muscles. Small but important amounts of glucose are also found in the plasma.

During aerobic conditions—when oxygen is available at the site of the mitochondria—fatty acids and glucose in combination are metabolized to carbon dioxide and water. For each molecule of glucose 38 or 39 ATP can be formed depending on whether glucose or glycogen is the substrate. For each fatty acid about 130 ATP can be formed. The latter figure varies depending on the type of fatty acid that is metabolized.

Since oxygen is a prerequisite for this reaction it is possible to calculate how much energy has been converted at rest and during exercise by measuring oxygen consumption. This is done at the level of pulmonary ventilation—see below. When fatty acids are used as substrate 19.3 kJ (4.7 kcal) is transformed for each litre of oxygen used. Corresponding value for glucose is 21.0 kJ (5.0 kcal) and for protein 18.8 kJ (4.5 kcal). However, for most calculations of energy expenditure at rest and during exercise a figure of 21 kJ (5 kcal) for each litre of oxygen can be used.

Respiratory quotient (RQ) is the volume of carbon dioxide formed divided by the volume of oxygen used—for measurements see below. Since fat oxidation has a RQ of 0.7 and glucose 1.0 it is possible using RQ determinations to evaluate the relative contribution of fat and carbohydrate, respectively, in energy metabolism. At rest and during submaximal exercise RQ is normally about 0.80 to 0.85 and reaches 1.0 during heavy exercise. Thus, at rest and during submaximal exercise, fat and carbohydrate are combusted to about an equal extent while during heavy exercise, when RQ is about 1.0, only carbohydrates are metabolized (Figure 11.1). It should be emphasized that carbohydrate- or fat-rich diets alter the RQ at rest and during submaximal exercise.

The aerobic reaction of fat and carbohydrate metabolism is slower than other energy systems. On the other hand, the stores are very large for fat and intermediate for glycogen. The stores of glycogen both in the liver and in the muscles can be increased by carbohydrate-rich diets. Supplementation with solutions containing carbohydrates but not fatty acids increases physical and mental endurance during prolonged exercise.

The limitation of the aerobic energy system is the maximal availability of oxygen at the site of the mitochondria, delivered through the oxygen transport system—see below. Endurance, defined as the capacity to carry out prolonged submaximal exercise, is to a large extent limited by the glycogen stores in the muscles and liver.

Adenylate Kinase Reaction

This special energy pathway is not very well investigated but is believed to be used only during extreme physical stress conditions. In this reaction two ADP react to form one mole of ATP and one mole of AMP (aminomonophosphate) in an attempt to produce ATP very quickly and to reduce the amount of ADP in the muscle. To keep this reaction going forward AMP has to be degraded by deamination. In several subsequent degrading reaction steps uric acid will be formed and can be used as a marker for the net loss of ATP. But more importantly, during this last reaction step oxygen free radicals can be formed, which may negatively influence cell membranes, several biochemical and other functions and structures in the muscle. Under normal conditions this reaction is of little value in the total energy output.

Summary

The energy metabolism for generating ATP to the muscle contraction is complex and not fully understood. It includes reactions which can deliver energy very fast—such as the adenylate kinase reaction, creatine phosphate and glucose/glycogen spliting. The negative aspects of these reactions are the limited stores and negative effects of the reactions. Aerobic breakdown of fat and carbohydrates provides a more patient and durable energy metabolism. The aerobic energy systems are fairly slow but stores are large. The metabolites of these reactions have hardly any negative effects. In the discussion of energy balance and weight maintenance it is only the aerobic metabolism that is of interest.

