

ENERGY: INTAKE AND NEEDS

One of the few incontrovertible facts about obesity is that weight is only gained when energy intake exceeds energy needs for a prolonged period.

Jebb (2007)

2.1 Introduction

There is only one way in which humans can obtain usable energy, and that is from the food and drink they consume. Different foods provide different amounts of energy. (You have already met the idea of foods of high and low energy density in Section 1.7.) Most of the energy in food is released by processes in the body that also require oxygen to be available. The oxygen is needed for the chemical reactions that release the energy stored within the structures of particular types of food. These energy-releasing processes take place in every cell of your body and will be discussed in Section 2.6. Oxygen is obtained from the air when it is inhaled into the lungs and is carried by the bloodstream to all the body's cells. So oxygen is available all the time; stop breathing and you die. But food is different. You breathe continuously but you do not eat continuously. Yet the body requires a continuous supply of energy. In Chapter 4, you will find out how the body manages to keep its cells supplied with a continuous energy source despite a fluctuating intake of food.

Food has many attributes. At a practical level, it provides material to enable growth and renewal of body tissues as well as providing energy. At an emotional level, it often has pleasurable associations, providing a focus for social gatherings or a respite from boring occupations. In this chapter, the emphasis will be on understanding the chemical nature of food as it relates to providing the body with an energy source.

Energy is used for physical activity and a myriad of other processes that take place in the body, ranging from growth and repair of tissues to 'house-keeping' activities such as breathing, sleeping, thinking and digesting food. Underlying all such activities are chemical processes taking place in the body. **Metabolism** is the collective name given to these chemical processes.

Different individuals have different energy requirements. An individual is in a state of energy balance if the following equation applies to them:

$$\text{total energy intake (TEI)} = \text{total energy expenditure (TEE)}$$

When energy intake is greater than energy expenditure, the surplus will most frequently be stored as fat, and the individual is said to be in a state of **positive energy balance**. (An unfortunate term, as most people feel anything but positive about their weight gain.) Conversely, if energy intake is less than energy expenditure, the individual is in a state of **negative energy balance** and they will lose weight as fat stores in the body are mobilised to provide energy.

2.2 Energy intake

To measure your energy intake exactly is a difficult and tedious affair. Nor is it straightforward because foods (such as eggs, tomatoes, cakes, cheese and apples) consist of a number of components, different amounts of each component and not all of the components of food provide energy. For example, if you enjoy following a recipe to make a particular cake, you might not weigh out *exactly* the same amount of butter every time, and the eggs you use will be very unlikely to weigh *exactly* the same every time! Even apples from the same tree will not all have the same calorific (energy) value; as well as size differences, the proportions of sugars alter as the fruit ripens.

The components of food that are digested, absorbed and essential for use in bodily processes are known as **nutrients**. These are divided into:

- **macronutrients** (fats, proteins and carbohydrates): food groups that provide energy
- **micronutrients** (vitamins and minerals): food groups that are essential for body functioning, but which are required in small amounts and do not provide an energy source for the body
- water.

In order to lose weight, it is necessary to move into a state of negative energy balance, so it would seem obvious that it is necessary to reduce intake of the macronutrients, i.e. eat less fat, carbohydrate and protein. However, the macronutrients cannot be entirely omitted from the diet because, in addition to providing energy, they provide other essential materials, some of which cannot be stored but must be provided continuously. Therefore, it is important to maintain a balanced diet. A balanced diet contains six key nutrient groups (the macronutrients, micronutrients and water) in appropriate amounts for health. One difficulty with advising on a balanced diet is that ‘appropriate amounts’ depend on individual levels of activity and weight as well as age, gender and ethnicity. Although there are general guidelines advising on healthy, balanced diets issued by governments and the WHO, anyone with a serious weight problem needs to consult their doctor, who will enrol the support of a dietitian (a person with a professional training in nutrition and diet) to devise a personal plan for weight loss. Unfortunately in many countries, including the UK, this is not always possible as there are too few dietitians to meet the demand.

In the rest of this chapter, we briefly consider the guidelines offered for achieving a balanced diet and then explore in detail the chemical nature of the macronutrients so that you can understand how energy can be released from these substances. Finally, we see how the body uses up these resources in various activities, making it essential that we eat regularly.

2.3 What is a balanced diet?

Figure 2.1 shows the balance of foods in the diet recommended by the UK Food Standards Agency (FSA).

- ◆ Name the essential nutrients.
- ◆ Fats, carbohydrates, proteins, vitamins, minerals and water.

◆ Macro- and micro- are derived from the Greek *macros* and *micros*, meaning large and small, respectively.



Figure 2.1 The ‘eatwell plate’: a guide to choosing a healthy, balanced diet.

- ◆ Does Figure 2.1 enable you to identify any specific nutrient that might be overrepresented in your diet?
- ◆ Figure 2.1 is a representation known as a pie chart. It enables you to see the relative proportions of each of the food categories that are likely to make up your diet. It is a fairly crude guide and does not allow you to identify any nutrient that might be overrepresented in your diet.

You might have noticed that the food categories used by the FSA do not equate to the nutrient groups. For example, fruits and vegetables are sources of carbohydrate but some of them also contain protein and fat (e.g. bananas, avocado and melon).

- ◆ What proportion of your diet should be composed of fruit and vegetables?
- ◆ Fruit and vegetables should make up a third of your daily intake.

The message in Figure 2.1 is simple and it emphasises balance rather than focusing on specific nutrients.

However, many organisations do offer guidelines on specific nutrients. The WHO, for example, suggests that carbohydrate should be somewhere between 55 and 75% of a person’s daily energy intake, protein 10–15% and fat no more than 10%. The problem for the individual who wishes to adhere to these guidelines is that most foods consist of a mixture of nutrients.

- ◆ Although not everyone eats the same food, different communities each tend to have a typical diet. For the three types of community shown in Figure 2.2, which one most closely matches WHO guidelines? What comment would you make about the Western diet?
- ◆ The plantain-eating community’s diet most closely matches WHO guidelines, although the intake of fat and protein is a bit low. On the other hand, Figure 2.2 suggests that in Western communities there is too great an intake of fat and protein.

