16 Carbohydrates

Summary

Carbohydrates provide most of the energy in the diets of most humans. They are abundant in plant foods but not in animal foods. A diet low in carbohydrate must be relatively high in fat, protein and/or alcohol if it is to provide the same amount of energy; a diet very low in carbohydrate is associated with metabolic abnormalities. Man is better able to accommodate a high rather than a low carbohydrate diet.

Carbohydrates can be monosaccharides, disaccharides, oligosaccharides or polysaccharides. The sweetness of carbohydrates varies and there are non-carbohydrate sweeteners.

Diabetes is a condition in which the blood glucose concentration is too high due to insufficient insulin. Diet plays an important part in the development of the diabetes associated with obesity and with alcohol abuse. Diet is also important in the management of all types of diabetes.

Function of carbohydrate

The principal function of carbohydrate in food is to provide energy. There is variation in carbohydrate consumed throughout the world. Australians obtain 20 to 60 per cent of

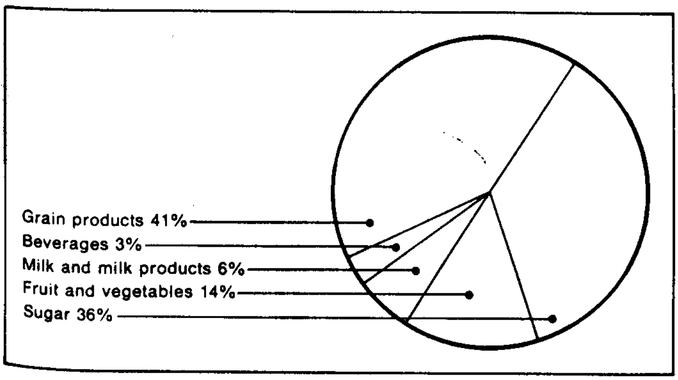


Figure 16.1 Relative contribution of different foods to carbohydrate energy in the Australian diet.

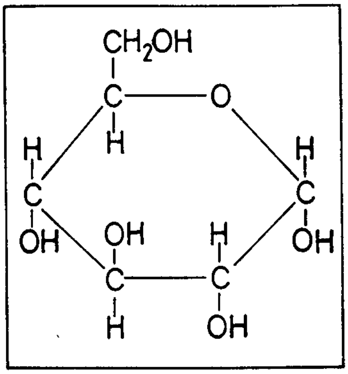


Figure 16.2 Glucose.

their energy needs from carbohydrate. Hunter-gatherers and subsistence farmers obtain 60 to 90 per cent of their energy needs from carbohydrates. It is unusual in traditional food cultures to find intakes as low as the 10 per cent in, for example, Dr Atkins weight-reduction diet.

Hunter-gatherers are usually more successful in gathering carbohydrate rich plants, roots and fruits than they are in hunting protein-rich animals. Studies of African Bushmen, for example, suggest that the sweet carbohydrate-rich foods (for example honey) were highly prized. Such foods may fulfil energy needs. Man has taste buds for sweetness (the others are for sour, bitter and salt), and the foetus and newborn also appear to favour the ingestion of sweetened liquids. Sweetness might draw attention to energy-dense foods, of importance to the survival of the physically active hunter-gatherer.

Carbohydrate has an energy value of 16 kilojoules per gram (4 kcal/g); alcohol 29 kJ/g (or 7 kcal/g) and fat 37 kJ (or 9 kcal/g) have higher values. Carbohydrate-rich foods, such as cereals, fruits, berries and vegetables, have their energy density lowered by the presence of non-absorbable carbohydrate (dietary fibre) and/or water.

The blood glucose, often called 'blood sugar', concentration is raised after a meal containing carbohydrate; it is maintained at other times by the body's own synthesis of glucose (gluconeogenesis*) or release of glucose from glycogen* stores. The nervous system, including the brain, can obtain the glucose it needs as an energy supply at any time. Gluconeogenesis can take place from amino acids, glycerol, lactic acid and pyruvic acid. With prolonged fasting, the brain can use ketone bodies (acetone, aceto acetate and betahydroxybutyrate) as fuels.

Gluconeogenesis: the new formation of glucose.

Glycogen: a storage form of carbohydrate in animal cells, such as liver and muscle. It is a polysaccharide consisting of a chain or polymer of glucose molecules.