MEASUREMENTS OF ENERGY METABOLISM

Oxygen Consumption

Oxygen in the ambient air is transported by the pulmonary ventilation and in the main circulation to the muscle capillaries, from which through diffusion it reaches the muscle mitochondria. To quantify the amount of oxygen involved in metabolism in the mitochondria, the oxygen uptake is measured at the site of the pulmonary ventilation using the Douglas bag method or automatic analysis systems. The volume of expired air and the oxygen and carbon dioxide concentration in the expired air are measured. Since the oxygen and carbon dioxide in the inspired air normally is 20.94 and 0.03%, respectively, it is easy to calculate the amount of oxygen that has been taken up and carbon dioxide that has been produced in litres per minute, both at rest and during exercise (1). The error in measuring oxygen uptake during submaximal and maximal exercise with these methods is now less than 2%.

At rest oxygen uptake in a normal trained or untrained young man with body mass 70 to 75 kg is about 0.25 litres per minute. Corresponding value for a young woman of the same age is somewhat less due to smaller body mass. With increasing age resting oxygen uptake decreases mainly due to decreasing muscle mass. During exercise oxygen uptake normally increases linearly with increasing rate of work up to maximal exercise.

Table 11.1 Maximal aerobic power and energy expenditure during 1 hour of exercise

	$\dot{V}O_{2max}$ (litres per minute)	kJ per hour
Untrained women		
25 years	2.3	1400
50 years	1.9	1200
75 years	1.4	900
Untrained men		
25 years	3.3	2100
50 years	2.7	1700
75 years	2.0	1300
Endurance athletes		
women	4.0–4.5	4200–4800
men	5.0–7.4	5400–7800

The maximal aerobic power is defined as the peak oxygen uptake during dynamic exercise with large muscle groups under normal atmospheric conditions. In order to ensure that the maximal oxygen uptake has been reached the linear relation between oxygen uptake and submaximal work load should 'level off' at maximal oxygen uptake. High values for blood lactate concentration and heart rate can only be used as indications that maximal oxygen uptake have been reached. Maximal aerobic power in most healthy mean and women is limited by the capacity of the heart to pump blood during maximal exercise (maximal cardiac output). However, maximal oxygen uptake can be modified by many factors such as lowered oxygen carrying capacity in the blood (anaemia), medication and other factors. Values of maximal oxygen uptake in trained and untrained men and women are given in Table 11.1.

Direct measurements of oxygen uptake can only be done with specialized laboratory or field test equipment. Furthermore, in some activities such as prolonged work or in many work situtions direct measurements of oxygen uptake are more or less impossible. Therefore, energy expenditure must usually be evaluated by other methods.

Heart Rate

Measurement of heart rate during physical activity is one possible way to estimate oxygen consumption and energy expenditure. The background for this is that there is roughly a linear relationship between oxygen uptake and heart rate for most types of physical work under normal conditions (1).

However, it must be emphsized that the heart rate for a given absolute and even relative (per cent of maximum) oxygen uptake can vary extensively, for example with age, different peak heart rates, training status, diseases, psychological status and stress, medication (beta-blockers) and many other factors. Therefore, each estimation of energy expenditure from heart rate recordings should be done individually, taking all these variations into consideration.

The estimation of energy expenditure from heart rate recordings is done first by establishing the relationship between heart rate and oxygen uptake during increasing rates of work on a cycle ergometer, treadmill or the type of exercise that the subject is performing. The energy expenditure can thereafter be estimated by interpolation from heart rate recordings during the actual activity.

If all these measurement are done properly, the error of the method for estimation of energy expenditure from heart rate recordings during the actual work is in the range of $\pm 15\%$. However, this method is less accurate than the direct measurement of oxygen uptake due to the temporary variation in heart rate caused by static work, psychological stress etc. Therefore, estimations of energy expenditure from heart rate recordings must be done with great caution.

Core Temperature

Determination of core temperature during or immediately after exercise can also be used for estimation of energy expenditure during dynamic exercise. The background is that there is a close relationship between core temperature and the relative oxygen uptake (1). Thus, if the exercise has persisted for longer than 15 to 20 minutes and has been performed under normal conditions (e.g. within the air temperature range of approximately from 5 to 35°C), a core temperature of 38.0°C indicates a relative energy expenditure of about 50% of maximal aerobic power. At an average energy expenditure of 75% of maximal aerobic power the core temperature is approximately 38.8°C. These figures are consistent for men and women, irrespective of whether the individual is untrained or well trained or has a maximal aerobic power of 3 or 6 litres per minute.