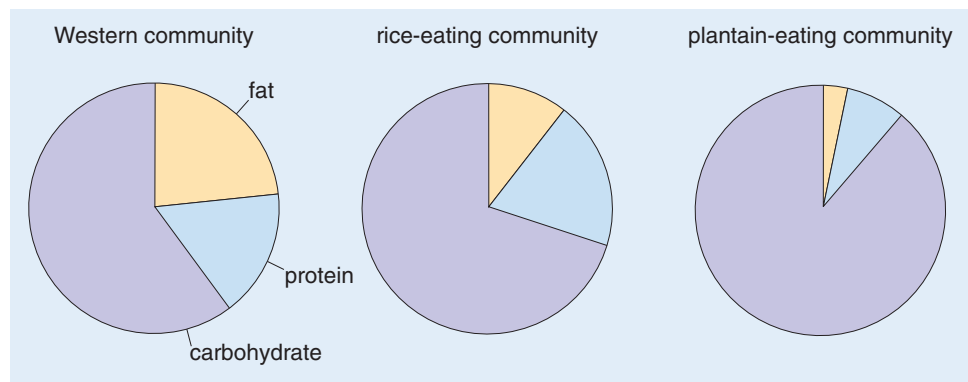


Figure 2.2 Percentage intake of the macronutrients in three types of community characterised by different diets. Plantain is a tropical tree with a banana-like fruit.

Another food group that is not nutritious – i.e. it is not a nutrient – but is important to include in our diet is *fibre*. Fibre (roughage) is non-digestible carbohydrate, but it has an important role in aiding the movement of food through the gut, as you will discover in Chapter 3.

- ◆ Alcohol is not a carbohydrate, protein or fat, but it does provide energy. Why is it not classified as a nutrient?
- ◆ Alcohol is not essential for body function (whatever some people may think).

Other components of the human diet are not nutrients at all, as they do not provide energy, nor do they perform any other essential function within the body, but are eaten for other purposes. For example, spices and other flavourings help make food more palatable, and tea and coffee drinks, while providing a good source of water, may also contain other valuable substances such as antioxidants.

2.4 The chemical nature of macronutrients

To describe the structure of the macronutrients, you require knowledge of some of the language used by chemists. Everything around us, and in us, is made up of *atoms*. Atoms are the basic building blocks for everything, from naturally occurring substances such as rocks, trees, copper and gemstones to manufactured articles such as plastics and paper. Some atoms exist individually (helium exists as individual atoms in the atmosphere) but mostly atoms are only stable when joined to other atoms (oxygen exists in the atmosphere as two oxygen atoms joined together). When atoms join together, they are held by forces that are known as *chemical bonds*. Two or more atoms held together by chemical bonds are known as a *molecule*. When different types of atoms join together, chemists describe the substance as a *compound*: water is a compound, made from oxygen and hydrogen atoms. Macronutrients are also compounds that contain oxygen and hydrogen atoms, but they contain other atoms too, such as carbon. They are mostly large molecules so are described as *macromolecules*.

The roles of the macronutrients are outlined below.

- Carbohydrates are usually the main energy source for the body.
- Fats (scientifically known as lipids) are a rich source of energy, as well as being key components of cell membranes and signalling molecules such as those used for sending information between different areas of the brain and other parts of the nervous system.
- Proteins are involved in the growth, repair and general maintenance of the body. Many hormones, which are the signalling molecules carried in the bloodstream, are proteins. Dietary proteins consumed in excess of the need for maintenance can be used to provide energy.

2.4.1 Carbohydrates

Carbohydrates are a large group of compounds and include sugars, starch and fibre.

The simplest form in which a carbohydrate can exist is as a monosaccharide. There are three monosaccharides that are important in the human diet: glucose, galactose and fructose. When two monosaccharides link together, a disaccharide is formed, and when many monosaccharides link together, a polysaccharide is formed (see Figure 2.3a). For example, sucrose (table sugar) is a disaccharide made up of one glucose and one fructose molecule, and lactose (which is found in milk) is made up of one glucose and one galactose molecule.

Derived from the Greek, *mono-* means one, *di-* means two and *poly-* means many; *saccharide* comes from the Latin for sugar.

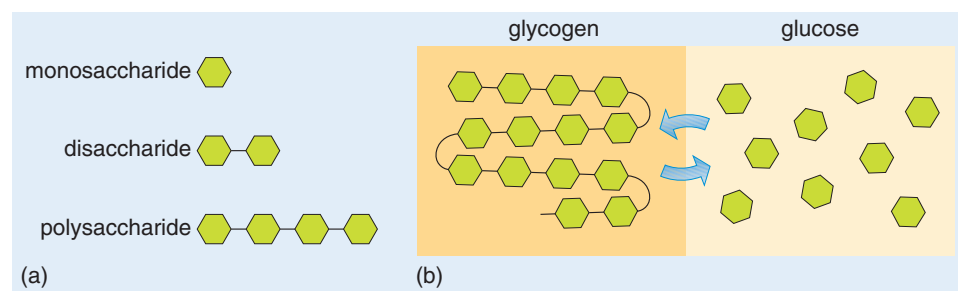


Figure 2.3 (a) Schematic diagram of a monosaccharide, a disaccharide and a polysaccharide. (b) Schematic representation of the interconversion of glucose and glycogen in the body.

◆ Polymers are chemical compounds formed from repeated units.

Polysaccharides can contain thousands of monosaccharide units. The main polysaccharide found in the human diet is a polymer of glucose called **starch**, which is derived from plants and is found in potatoes and cereals. Animals also have an energy storage polysaccharide called **glycogen**, which is also made up of glucose molecules, although in a different arrangement of units. Glycogen is stored in the liver, kidney and muscle and can be broken down into its constituent glucose molecules when the body requires energy, as illustrated in Figure 2.3b.

Glucose cannot be stored in body cells (other than as glycogen in liver, kidney and muscle and, by conversion to fat, in adipose cells) and the brain cannot use any other energy source in the short term, so the body must ensure that there is a steady supply of glucose in the bloodstream from which brain cells can extract glucose according to their needs. The way in which glucose supplies are maintained and used to provide a continuous source of energy for the brain will be considered in Chapter 4.