Carbohydrate in food can be channeled into the body's fuel supply by conversion to fat, but the reverse cannot take place (see chapter 13, Metabolism).

In food, the functions of carbohydrate are to provide:

1. energy;
2. taste, including sweetness;
3. texture; and
4. appearance.

In the body absorbable carbohydrates provide:

1. fuel;
2. structure, mainly inter-cellular;
3. ribose for the synthesis of the nucleic acids DNA and RNA; and
4. sugar units that may be attached to proteins to make them functional.

In the body, non-absorbable carbohydrates (dietary fibre) contributes to:

1. gut function; and
2. modulation of nutrient absorption.

Carbohydrate chemistry

Carbohydrates contain carbon (C), hydrogen (H), and oxygen (O) atoms assembled into a molecule, such as glucose (figure 16.2), or two or more such molecules joined together. Sometimes nitrogen (N) is also found as an amino group (NH_2) in the sugar, which then becomes an 'amino sugar' (e.g. hexosamine).

Carbohydrates can be monosaccharides*, disaccharides* (figure 16.3), oligosaccharides* or polysaccharides* (figure 16.4). Another group is the glycosides, each formed from a sugar and one of a number of other substances. An example is the cyanogenetic glycosides found in cassava and apricot kernels (see chapter 25, Natural toxicants in food).

Monosaccharide: a carbohydrate consisting of one basic unit.

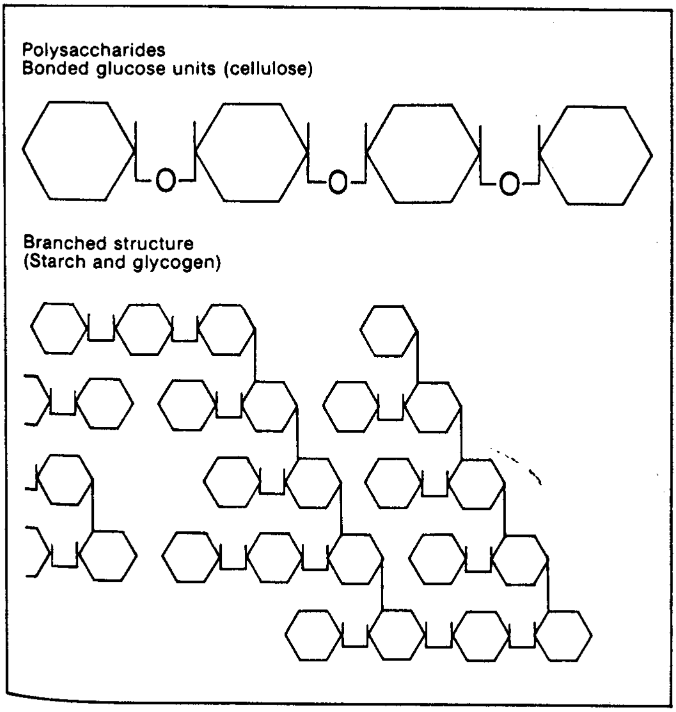
Disaccharide: a carbohydrate consisting of two basic units.

Oligosaccharide: a carbohydrate consisting of a few basic units.

Polysaccharide: a carbohydrate consisting of many basic units. Starch and glycogen are polysaccharides.

Carbohydrates in food

Natural carbohydrates are found principally in cereals, vegetables, and fruits and, to a lesser extent, in dairy products. They are also added to a host of food products. One of the reasons for the use of carbohydrates as food additives is their sweetness, but not all carbohydrates are equally sweet. For the purposes of comparison, sucrose is used as the reference carbohydrate. Fructose, derived from sucrose, is sweeter than sucrose itself.



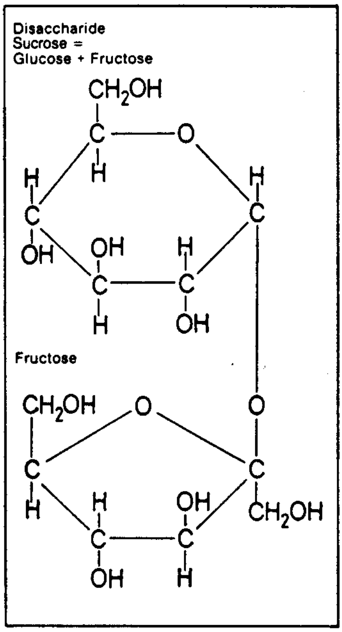


Figure 16.3 Disaccharide: sucrose.