This method has its limitations, such as the inertia of the core temperature with time and changes in energy expenditure. Furthermore, core temperature rises for a given energy expenditure during hypohydrated conditions, with extreme adiposity and some other conditions. Nevertheless, this method may be very useful in some situations, such as during intermittent exercise, in which the rate of work changes rapidly and also during physical exercise with high levels of psychological stress. In this latter situation the heart rate is increased due to the effect of catecholamines and, thus, the normal relation between heart rate and oxygen uptake is changed and not valid. In this and some other situations measurements of core temperature may be the best method to estimate the relative energy expenditure during exercise. In addition, maximal aerobic power must be measured or estimated.

Double Labelled Water

The doubly labelled water method is one of the best and in many situations the only possible method for estimation of energy expenditure over long periods (2). The method makes it possible to measure the total energy expenditure during periods up to 2 weeks under free-living conditions with a minimum of inconvenience for the individual. At the start the individual drinks water containing two isotopes ($^2H_2$ and ^{18}O). The two isotopes will then be diluted in the total body water pool. Both leave the body as water but in addition the oxygen also disappears as carbon dioxide as a result of the energy metabolism. By measuring the concentration of $^2H_2$ and ^{18}O in urine at the start and after some time the total energy expenditure during the period can be estimated. The only drawback of this method is the high cost of the isotopes and analysis, so that it is only feasible for studies with a small number of subjects.

Dietary Intake

If total body mass and its composition is unchanged over time, then energy expenditure must equal energy intake. Thus, measuring dietary intake may be one possibility to estimate total energy turnover over a prolonged period (weeks). However, under- and overreporting is very common, especially in obese subjects (3). Furthermore, there are normal variations in body weight of $\pm$ 1–2 kg even over fairly short periods of time. One kilo body mass change due to for instance body water shifts can indicate a fat mass change of about 27 MJ (6500 kcal), which equals more than 2 days' normal free-living energy expenditure in most individuals. Therefore, one must be cautious about making assumptions based on estimations of energy expenditure from individually reported dietary intakes.

Summary

Energy expenditure is best estimated by measuring oxygen consumption, since direct calorimetry is not a practical method. For calculation of energy expenditure for a fairly short period of time aerobic power times duration can simply be used. However, this procedure is not useful and possible in many practical situations outside laboratory settings. Therefore, calculations of energy expenditure from indirect estimations of oxygen consumption by heart rate recordings and core temperature measurements during and after physical activity, respectively, are well-accepted methods. For calculations of energy expenditure for longer periods of time (days and weeks) only the diary intake and doubly labelled water methods are valid and possible. In all these methods there are many different possibilities for erroneous recordings and calculations. Therefore these methods must be used with caution.

ENERGY EXPENDITURE AT REST

In general medicine and medical practice the interest in energy metabolism is often focused on basal metabolism. This is easy to understand because variations in basal metabolic rate (BMR) can be in the range of 30–40%. This variation can account for large increases and decreases in body weight, especially if they persist for a long period of time. The reason for the inter- but also intra-individual variations in BMR can only partly be explained by variations in active body mass—mainly muscle mass. Therefore, a mitochondria protein—the uncoupling protein (UCP), found in the mitochondria in the brown adipose tissue—is of great interest in this respect.

Brown adipose tissues have many mitochondria. The energy released in the brown fat cells is to a lesser degree than in other cells used for active phosphorylation of ADP to ATP and more for thermogenesis. Recently, proteins which have structures very like the UCP ones in brown adipose tissue have also been found in muscle tissue. Although there are many questions to be answered regarding the presence of the UCP-like protein in the muscle (exact function, regulation etc.), it can be speculated that this protein might explain why only about half of the oxygen used in metabolism in the muscles is used for active phosphorylation of ADP at rest (4). The consequence could be that some part of the energy taken in is not stored in the body, if the energy released in the metabolism is not used for mechanical events in the muscle but only increases the thermogenesis. Of interest in this discussion is that it has been shown that there are differences between overweight and normal-weight individuals in how this UCP-like protein is expressed in mRNA (5).