2.4.2 Lipids

Lipids are defined as being insoluble in water and encompass fats (solid) and oils (liquid). Unlike carbohydrates, lipids do not form polymers, but aggregates of individual and different lipid molecules can associate together. The lipids that store energy are the **triacylglycerols** (often shortened to **TAGs**), which are made up of three **fatty acid** molecules combined with one molecule of **glycerol**, as illustrated in Figure 2.4a. The fatty acid chains tend to be of different lengths; the longer the chain, the more energy it has stored in it.

◆ Derived from the Greek, tri- means three.

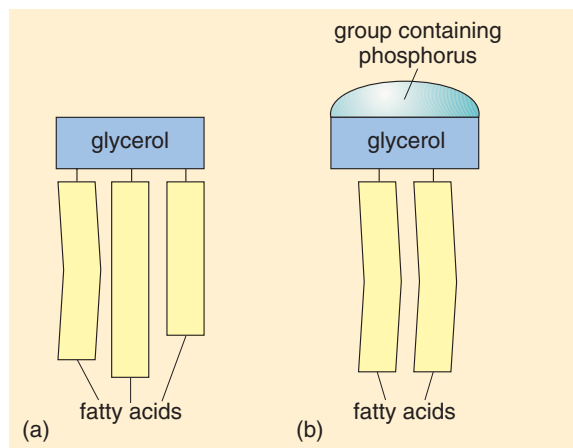


Figure 2.4 (a) Schematic representation of a TAG molecule. Note how three different fatty acids (shown by different lengths) are attached to this glycerol molecule. One fatty acid is bent in one place; it is described as a monounsaturated fatty acid. (b) Schematic representation of a phospholipid molecule. Note how these are formed from two fatty acids and glycerol together with another group of atoms that includes a phosphorus (P) atom.

- ◆ What is the name of the tissue that stores the TAGs?
- ◆ TAGs are found in the adipose tissues of the body.

In everyday speech, adipose tissue is called ‘fat’, and the definition of obesity uses that term too. You will also find the TAGs being referred to as ‘fat’. In the context of obesity, and within this book, it should be clear when the term ‘fat’ is being used to mean adipose tissue and when it is being used to refer to TAGs.

There are other types of lipids in our bodies, but they are not used as energy stores. Examples include another class of fatty molecules called phospholipids (Figure 2.4b). Phospholipids form the major component of the cell membranes. Cholesterol, a lipid with several vital roles in the human body, is also a component of cell membranes. Additionally, cholesterol is a **precursor** (building block) molecule for the manufacture of other molecules such as the male and female sex hormones (testosterone and oestrogen), vitamin D and bile salts (which are important for digestion, and about which there will be more in Chapter 3).

2.4.3 Proteins

Proteins are a large and diverse group of biological molecules. Each protein is built up of small molecules called **amino acids**, i.e. proteins are polymers of amino acids. Very short chains of up to about 30 amino acids are called **peptides**. Proteins are made within cells using combinations of 20 different amino acids. There are eight amino acids that humans cannot make, so must be taken in as part of the diet. (These are therefore known as essential amino acids.) The many thousands of different proteins each have a particular biological function and structure. Proteins are constantly being synthesised (made) within cells under ‘instructions’ from genes (Figure 2.5).

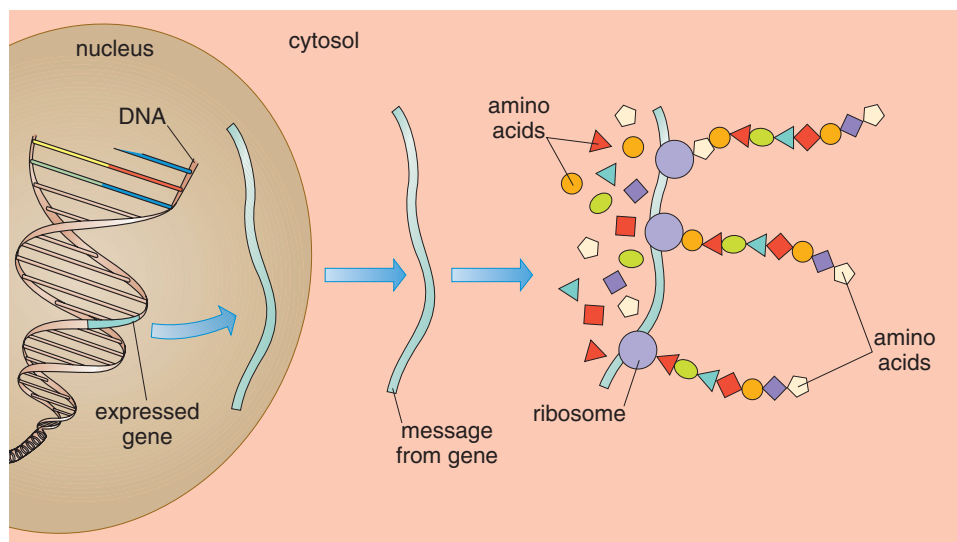


Figure 2.5 Genes make proteins. To allow the gene to be expressed, the long DNA molecule cannot remain packed into the chromosome structure. It unravels enough for the gene to be exposed and be able to make a messenger molecule. This message goes into the cytosol, and organelles called ribosomes attach to it and are able to make the protein specified by the gene.

Different cells will be making different proteins, each of which will have a particular biological function and structure. For example, skin cells make the components to make more skin cells, whereas a salivary gland cell might be making saliva. From your own experience, you know that salivary gland cells vary in the amount of saliva that they produce over 24 hours. It is characteristic of genes that their activity varies over time. When a cell is actively making a protein under instructions from a gene, the gene is said to be being **expressed**. When a gene is not making protein, it is said to be *switched off*.

So it is genes that provide the ‘instructions’ for amino acids to be linked together to form protein chains. As each chain consists of hundreds of the 20 different types of amino acids, there are thousands of possible sequences. Each particular type of protein molecule has its own unique sequence of amino acids along its length, just as a word has a unique sequence of letters. As in forming words, not all the letters of the alphabet are used, so in any one protein some amino acids may not be used at all whereas others may occur many times. The chain of amino acids is then folded into unique three-dimensional structures appropriate for that protein’s function.

Sometimes an error will be found in the genetic material of a new cell and as a result a gene might be unable to specify the correct sequence of amino acids to form its protein. The faulty gene is then said to have a **mutation**. There will be more on the contribution of genetic mutations to the development of obesity in Chapter 6.