Figure 16.4 Polysaccharides.

Table 16.1 Carbohydrate content of selected foods (per 100 gram portion)

Starch		*Oligo-saccharides*		*Sucrose*		*Lactose*		*Glucose*		*Fructose*	
HIGH CONTENT											
Rice	87 g	Molasses	55–70	Soft drinks	10 g/100 ml			Grapes	6 g	Grapes	6 g
Bread: wholegrain wheat flour	40 g			Biscuits Confectionery	15–35 g 40–100 g						
wholegrain white flour	48 g			Breakfast cereals: sugar frosties	40 g						
Spaghetti	81 g			sweetened muesli	20–40 g						
Biscuits	20–50 g			All-Bran	15 g						
Haricot beans	43 g										
Lentils	51 g										
Potato	8–20 g										
MEDIUM CONTENT											
Peas	7 g	Beans	0.2 g	Flavoured milk (added sucrose)	4 g	Milk (fresh cow's)	5 g	Berries	2 g	Berries	2 g
Broad beans	7 g			Yoghurt (flavoured added sucrose)	9 g	Yoghurt	4–5 g	Yoghurt	1–2 g		
Sausages, (Australian) grilled	up to 6 g			Tomato sauce Grapes	3–4 g 1–2 g	Cream	2–3 g	Pumpkin Tomatoes	1 g 1 g	Pumpkin Tomatoes	1 g 1 g
								Sweet white wine	3 g	Sweet white wine	3 g
LOW CONTENT											
Meat and most meat products											
Oils, butter, margarine, cheese											
Vegetables such as lettuce, parsley, radish											

The most commonly encountered food carbohydrates are shown in table 16.1 according to the kind of food in which they occur and their relative concentration. All these carbohydrates contribute energy in similar ways. The energy contribution from carbohydrates in many foods can be doubled readily by the addition of sucrose, commonly called 'sugar', either in food manufacture (of which we may or may not be aware) or at the table, where we can control the amount added.

There has been a suggestion that fructose, as such or derived from sucrose, may have nutritional properties different from glucose. It is, for example, less dependent on insulin for its utilization. More importantly, some individuals cannot handle certain carbohydrates. Although all humans can digest lactose (milk sugar) at birth, only about 15 per cent of mankind (mainly Europeans) can accomplish this after about four years of life. Therefore, the universal use of milk or milk products in which lactose has not been broken down to glucose and galactose is not possible without lactose malabsorption occurring. In yoghurt, this breakdown is partially accomplished, and this is a traditional food of some lactose-intolerant groups. The ability to hydrolise starch is acquired in the first few months of life and allows the consumption of solid foods in preference to milk. More rarely, some individuals cannot metabolise carbohydrates like galactose or fructose. See chapter 8, Food processing, and chapter 10, Food preparation, for further discussion of carbohydrates in food.

Carbohydrate metabolism in man

The sources of glucose in the blood are:

1. From food after digestion and absorption. Galactose and fructose, also obtained from dietary carbohydrate, are converted to glucose in the liver.
2. From the body itself, from:

(a) glycogen stores: starch is the glucose storage form in plants; glycogen is the storage form in animal tissues. Glycogen stores are principally in liver and muscle (skeletal, cardiac and smooth muscle); or

(b) gluconeogenesis: this is the new ('neo') formation ('genesis') of glucose. Ordinarily this occurs in the liver, but after a prolonged fast, it occurs in the kidney as well. Gluconeogenesis maintains the blood glucose at about 3.5–5.0 mmol/l overnight and during prolonged exercise. During exercise glycogen is also mobilised.

Gluconeogenesis can take place from amino acids, lactic acid, and glycerol, but not from fat (see chapter 13, Metabolism). However, the mobilisation of free fatty acids from adipose tissue as an energy source in the fasting state is one factor that stimulates gluconeogenesis.