Studies in rats have shown that regular endurance training decreases the mRNA linked to the UCP in muscles (6). On the other hand, after an endurance exercise session the activity of UCP is increased (7), which might explain part of the increased post-exercise oxygen consumption. Regular physical training increases muscle and mitochondrial mass and as a consequence presumably also the amount of UCP. Thus, both acute and chronic exercise is of importance for the BMR and consequently the energy balance in both normal-weight and overweight individuals.

If UCP is downregulated by physical activity then its activity should increase with physical inactivity, leading to an increased BMR per kilo lean body mass. On the other hand, muscle mass is reduced as a result of physical inactivity. In any case, when studying changes in body weight, diet and eating habits and level of physical exercise in individuals, in groups and also in population investigations, it is obvious that the energy turnover both during and after exercise as well as the influence of exercise on BMR must be considered. Thus, level of physical exercise is therefore of vital importance in the discussion of energy balance in humans.

Summary

About two-thirds of the energy expenditure over 24 hours amounts to the resting energy metabolism. New findings regarding the uncoupling protein can shed new light on BMR and might to some extent explain the variations in BMR between individuals and perhaps also changes in BMR with time and ageing.

ENERGY EXPENDITURE DURING EXERCISE

Intensity and Duration

One cannot apply strict mathematical principles to biological systems, but when analysing energy balance for longer periods of time, energy metabolism during and after exercise must be taken into account. It is obvious that both the intensity and the duration are the main determinants of energy expenditure during exercise. However, many factors may modify the energy expenditure for a given rate of work and the total cost for certain activities. For this reason it is difficult to give exact figures for the energy cost of exercise. Therefore the discussion of energy expenditure should be based on individual conditions and values given for certain activities or for groups of subjects are subject to large uncertainties.

During short-term (a few minutes) hard dynamic muscular exercise carried out with large muscle groups, the energy metabolism may increase to 10–15 times the BMR in untrained subjects and 25–30 times the BMR in well-trained athletes from endurance events. However, due to muscle fatigue during heavy exercise the duration of exercise is often fairly short. In such cases the total energy expenditure is relatively low. On the other hand, low-intensity exercise, which may require half or two-thirds of the individual's maximal aerobic power, can be performed for a very long time even by an untrained individual. In this case total energy turnover can be fairly high.