Typically, somewhere between 12 and 18% of our total body weight is protein. Most of this is muscle and skin. Other body proteins include hair, nails and hormones. There is a constant process of protein synthesis and breakdown going on throughout the body. This is termed *protein turnover*.

- ◆ Why do you suppose we need a constant supply of protein? Couldn’t the body simply keep recycling the amino acids in its own proteins?
- ◆ Protein is constantly lost from the body, e.g. via the shedding of skin cells and through bodily secretions (such as saliva, digestive juices and sweat). Loss is also heavy at times of illness and injury, with loss of blood and damaged tissues.

Under normal circumstances, body protein is not used to release energy. However, the body’s own muscle tissue will be broken down to provide energy under conditions of starvation. In fact, this process begins before fat stores have been used up. Hence muscle wasting can occur when slimmers are on very restrictive diets (see Chapter 8).

2.5 Measuring energy intake

Your energy intake depends on what foods you eat, but how can you know how much energy each morsel provides? Some processed foods give this information on the packet, but how has this been measured? What about raw food, such as meat and vegetables?

◆ The glands that secrete sweat, saliva and digestive juices are called exocrine glands.

Energy is measured in **kilocalories (kcal)** or kilojoules (kJ): one kcal is approximately 4.2 kJ. Although the kilojoule is the internationally agreed scientific unit for measuring energy, we will use the kilocalorie in this book because that is the term most commonly used by the food industry. (It is, of course, equivalent to 1000 calories, but in discussions of dieting the kilocalorie is shortened to calorie in some parts of the world – so ‘calorie counting’ is actually ‘kilocalorie counting’.) A kilocalorie is defined as the amount of energy required to raise the temperature of 1 litre of water by 1 °C. Scientists and food technicians burn known quantities of a food in oxygen and measure the heat output to gain an indication of the energy content of foods. There are various tables published that give the calorific values of most foods, but they are somewhat approximate. For example, the calorific value of a cake, a biscuit or a stew will depend on the precise mix of ingredients that have been used. Nevertheless, most processed foods have an indication of their calorific value. The heat energy that is released by burning the food in oxygen is equivalent to the energy released in the body when the complex molecules in the food are broken down.

The approximate energy yields of the macronutrients are shown in Table 2.1.

- ◆ How many times greater is the energy yield of fat than that of protein (in kcal g⁻¹)?
- ◆ Fat yields 9 kcal g⁻¹ of energy and protein yields 4 kcal g⁻¹ of energy. So fat yields $\frac{9}{4} = 2.25$ times more energy per gram than protein.

g⁻¹ is the conventional scientific way of writing ‘per gram’; m⁻¹ means ‘per metre’, and so on.

In other words, fats are a more concentrated form of energy. They are more energy-dense than protein and carbohydrate, so it is therefore rather too easy to take in more energy than one requires when eating a high-fat diet, and to discover subsequently that the excess is being stored as fat in the adipose tissues of the body.

In Chapter 8, you will look more closely at the way energy intake can be calculated and related to weight gain. In the next section, you will gain an idea of how energy stored in food is released and is used to drive the metabolic activities of cells.

Table 2.1 Approximate energy yields of the macronutrients.

Macronutrient	Available energy/kcal g ⁻¹
carbohydrate	4
fat	9
protein	4

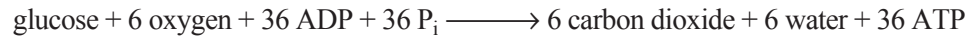
2.6 Releasing energy from food

Energy is needed in every body cell. *Mitochondria*, the oval-shaped structures in Figure 1.5a, are often called the power houses of the cell because it is within them that a molecule called **adenosine triphosphate (ATP)** captures energy released from nutrients such as sugars (e.g. glucose) and fats (e.g. fatty acids) by the process of **cellular respiration**. Cells that are very active, such as muscle cells, will contain many mitochondria. For glucose, cellular respiration can be summarised in the following word equation as:

glucose + oxygen \longrightarrow carbon dioxide + water + energy

ATP can be thought of as an ‘energy currency’ (like money) which can be made and then spent to get things done. Unlike money, it cannot be saved. Each ATP molecule typically exists for only a very brief period – a matter of seconds – before being utilised to provide energy for processes such as the synthesis of new macromolecules – for example, proteins.

We can write ATP where previously we had written energy:



This tells us that a single molecule of glucose (on the left side of the equation) will produce 36 molecules of ATP (on the right), provided that 6 molecules of oxygen, 36 molecules of ADP (adenosine diphosphate) and 36 molecules of inorganic phosphate (P_i) – one of the minerals your diet needs to contain – are available with the glucose.

Although the equation above shows glucose as the provider of energy, all three macronutrients (carbohydrates, fats and proteins) can be used to provide energy, as can be seen if you look at the upper portion of Figure 2.6. This figure shows *biochemical pathways (metabolic pathways)* in the cell. It indicates that energy is not released explosively in one fireball, as when sugar is set alight. Instead, energy is released gradually through a series of chemical transformations that involve the breaking and re-forming of chemical bonds, and the rates at which these occur are carefully controlled by **enzymes**. Enzymes are large protein molecules that have the ability to accelerate a *particular* chemical reaction in a cell. Enzymes remain unchanged at the end of the reaction. There are in fact many more tiny steps in these metabolic pathways than are shown in Figure 2.6.

- ◆ Why do you suppose that energy-containing food molecules are gradually broken down through a series of small steps that yield molecules of ATP at several stages?
- ◆ A sudden massive energy release, as occurs with burning, would destroy the cells of the body.

Figure 2.6 makes the important point that whether glucose, fatty acids, glycerol or amino acids are used to provide energy, they all enter into common biochemical pathways in the cell. However, they do not all yield the same amount of energy (a fact that cannot be deduced from Figure 2.6). Under ordinary circumstances, carbohydrates form the major component of most people’s diets, and therefore most energy is obtained from carbohydrates.

- ◆ Although most of your energy is likely to be derived from carbohydrates, which nutrient type provides the most energy per gram?
- ◆ Fat provides the most energy per gram (see Table 2.1).