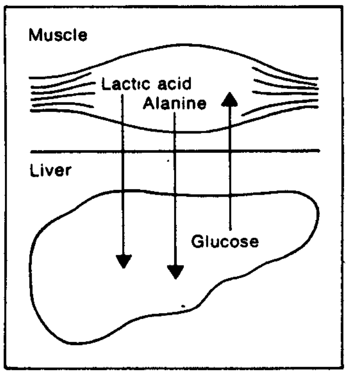


Figure 16.5 Regeneration of glucose for muscle from lactic acid and alanine produced by muscle during its metabolism.

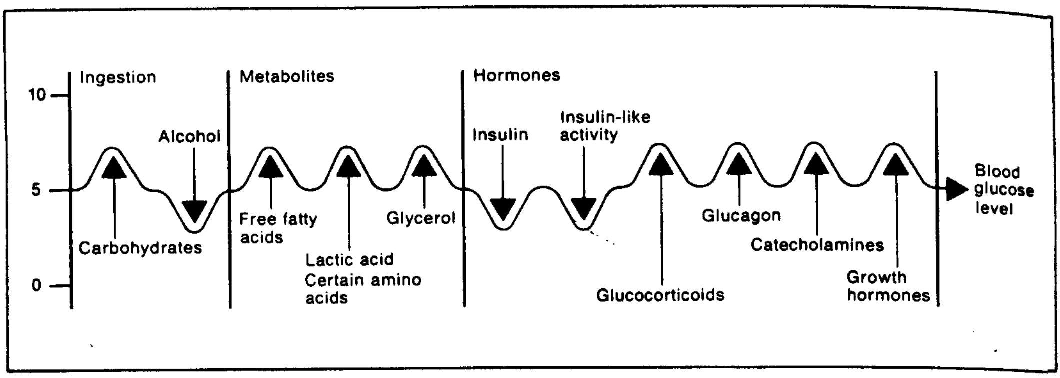


Figure 16.6 Regulation of blood glucose concentrations by ingestion of different foods and beverages, products of metabolism and hormones.

Both lactic acid and the amino acid alanine are released from skeletal muscle during exercise and reconverted to glucose in the liver, the glucose is then available for muscle. These events have been described as the lactic acid (Cori) and glucose-alanine cycles (see chapter 13, Metabolism).

There are several reasons for the need to maintain a continuous supply of glucose in the blood, including the following:

1. There is always a minimal need for glucose even at basal metabolic rates for the maintenance of energy-producing pathways (the citric acid cycle in particular).
2. Glucose is an essential energy source for the nervous system and for red blood cells, except when the body has adapted the use of ketone bodies because of prolonged fasting or starvation.

The regulation of blood glucose is achieved by a number of factors affecting its entry into blood and its disposal (figure 16.6).

Insulin: the only hormone that has been established that will lower blood glucose. It is a small protein produced in the beta cells of the pancreas, and it acts principally on liver, muscle and fat cells.

Insulin* not only increases the uptake of glucose in peripheral tissues, such as skeletal muscle and heart (cardiac) muscle, but also enhances glycogenesis (formation of glycogen) and suppresses gluconeogenesis.

The regulatory roles of insulin extend beyond carbohydrate metabolism; it also has the following effects:

1. it lowers blood glucose;
2. it lowers blood amino acids and promotes protein synthesis;
3. it lowers plasma free fatty acids and triglyceride concentrations; and
4. it affects the body's immune system.

Anabolic: the building-up of molecules.

Catabolic: the breaking down of molecules.

Insulin has been described by Dr George Cahill of Harvard University in Boston as the hormone of the fed state. It responds to the rises in blood glucose and amino acids after meals and moves them into cells. It is an anabolic* hormone that increases glycogen, protein, and fatty acid synthesis. Hormones that act in the opposite direction are catabolic*. By the same token, the lack of insulin will be associated with catabolism.