Variations in Energy Expenditure During Submaximal Exercise

Variations in energy expenditure for a given sub-

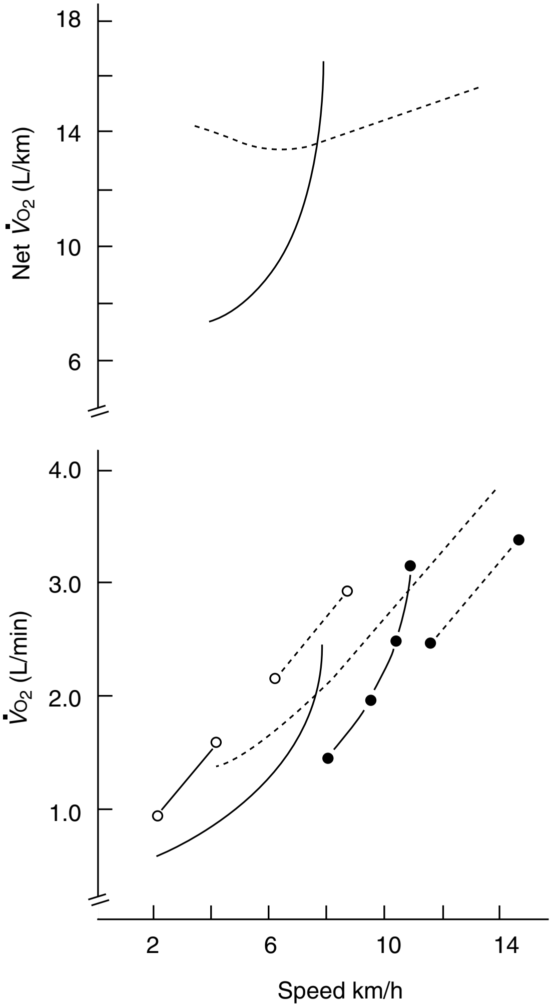

Figure 11.2 Energy expenditure (as measured by oxygen uptake) during walking and running

maximal rate of work are due both to individual variations in economy of locomotion, such as different technique and body mass, and to temporary interindividual factors, such as changes in core temperature and choice of substrate.

Energy expenditure (as evaluated from oxygen consumption) during walking and running is illustrated in Figure 11.2. At low speeds—2–5 km per hour—walking costs less than running; that is oxygen uptake during walking is less than in running at the same speed. This is true for both energy expenditure per minute of exercise and net cost of energy per kilometre covered. However, at speeds greater than 6 to 8 km per hour running is more effective than walking in both these aspects. The upper panel of the figure also shows that the net energy cost for running per kilometre is more or less independent of speed. For a normal man with a body mass of 70 to 75 kg the energy expenditure during running is about 280 to 300 kJ per kilometre independent of speed, while walking for the same man may cost between 150 and 350 kJ per kilometre depending on speed. It must be emphasized that well-trained male and female racewalkers and long-distance runners have much lower values for energy expenditure both per minute and net per kilometre than normal, untrained individuals.

Women and children have lower energy cost for a given speed in walking and running due to their lower body mass. However, energy expenditure calculated per kilo body mass is the same for men and women whereas children have higher values. The energy expenditure also increases with body weight. Overweight individuals can have 50% and higher energy expenditure for a given walking speed. For example, during uphill treadmill walking (4–5 km per hour, 4° elevation) the oxygen uptake in an untrained overweight woman with a BMI of 35–40 may be maximal. Thus, for a given low walking speed the variation in energy expenditure can be up to 100% in a normal population.

The energy expenditure at a given speed varies also with different conditions such as surface, uphill and downhill walking and running, wind resistance etc. People with joint disease, an amputation or other physical handicaps have decreased locomotion economy, that is the oxygen uptake for a given submaximal rate of work is increased.

In some types of exercise in which technique is very important, such as swimming, the energy expenditure at a given speed may vary by more than 100% for poor and good swimmers for the same swimming stroke but also for different swimming strokes in the same individual. On the other hand, the energy expenditure for submaximal cycling is about the same for well-trained cyclists and as it is for runners for instance.

In high speed activities in which wind resistance increases, the energy expenditure increases curvilinearly. In addition, the style, position and/or equipment can influence the energy expenditure for a given speed. This is particularly true in cycling but also for running. For example, running behind another runner may save up to 6% in energy cost because of the wind protection.

There are situations in which the energy expenditure for a given submaximal rate of work is increased such as in hypothermia due to shivering, in very cold climates due to resistance of cold, stiff clothes and when for instance running technique is impaired for various reasons. However, in most such situations the magnitude of the increased energy expenditure for a given rate of work is of little quantitative importance. On the other hand, in many situations the energy expenditure for a given rate of work does not change. There are no major changes in energy expenditure for a given rate of work with variations in hot or moderately cold climate (except for shivering), in moderate altitude compared to sea-level, in anaemia and most diseases including most types of medication, although in these conditions the physical performance can be severely impaired. It should also be emphasized that although the energy expenditure at submaximal work is not changed, the total energy expenditure may be reduced due to the individual becoming fatigued earlier.