(You might also have reflected that although Table 2.1 gives a single value, it must be an ‘average’ value because TAGs with long fatty acid chains release more energy than those with shorter fatty acid chains (Section 2.4.2).)

Box 2.1 Metabolic pathways to ATP production

Food is broken down in the gut (shown at the top of Figure 2.6), a process which will be described in Chapter 3. The molecules that can be used by cells to produce ATP are glucose, amino acids, fatty acids and glycerol. These molecules leave the gut and are circulated around the body in the bloodstream. All body cells can withdraw from this resource the fuel molecules and the oxygen they need to produce ATP. Most of the cell's ATP is made in the mitochondria, but some ATP is made in the watery cytosol as a result of the metabolic reactions that convert molecules of glucose and glycerol into a chemical compound called pyruvate. Amino acids can be converted into pyruvate too, but if you follow the metabolic pathway between amino acids and pyruvate you will note that no ATP is formed. Pyruvate is transported into the mitochondria, where it is converted into acetyl CoA. Fatty acids and amino acids can also be converted into acetyl

CoA. In fact, fatty acids are converted to acetyl CoA in a number of chemical transformations, requiring oxygen and glucose, that generate a great deal of ATP. Acetyl CoA enters a pathway called the TCA cycle, where more ATP is made. Waste carbon dioxide is also produced at this stage (as is produced from the earlier conversion of pyruvate into acetyl CoA). Other products of the TCA cycle are further processed to make more ATP, and this step requires oxygen and produces water as a waste product.

This is not a diagram to memorise! The points of interest are that carbohydrates, fats and amino acids, despite being very different, can all be metabolised to produce ATP and that they all finally enter common pathways to produce ATP. Also, these energy-producing pathways are busy in all your cells all the time – although activity is not equally frenetic in all areas at all times.

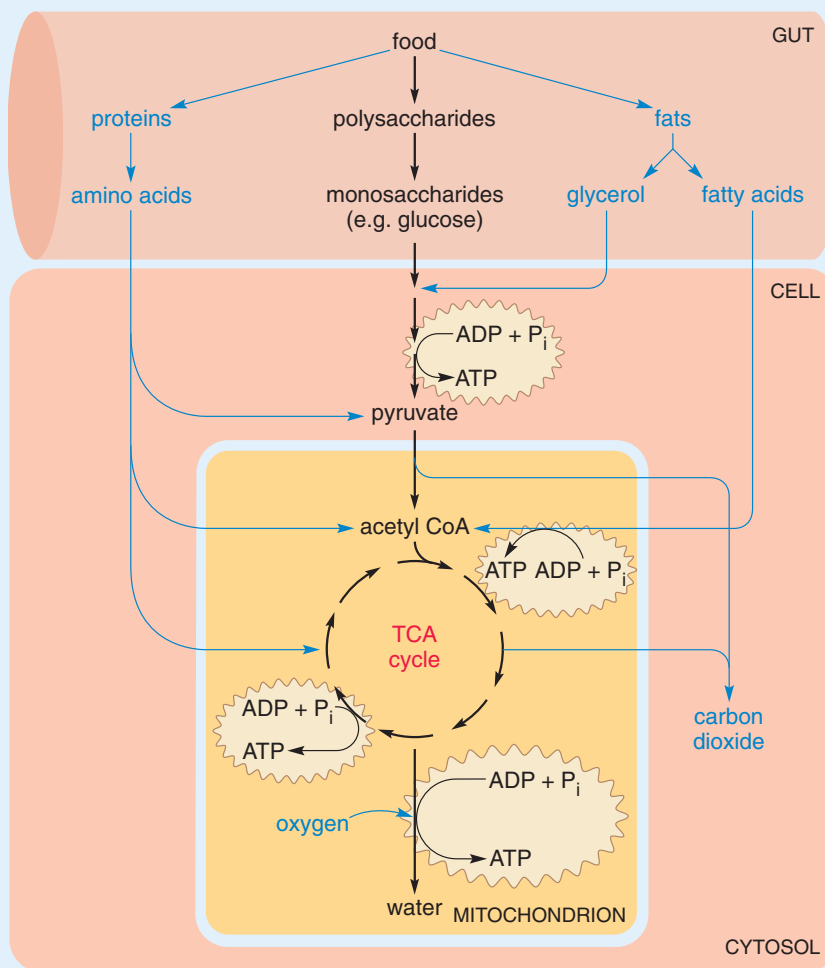


Figure 2.6 Summary of the fates of proteins, carbohydrates and fats in metabolic pathways that result in the production of ATP. Mitochondrion is the singular of mitochondria.

Although the energy released when nutrients are metabolised in the body is immediately used as the ATP molecules provide energy to enable other chemical reactions and cellular processes to proceed (i.e. it enters other biochemical pathways), a lot of energy (60–75%) is lost as heat. This heat maintains the body temperature. The liver produces more heat than any other organ because, as you will discover in the next two chapters, it is continuously, metabolically very active.

- ◆ Which other cells would you expect to use large amounts of energy and generate a lot of heat?
- ◆ Muscle cells have high energy requirements when individuals are physically active and you will know how hot you can become if you are being very energetic! You might have added that muscle cells ‘shiver’ (vibrate) to produce heat when you are cold – for example, after a swim in cold water. Although muscle cells can produce a lot of heat, their activity is intermittent.

2.7 Energy expenditure

When thinking of energy expenditure, you might have imagined that physical activities such as walking and active sports would be the main users of energy. Although physical activity is obviously energy-dependent, it is not the main user of energy in the majority of people. The major component of TEE is the **basal metabolic rate (BMR)** (sometimes called the resting metabolic rate), which is the amount of energy required to carry out the basic processes of life – the processes that continue as you sit quietly or lie asleep, such as breathing and the beating of your heart. BMR values are remarkably constant when related to lean body mass – body weight (mass) minus the weight (mass) of the fat tissue. The greater the lean body mass, the greater the BMR. People who are obese have a higher BMR because they have an overall greater body mass, i.e. both their lean and fat body mass are greater than those who are of healthy weight. Of course this means that as a person loses weight, their energy needs decrease; this lowering of BMR is just one of the many small ways in which the body’s metabolism opposes efforts to become slimmer! BMR also changes with the age of the individual and differs between the sexes. It declines with age due to a decline in lean tissue mass. So older people have a decreased energy need and should reduce energy intake (eat less) if they want to avoid putting on weight.