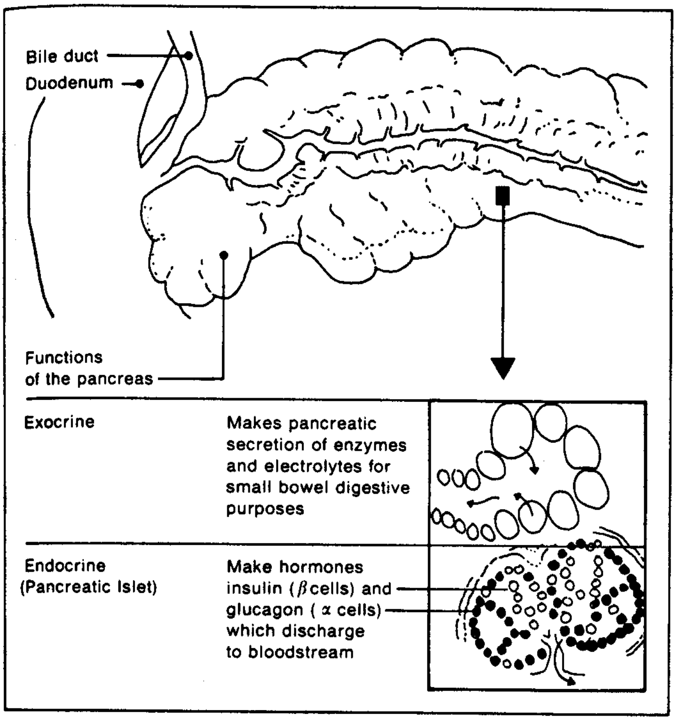


Figure 16.7 Insulin is produced by cells in the islets of the pancreas known as ß cells. The islets are the hormone-producing or endocrine part of the pancreas. The exocrine part of the pancreas makes digestive juice.

Dental caries

The presence of dental caries or tooth decay is one of several nutritionally related diseases of the mouth.

The extent of dental caries is generally indicated by the DMF index. This is a score for dental caries which expresses the extent to which teeth are decayed (D), missing (M), and filled (F). In 1959, Australian 11 to 12-year-olds had a DMF of 11, compared with about 9 in the U.S.A. and Great Britain, 4 in Japan and less than 1 in China. The corresponding per capita sugar consumptions were respectively, about 52 kg, 48 kg, 52 kg, 15 kg and 2 kg. Generally, the higher the sucrose consumption, the greater will be the prevalence of dental caries.

Although the presence of carbohydrate in the mouth is essential for the development of dental caries, it alone is not responsible. The four factors recognised are shown in figure 16.8. Not all individuals are equally susceptible; it is still not fully understood what contributes to the variation in this host factor. The longer the carbohydrate is present in the mouth, the greater likelihood of damage to the teeth; this is the time factor. The role of bacteria as a component of dental plaque and in the development of dental caries is shown in figure 16.9. Bacteria that have been incriminated include

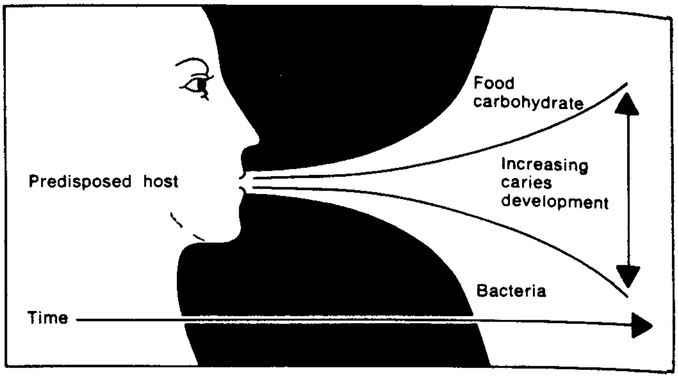


Figure 16.8 Food is not the only factor in the development of tooth decay.

Streptococcus mutans and *Streptococcus sanguis*. The bacteria not only generate enamel-damaging acids such as lactic acid from carbohydrates, but also form the insoluble polysaccharides of the plaque.

The following factors reduce dental caries:

1. the improvement of salivary flow by chewing certain foods;
2. drinking water with meals;
3. preference for unrefined over refined carbohydrate foods*;
4. fluoride intake;
5. mechanical removal of dental plaque, by chewing sticks in traditional societies, toothbrush in western society (devised by the Chinese in the fifteenth century);
6. the use of antibacterial agents; and
7. possibly the consumption of milk.

Refined carbohydrate foods: characterised by having little or no dietary fibre in association with them.