The average energy expenditures for different activities performed for more than 10–15 minutes by a man aged 20–30 years are given in Table 11.2. It must be emphasized that these values are subject to large interindividual variations, as discussed above.

Table 11.2 Average energy cost for different activities for a 20- to 30-year-old man

	kJ per minute
Complete rest	4–7
Sitting	6–8
Standing	7–9
Standing, light activity	9–13
Light housework	13–30
Gardening activities	15–45
Walking	
3 km per hour	15–30
5 km per hour	20–40
7 km per hour	30–60
Running	
7 km per hour	30–50
9 km per hour	40–70
11 km per hour	50–90

Substrate Use During Exercise and Physical Training

As stated above, fatty acids and carbohydrates in combination are used during submaximal exercise. A common question in this discussion of substrate utilization is: Which is the best way to burn fat during exercise?

From Figure 11.1 it can be seen that the RQ for an untrained person (upper part of the shadowed area) is about 0.85 to 0.88 at exercise intensities from about 25 to 60% of maximal aerobic power. This means that the fat and carbohydrate contribution to the energy expenditure is 45 and 55%, respectively. From these data the substrate use during exercise can be calculated.

The total fatty acid contribution to the exercise expenditure is highest at around 60% of maximal aerobic power, which is a pace that even an untrained person can exercise at for some time. This means that for an untrained individual with a maximal aerobic power of about 3.3 litres per minute, 0.50 g of fat is used per minute at this intensity. Suppose that this individual through physical training increases his/her maximal aerobic power by 0.5 litres per minute, which is possible in 4 to 5 months of endurance training. Compared to the situation before the training period, two observations can be mentioned regarding the fat and carbohydrate contribution to the energy expenditure. Firstly, for a given submaximal relative but also absolute rate of work the RQ is lowered (lower part of the shadowed area in Figure 11.1). Thus, more fatty acids are used and the stores of carbohydrate are utilized less. Secondly, the intensity for peak fatty acid contribution to the energy expenditure has increased from 60% to about 70% of maximal aerobic power. This means that the peak contribution of fatty acids in this individual has increased due to the training effects from 0.50 to 0.75 g per minute. In addition, the individual can probably be active for longer periods of time after the training period and, thus, increase the fatty acid turnover still more. For instance, if she/he increases the exercise time from 30 minutes before to 45 minutes after the training period at the exercise intensity at which she/he can exercise fairly easily, then the fatty acid breakdown increases from 15 g to 30 g for the exercise period. The increased use of fatty acids at a given rate of work and the higher speed of exercise may be of interest not only in conditioning exercise such as jogging and cycling but also in the everyday ‘behaviour’ type of exercise (climbing stairs, walking short distances etc.) as part of the energy expenditure in the discussion of energy balance.

Maximal Exercise

Variations in maximal power are due to age, genetic endowment, body size, physical activity and some other factors and can partly explain differences in total energy expenditure for different reasons. Individuals with high maximal aerobic power will more likely walk distances or climb stairs than use cars and elevators. They can more easily carry loads and they may in general be more physically active in normal life. In addition, due to increased energy intake when physically active they also have increased intake of essential nutrients. But the total daily need and turnover for essential nutrients increases less than the increased total daily energy need and turnover when a person becomes more physically active. Therefore the difference between intake and turnover of essential nutrients widens with increasing levels of physical activity under the assumption that the individual is in energy balance while trained and untrained.

Total Energy Expenditure

As stated above, duration of exercise may be more important than intensity for total energy expenditure. In Table 11.1 the total energy expenditure is given for one hour of exercise such as walking in uneven terrain, cycling or playing a game of tennis, volleyball or table tennis in a moderate fashion. The intensity of these types of physical activities is on average about 50 to 60% of maximal aerobic power when carried out as free-chosen physical activity. The rate of work of 50 to 60% is easily performed even by an untrained person for one hour. The individual maximal oxygen uptake values for untrained men and women at different ages and endurance athletes are also given in Table 11.1.