- ◆ If comparing a man and woman of the same height and weight, who would you expect to have the higher BMR and why?
- ◆ You would expect the man to have the higher BMR because he has the greater proportion of lean tissue (see Section 1.3.3).

It is estimated that in most people BMR consumes 60–70% of TEE if they are leading fairly sedentary lives. BMR increases in pregnancy and lactation (see Chapter 6) and also when the body is diseased. (Metabolic rate increases by about 8% for every 0.5 °C increase in temperature, e.g. during a fever.)

When we eat, our energy expenditure increases and is known as diet-induced thermogenesis (DIT). The processes involved in digesting food, about which

there will be more said in Chapter 3, take a lot of energy. The admonition not to eat just before taking exercise is based on the premise that the body will be stressed by the competing demands for energy. (Also, the food entering the stomach can stretch the stomach and put pressure on other organs in the vicinity.) Over 24 hours, the work required to digest meals can account for as much as 10% of TEE.

- ◆ If you were to reduce the amount of food you ate over 24 hours, what would happen to the amount of energy expended?
- ◆ If you eat less food, you reduce your absolute energy expenditure (i.e. you reduce DIT).

This has repercussions for anyone trying to lose weight by eating less. When you eat less, the amount of energy you need for DIT decreases, thereby diminishing the effect of your efforts. This is a fairly small effect, but it is unhelpful.

Further energy expenditure is necessary to carry out everyday activities beyond the energy required for the BMR and DIT. Physical activity (such as walking) is the second highest user of energy at around 20–40% of TEE in people who are relatively sedentary. The value is noticeably different in very active individuals, as can be seen in Vignette 2.1 (overleaf). Obese people have higher energy expenditure when they undertake physical activity because they have a greater body mass to move. One small comfort for them: this time the body's conformation is working in their favour! However, as they successfully lose weight, they will lower their energy expenditure if their level of physical activity is unaltered, so can compensate for this by increasing the time and/or intensity of their exercise. The evidence is that there are many obstacles to taking exercise for overweight and obese people (see also Chapters 7 and 8), but that as they lose weight and improve their physical fitness it becomes easier and more pleasurable to undertake physical activities.

The amount of physical activity, apart from formal exercise, can vary considerably even between individuals who apparently lead very similar lives. Running rather than walking up stairs and fidgeting rather than sitting still can make big differences to the amount of energy used.

Table 2.2 shows estimates of energy expended during different activities for a 70 kg non-obese person.

Table 2.2 Estimates of energy expenditure per hour during different activities for a 70 kg non-obese person.

Form of activity	Energy expended/kcal h ⁻¹
lying still, awake	77
sitting at rest	100
typing rapidly	140
dressing or undressing	150
walking on level at 4.8 km h ⁻¹	200
jogging at 9 km h ⁻¹	570



Figure 2.7 Richard out training.

Vignette 2.1 Richard, Ben and their levels of physical activity

Richard (Figure 2.7) is in his twenties and, in addition to training for a career as a physiotherapist, he cycles competitively. Competitive cycling makes huge energetic demands and he has to plan ahead to ensure that these demands are met. For example, when he is in training and cycling 3 hours a day, he needs to ensure an intake of 5000 kcal; when he cycles 6 hours a day, this has to go up to 7000 kcal. Richard points out that cycling is one of the few sports where eating is compatible with exercising – in fact, on the long rides it is essential to eat or he has insufficient energy to make the final burst to the finishing line. The kinds of foods he uses are liquid energy drinks and concentrated-energy cereal bars. Richard says he finds it hard to eat enough when he is in training and he also uses a body monitor to make sure that his body fat does not drop below 11%. His BMI is usually a healthy 22–23.

Richard and his friend Ben notice a story in the local newspaper about a young man of a similar age to themselves who has a genetic disorder called Prader–Willi syndrome that causes compulsive eating. The paper reports that this young man consumes 5000 kcal a day, at a cost of £9000 a year, and now weighs 40 stone and is unable to move out of his chair. Richard remarks that this dramatically demonstrates how lack of exercise causes obesity. Ben is not so sure. He points out that, unlike Richard, he has never been keen on exercise. He left school to work as a scaffolder 6 years ago and the two young men have remained exactly the same size, even able to borrow each others' clothes when going out.

A year after this conversation, Ben got a job driving buses and put on 2 or 3 stone (13–19 kg) rapidly, despite not changing his eating habits or his (almost non-existent) exercise habits. Richard tells Ben that 'exercise' does not have to be a formal sporting activity and Ben is now convinced that as a scaffolder he was actually taking a great deal of exercise. Ben started to exercise at the local gym and returned to a scaffolding job. Within a year he had lost all the weight he had gained as a bus driver.

2.8 Controlling weight

You are now in a position to consider the problems that face every individual in relation to keeping to a comfortable and static weight. The only way this can be achieved is by exactly balancing energy intake and energy expenditure. Yet most people live varied lives from day to day; varied in the types and amounts of food they eat and varied in the amount of activity they undertake. In this section, we consider whether it is possible that, just as activities such as breathing and temperature regulation occur without conscious thought, the body has mechanisms that enable it to maintain a stable weight without the individual having to think about what they are doing.

2.8.1 Homeostasis

As mentioned in Section 1.7, the body has a remarkable ability to regulate its activities without any conscious input being made. Important variables critical for life are held within limits and are said to be *regulated variables*. A well-known

example is body temperature. An often-used measure for determining whether someone is unwell is to ‘take their temperature’ using a clinical thermometer. The thermometer is marked at 36.5 and 37.5 °C, and if the temperature reading falls between these two marks, the person is deemed to be well as their body temperature is being maintained at around 37 °C. This level allows normal physiological activity, i.e. the body systems involved in maintaining temperature are functioning normally. (**Physiology** is the study of the relationship between structure and function of body systems.) The normal functioning involves a self-regulating mechanism whereby any deviations from optimum conditions in the body tend to cause responses that return the system to the optimum.