The school tuckshop has been the centre of much debate in regard to dental caries. Initially some tuckshops were set up as fundraising efforts without the question of types of food to be sold being an issue. Recently many school canteen managements have adopted a policy of selling only food unlikely to promote dental caries. It is now clear that any profits made by selling undesirable items are more than offset by the added costs incurred by the extra dental caries. And this costing does not take into account the wider nutritional

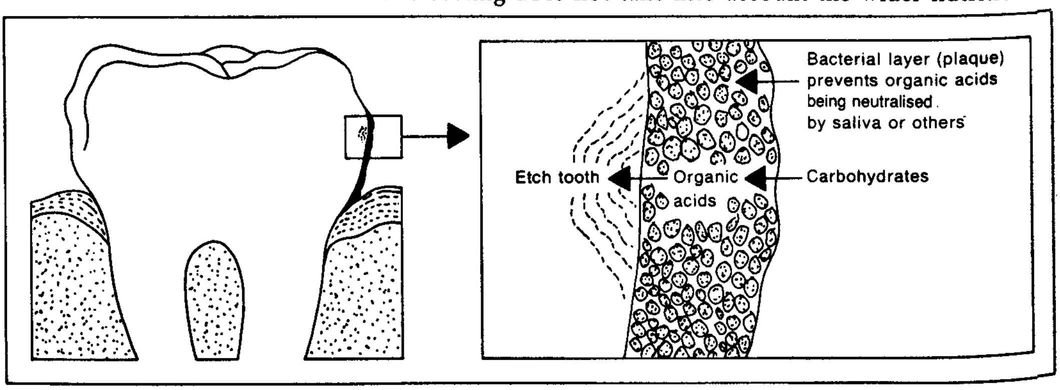


Figure 16.9 The development of plaque-containing bacteria facilitates damage to the enamel of the tooth by organic acids produced by the bacteria.

and health consequences. The educative role of the school canteen in health and nutrition is now appreciated, especially when combined with curriculum activities and endorsed at home.

Diabetes mellitus

Diabetes mellitus is that condition in which there is insufficient insulin to maintain blood glucose in the normal range. The World Health Organization now recommends that glucose tolerance, or the body's handling of glucose, be assessed by measurement of blood glucose for two hours after ingestion of 75 g glucose in the fasting state. The acceptable limits are shown in figure 16.10.

Symptoms of diabetes are excessive thirst and excess passage of urine because osmotically* active glucose is being excreted in the urine. More water is required to handle the glucosuria (glycosuria)*. Glucose generally 'spills over' from blood into urine when blood concentrations are above 10 mmol/l, the normal renal threshold*.

The classical situation in which blood glucose concentrations outside the normal range are found is in juvenile-onset diabetes (JOD) where there is little or no insulin secretion by the beta cells of the islets of the pancreas which are responsible for the body's insulin production.

However, a relative lack of insulin can also occur. In maturity onset diabetes (MOD), despite higher than normal plasma insulin concentrations, blood glucose concentrations are still abnormally high. This suggests that there is resistance to insulin action. In most maturity onset diabetes, obesity is present, and this is thought to lead to the insulin resistance. There is actually a strong genetic predisposition to MOD in certain families, but it does not manifest unless obesity develops. Most MOD is preventable and families known to have the condition should be strongly counselled against becoming overweight. Furthermore about nine out of ten diabetics in Australia are of the MOD type, so most diabetes in Australia is preventable.

Many people think that sugar (sucrose) damages the pancreas and thereby causes diabetes. There is no good evidence for this. It is not correct to think that because diabetics are discouraged from having refined carbohydrates like sucrose that sucrose is a cause of the disease. Alcohol, on the other hand, can damage the pancreas.

Complications of diabetes

The complications of diabetes can be grouped as acute or chronic. Acute indicates rapid development, and chronic indicates slow development of the problem. Acute complications can be blood glucose at too low a level (hypoglycaemia) or blood glucose at too high a level (hyperglycaemia). Both can lead to coma. Chronic complications affect blood

Osmotically: osmosis is the movement of solvent molecules across a membrane into an area in which there is a higher concentration of solute to which the membrane is impermeable. An osmotically active substance is one which produces an osmotic effect. Glucose raises the osmotic pressure of the urine.

Glucosuria/glycosuria: glucose in the urine.

Renal threshold: the blood glucose concentration above which glucose will spill over into urine and be excreted by the kidney. It is generally about 10 mmol/l, although normally blood glucose concentration does not rise above 7 to 8 mmol/l.