The table shows that one hour of leisure time exercise yields an energy expenditure in an untrained person which corresponds to about one-quarter of 24 hour BMR, which is 7 MJ for men and 5–6 MJ for women. The importance of these types of regular physical exercise is illustrated when discussing body mass changes over time. It is not uncommon that body fat mass in many individuals increases 2 kg in one year. This corresponds to a daily energy imbalance of about 150 kJ. Unless net energy intake is increased this corresponds to an extra 10 minutes of walking per day. Furthermore, in order to maximize the beneficial effects of physical activity on health, and in prevention of diseases that are related to physical inactivity, the Surgeon General in the USA has recommended accumulated low-intensity physical activity of at least 30 minutes per day (8). Thus, regular low-intensity physical activity such as walking and cycling to work two times 15–20 minutes a day may be a good base for energy balance, body weight maintenance and good health.

Sporting activities can generate quite a large total energy expenditure. In male elite soccer matchplay the heart rate is on average some 25 to 30 beats per minute lower than peak heart rate obtained during maximal exercise. Core temperature after the game is above 39 °C as an average for the players in the team. Blood lactate concentration measured several times during the match varies between 4 and 10 mM. Thus, from these figures it can be calculated that the average energy expenditure during the game amounts to 75 to 80% of maximal aerobic power. For an average male elite player with a maximal oxygen uptake of 4.5 litres per minute the total energy expenditure for a whole game including some warm-up can be calculated to be about 7.5 MJ (1800 kcal) which is about the same as the BMR for 24 hours. Corresponding values for total energy expenditure for a female elite player are some 20% less (9).

The energy cost of a marathon race (42 km) for a 30- to 40-year-old man who performs the race in 4 hours is about 12–15 MJ (3000–3500 kcal). However, in order to be able to carry out the race in 4 hours the training during the preceding 6 months can be calculated to be about 400 MJ. It is obvious that regular physical training for sport is of importance for energy balance and body weight control.

Summary

Energy for physical activity is generated though several complicated systems of which the aerobic splitting of fat and glucose is the most important one. For most people physical activity amounts to

about 30–40% of the total energy expenditure during 24 hours. The amount of exercise energy expenditure during 24 hours is dependent on intensity and duration but many other factors can influence energy expenditure.

In the population physical activity can be divided into four main parts. The difference between them is often not very clear. The lowest one is spontaneous activity, which is trivial activities such as moving arms and legs, take small steps etc. The energy needed for this type of activity is fairly small but for people who seldom sit still or move regularly the whole day the total amount can reach some volume.

The physical stress in most jobs is nowadays much lower than 20–30 years ago. Office work has very low energy demands. In industrial work monotonous and low energy expenditure physical exercise gives rise to overuse problems. On the other hand, other jobs such as construction work can reach a daily total average energy expenditure of 12 000–13 000 kJ or more. In general, physical activity in most work places does not add enough physical activity to the daily physical activity.

The next part is the 'behaviour' physical exercise, i.e. climbing stairs, walking a few blocks instead of taking a bus or car, often doing physically active things inside or outside the home. This type of activity is very important for energy balance. Over the day such activity can easily use 1000 kJ in extra energy expenditure. Of particular importance is the way that the person travels to work. In many countries it is common to ride a bicycle or walk 15–20 minutes to reach the workplace. This type of physical activity is of utmost importance for good health and body mass maintenance as well as for weight reduction in overweight individuals.

Physical conditioning can, if carried out on regular basis, create a daily energy expenditure well above 3000 kJ and, thus, well above the level for good health and body mass maintenance. Elite athletes often have a daily energy expenditure of 14 000–16 000 kJ (3500–4000 kcal); in some sports it may be even higher. In addition to energy expenditure during exercise, the effect of regular physical activity on resting metabolic rate is of interest.

Thus physical activity is very important for body mass maintenance. All its different parts must be considered when discussing energy balance.

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