Staying with the temperature example, when our body temperature falls, we start to shiver. This comes about because there are *neural* mechanisms mediated by specialised neurons (nerve cells) that detect the drop in body temperature and signal this information to the brain. The brain signals to muscles to start shivering, and the heat generated by these muscle movements will tend to return body temperature to normal. In the 1930s, the US physiologist Walter Cannon coined the term **homeostasis** to describe the various physiological systems which serve to restore the normal state, once it has been disturbed.

Homeostasis is an essential biological principle with two important and related aspects:

- life is only possible provided that certain key variables of the body are maintained within limits
- deviations from these optimum conditions in the body tend to cause responses that return the system to the optimum.

The type of response that we examined above (shivering in response to a fall in temperature) is an example of a **negative feedback** response. Negative feedback is the process by which a control mechanism reacts to a change in the output of the system by initiating a restoring action (Figure 2.8). Negative feedback systems maintain a preset state, so they are stable and an important feature of homeostasis.

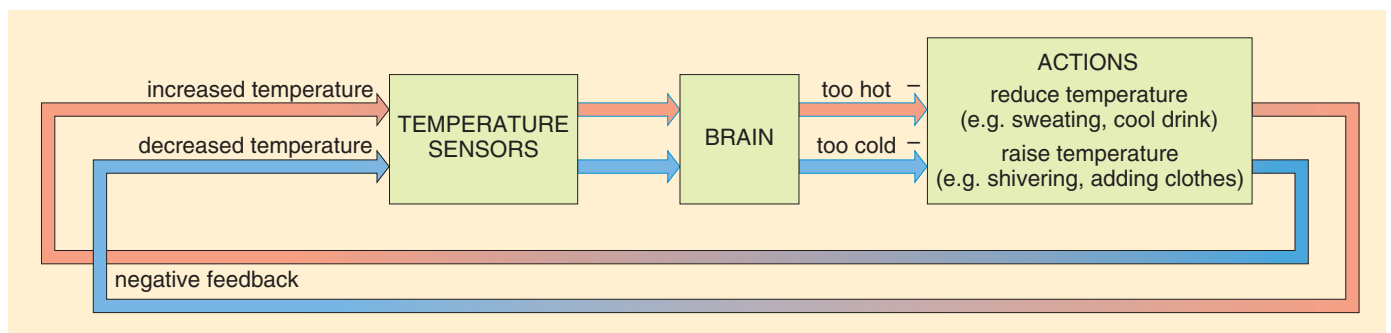


Figure 2.8 The principle of negative feedback, with body temperature as an example. The brain’s action is based on a comparison of the actual body temperature (from information provided by the temperature sensors) against an optimum value, which is set by the brain. If body temperature is not optimum, the brain then triggers action that will result in a body that is too hot being cooled (e.g. by sweating) or a body that is too cold being warmed (e.g. by shivering). These subsequent changes are *fed back* to the brain, *negating* the effects of the original, non-optimum situation and restoring body temperature to the optimum value. (The minus sign (–) represents this *negative* feedback in action, i.e. ongoing actions are inhibited.)

Although negative feedback is crucial in re-establishing normal conditions when deviations occur, it is not the only homeostatic mechanism involved in the maintenance of the body's internal environment.

- ◆ Think about your own experiences and try to recall some examples of where homeostasis is maintained by your *behaviour*, even though no deviations from normal have yet happened.
- ◆ In winter you might put on warm clothes before leaving your centrally heated home. You may eat breakfast even though you do not feel particularly hungry.

Such anticipatory actions are, in effect, a process that is termed **feedforward**, to distinguish it from feedback control where the response is to a disturbance that has already occurred. The above examples of feedforward are forms of behaviour that we perform in full consciousness of their effects and with this purpose in mind. In fact, there are other, involuntary feedforward mechanisms which also play an important role in homeostasis. You will learn more about these, particularly in Chapters 4 and 5.

Many of the regulated variables, such as body temperature, that are defended by homeostatic mechanisms are held nearly constant, regardless of circumstances. So it may seem strange to be suggesting that body weight is also a regulated variable, given the very substantial variation that we can observe both over the course of a lifetime and from one person to another. However, it is often argued that the relatively small degree of individual variation in body weight over short time periods implies that there must be some regulation. In addition, as you will see later in this book, there is a series of hormonal and neural mechanisms influencing energy intake that have many of the characteristics of a homeostatic system. Of course, body weight may also change – perhaps permanently – with changes in the environment. A plentiful supply of highly palatable food will increase the likelihood that humans (and their household pets!) become obese. However, even in this case, the typical pattern is for weight to increase and then be held, i.e. plateau at a new and higher level. Thus for body temperature it seems realistic to talk of a set point, even if we cannot identify its location in the body, whereas for feeding we often talk in terms of a sliding set point or a settling point. Despite this cautionary note, it still seems appropriate to discuss obesity in terms of failure of – or disturbance in – a homeostatic system.

2.8.2 Why homeostasis fails

How might automatic body weight regulation be achieved? To answer this question, you need to know more about eating behaviour (Chapter 5) and how food is digested and nutrients absorbed (Chapter 3) and then metabolised to provide energy or moved into storage (Chapter 4).

If you make the assumption that there is a homeostatic mechanism at work, but that it is currently failing to keep on top of the situation in many societies, then the following activity should help you to identify some possible reasons why this homeostatic mechanism is currently failing.

Activity 2.1 What does my body tell me?

Allow 10 minutes for this activity

In relation to energy intake, list any regulating body signals to which you respond: what makes you start eating and what makes you stop?

In relation to energy expenditure are you aware of any regulating body signals to which you respond?

Now look at the comments on this activity at the end of this book.

From the lists you generated in Activity 2.1, were there any signals that might predispose you towards achieving a positive energy balance? In other words, why might someone living in a modern urban environment eat more than they need and/or fail to utilise their energy intake to avoid gaining weight?

If you look at our list at the end of this book, the underlying factors that appear relevant are:

- ready availability of highly palatable food
- the fact that for many people to get from A to B does not require much physical energy because they use some other form of transport (Figure 2.9).