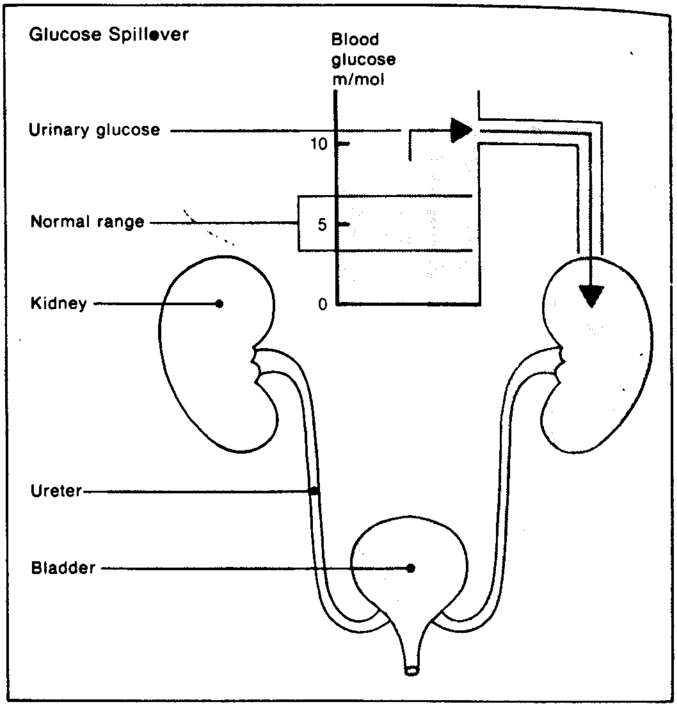


Figure 16.10 Glucose is found in the urine when blood concentrations exceed the 'renal threshold', usually about 10 mmol/l. However, normal blood glucose concentrations range between about 3 and 8 mmol/l.

vessels, nerves, the kidneys, and the eyes. Infections are also more common in uncontrolled diabetes.

Nowadays the acute complications rarely contribute to diabetic deaths; the major cause of death is macrovascular disease. Microvascular disease is more likely if blood glucose is inadequately controlled; in macrovascular disease blood lipids are also often inadequately controlled.

Hypoglycaemia occurs when excessive insulin or tablets that lower blood glucose are used by the diabetic. Alternatively, if a diabetic on insulin does not eat, hypoglycaemia will develop. Exercise without extra carbohydrate intake by the diabetic can also result in hypoglycaemia for two reasons: more glucose is used during exercise and insulin works better during exercise.

Hyperglycaemia in insulin-dependent diabetics can be associated with a rise in ketone bodies (acetone, acetoacetic acid, betahydroxybutyric acid) in blood; both reflect inadequate insulin. The disturbance in acid-base, electrolyte and fluid balance are the causes of coma.

Diet and diabetes

The dietary factors that could be responsible for the cause or development of diabetes include the following:

1. excessive energy intake over needs (obesity);
2. alcohol abuse;

3. iron overload in susceptible individuals, leading to 'haemachromatosis' (rare); and
4. food toxins (not proven).

Management of diabetes includes a diet characterised by the following elements:
1. high carbohydrate intake (50 per cent energy intake);
2. high dietary fibre intake (30 grams a day from a variety of sources);
3. low fat intake (35 per cent energy intake); and
4. little alcohol intake (two or less standard drinks a day).

High carbohydrate. The contribution to energy of carbohydrate in the diabetic diet resembles that in the population at large, although this is often not generally recognised. Thus, in Japan, energy from carbohydrates is about 60–70 per cent and in Australia about 40 per cent. There has been no evidence that those diabetics on a high carbohydrate diet do less well. Indeed, when dietary carbohydrate is restricted, even in healthy subjects, glucose tolerance can be impaired. Epidemiological studies* indicate that diabetes is less prevalent in areas where total carbohydrate intake is higher.

Epidemiological: relating to the patterns of disease in a population.

If the body's insulin response to dietary carbohydrate is deficient or glucose disposal is impaired, even distribution of carbohydrate intake throughout the day is recommended. However, as newer insulin delivery systems (artificial pancreas) become available, even this advice may be unnecessary.