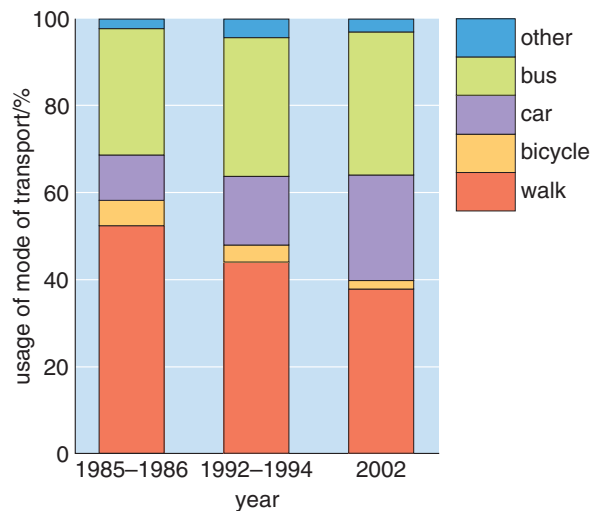


Figure 2.9 Modes of transport used by children aged 11–16 to get to school in the UK: trends over three decades, 1985/6–2002.

In Chapter 8 you will look in more detail at the effect upon a person's energy balance that could result from making the change from taking a bus to walking to school. You will also examine the effect of making a small but consistent reduction in eating habits, such as removing a packet of crisps from a lunch box. Meanwhile, study the graph shown in Figure 2.10, which shows the increase in the number of 'fast food' outlets opening in Singapore over the period from 1975–1995 and the prevalence of diabetes during that same period.

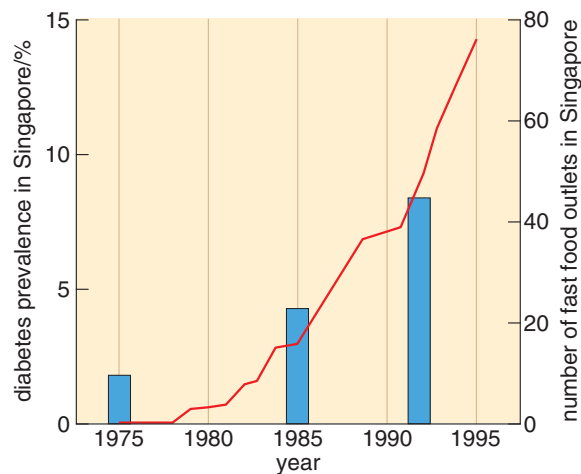


Figure 2.10 The number of ‘fast food’ outlets in Singapore over the period 1975–1995 (line) and the prevalence of diabetes (bars).

- ◆ Describe the relationship between the two variables in Figure 2.10.
- ◆ The Singaporean population was not free from diabetes in 1975 before the first ‘fast food’ outlet opened, but the increase in the number of people with diabetes follows the increase in the number of ‘fast food’ outlets.

Where one variable increases (in this case, the number of people with diabetes) as another variable increases (in this case, the number of ‘fast food’ outlets), there is said to be a **positive correlation** between the two variables.

You might be tempted to speculate that the increased availability of ‘fast food’ leads to people eating a less healthy diet and putting on weight. It is certainly true that obesity is an environmental risk factor for diabetes, but Figure 2.10 does not provide *evidence* for a causal relationship.

Indeed, it is true that much of the evidence implicating the obesogenic environment in the increase in the numbers of people who are overweight or obese is based on correlations such as that shown in Figure 2.10. Nevertheless, when you have read more about the way in which your body metabolises and responds to food, the evidence for the connection will become overwhelming.

2.9 Summary of Chapter 2

- 2.1 If energy intake exceeds energy expenditure, the body has a positive energy balance and will gain weight.
- 2.2 Energy is provided by the macronutrients – fat, carbohydrate and protein – in food. The WHO guidelines suggest that carbohydrate should provide 55–75% of a person’s daily energy intake.
- 2.3 Glucose (from carbohydrate), fatty acids and glycerol (from fat) and amino acids (from proteins) are the nutrient molecules that can provide energy for the body’s metabolic activity.

- 2.4 Fats yield more energy per gram than either carbohydrates or proteins.
- 2.5 Energy is released from nutrients within individual cells when and where it is needed. The energy is captured by a molecule called ATP, which almost immediately transfers this energy into other biochemical pathways.
- 2.6 For people leading relatively sedentary lives, the major part of their energy intake will be spent on general maintenance (staying alive), scientifically known as their BMR (basic metabolic rate). The absolute level of BMR is higher in obese individuals because they have a greater body mass to maintain.
- 2.7 Energy associated with digestion (DIT) can consume up to 10% of total energy expenditure (TEE). DIT expenditure will decrease if less food is consumed, e.g. when trying to lose weight.
- 2.8 Except in very sporty people, physical activity uses less than 40% of TEE.
- 2.9 Homeostasis describes the body's ability to hold many variables at a steady value, despite disturbances that alter these values.
- 2.10 Body weight does remain remarkably constant – in the short term, at least – and it is suggested that the development of obesity represents a failure of some of the body's homeostatic systems.
- 2.11 It might be that the body's homeostatic systems are failing under increasing pressure from an obesogenic environment.

Learning outcomes for Chapter 2

- LO 2.1 Define and use, or recognise definitions and applications of, each of the terms printed in **bold** in the text.
- LO 2.2 Explain the link between energy balance and body weight.
- LO 2.3 Outline the role of macronutrients, particularly in relation to providing energy.
- LO 2.4 Outline the role of ATP in cell metabolism.
- LO 2.5 Describe how energy expenditure relates to a variety of factors, including body weight.
- LO 2.6 Explain why the development of obesity is regarded as a failure of homeostatic mechanisms.

Self-assessment questions for Chapter 2

Question 2.1 (LOs 2.1 and 2.2)

Re-read Vignette 2.1 and state when Ben moves to a state of negative energy balance.

Question 2.2 (LO 2.3)

Is it true to say that amino acids are stored in the body as proteins, so that they can provide energy if neither carbohydrates nor fats are available? Explain your answer.

Question 2.3 (LOs 2.4, 2.5 and 2.6)

Which of the following statements about metabolism are true?

- (a) Energy can be stored for about 24 hours in any body cell as ATP.
- (b) Proteins are made from ATP.
- (c) The energy from food in the diet cannot be extracted without an input of energy.
- (d) The fact that body weight does not fluctuate dramatically in the short term suggests that body weight is a regulated variable.