Provided the energy intake does not change, a higher proportion of carbohydrate in the diet means that a smaller amount of fat will be consumed. This allows the diabetic to lower blood fats and reduce the risk of atherosclerosis.*

Atherosclerotic vascular disease: hardening of the arteries due to the accumulation mainly of lipids in the inner arterial wall.

High fibre. Population observations indicate that those that have a high fibre diet have less diabetes. Studies of different fibre sources and types (see chapter 17, Dietary fibre) show that in healthy subjects and in diabetics the rise in blood glucose after eating, and the insulin response, where present, are less when fibre is included in the diet. A high fibre diet may help avoid maturity onset diabetes where a genetic predisposition and obesity are present. Fibre itself may not

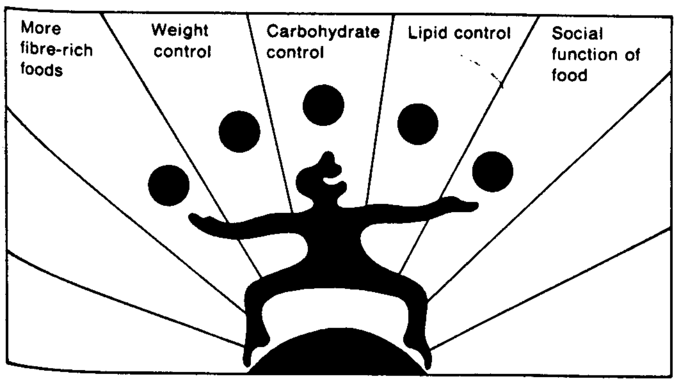


Figure 16.11 Diabetics, like non-diabetics, must ensure an adequate nutrient intake by having a variety of foods: dietary-fibre-rich foods are generally nutrient dense and their use helps weight, carbohydrate and lipid control.

be the only active food component. It may be that food components other than dietary fibre or physical characteristics conferred by fibre are the means by which high fibre foods have their effect on blood glucose.

Nutritional priorities for diabetics
1. Weight control
2. Carbohydrate control
3. Lipid control
4. Social function of food

In the present management of diabetes, one of the difficult aspects of carbohydrate control is hyperglycaemia after eating. An increase in dietary fibre is likely to be a significant contribution to this aspect of diabetic control. It would also appear that dietary fibres of certain types could contribute to the lipid-lowering potential of a diet.

Diabetic management can be more flexible and acceptable on a high rather than a low carbohydrate diet. Items such as wholemeal bread, fruit, potatoes, and peas can be included more often. It is necessary to examine the effects of intact foods on diabetic control rather than be limited to predictions on the basis of food composition tables in respect of absorbable carbohydrates. Indeed, there could be factors in addition to fibre, such as amylase inhibitors and glucose tolerance factor, that could modify blood glucose concentration. An emphasis on wholegrain cereals, fruit and vegetables in diabetic diets can be expected to raise the daily fibre intake from present Australian intakes of about 15–20 g a day to more than 30 g a day. It is wise to encourage a variety of dietary fibres to be ingested since each, potentially, has a different mode of action.

Further reading

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Questions

1. In the foods you eat, where is there most carbohydrate and of what kind is it? (See chapter 26, Food composition tables.)
2. Categorise high carbohydrate foods into nutrient dense and energy dense. (See chapter 1, Nutrition.) Does it matter?
3. How do you think the changing food patterns in Australia are likely to contribute to dental caries prevalence? (See chapter 2, History of Nutrition in Australia, and chapter 4, Australian eating patterns.)
4. To what extent do the eating and drinking habits of Australians increase the chances of developing diabetes?
5. Consider the following statements from a packet of raw sugar.

(a) For good health your body needs exercise, rest, fresh air, and a balanced diet.
(b) Sugar plays a part in a balanced diet and provides energy for your muscles to function at peak efficiency.
(c) Your body quickly converts sugar into glucose and fructose for instant or later use.
(d) These sugar forms quickly combine with oxygen in your blood stream to give immediate energy.
(e) Fructose and glucose not immediately used are stored in your muscles and liver as glycogen, which is later converted to energy when you need it.

To what extent do you think these statements are nutritionally correct?

FOOD & NUTRITION IN AUSTRALIA

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