BRIEFING PAPER

Vegetarian nutrition

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Summary

The number of people in the UK who claim to be vegetarian has increased dramatically during the last half century; statistics from the Second World War suggest that 0.2% of the population were vegetarian in the 1940s and it is estimated that, in 2000, between 3 and 7% of the population were vegetarian.

There is much interest in the potential effects of plant-based diets on a range of health outcomes and nutrition. A range of dietary practices followed by vegetarians has been identified, from the strict guidelines of the most restrictive macrobiotic diets, through vegan and lacto-ovo-vegetarian diets, to those that occasionally include fish or even chicken. The type of vegetarian diet followed by an individual may reflect the motive to be vegetarian; motives for being vegetarian include, amongst others, ethical and ecological issues, health concerns, sensory and taste preferences and philosophical teachings.

In addition to dietary choice patterns, vegetarians may differ from meat-eaters in a range of lifestyle behaviours: smoking habits, alcohol consumption, activity and leisure patterns and use of alternative therapies are all cited as examples. Furthermore, the body mass indices of vegetarians and vegans are typically 1–2 kg/m^2 lower than matched omnivores. It is therefore important to remember this complex web of dietary and non-dietary differences when interpreting the results of studies comparing vegetarians with meat-eaters, as such comparisons are not straightforward.

In terms of nutrient intakes, the key nutritional issue for vegetarians and vegans is whether the nutrients supplied by meat and fish, in an omnivorous diet, can be provided in adequate amounts in foods that are acceptable to vegetarians and vegans. In the UK, for example, meat and meat products provide a major contribution to intakes of protein, iron, zinc, vitamin B_{12} and vitamin D. Conversely, compared with omnivorous diets, plant-based diets are reported to contain more folate, fibre, antioxidants, phytochemicals and carotenoids. Vegans, however, may have low intakes of vitamin B_{12}, vitamin D, calcium and iodine. UK studies comparing lacto-ovo-vegetarians, vegans, fish-eaters and meat-eaters have shown that lacto-ovo-vegetarians and vegans obtained a considerably lower proportion of dietary energy from total fat and saturated fatty acids (saturates) than fish-eaters and meat-eaters. Vegetarians and meat-eaters alike are advised to limit their intake of atherogenic saturates.

A well-planned, balanced vegetarian or vegan diet can be nutritionally adequate, although more extreme diets, such as strict macrobiotic and raw food diets, are often low in energy and a range of micronutrients, making them wholly inadequate and inappropriate for children. Weaning onto a vegetarian diet follows the same principles as weaning onto an omnivorous diet, although care must be taken to ensure that a vegan diet is sufficiently energy- and nutrient-dense for children. Studies of UK vegetarian and vegan children have revealed that their growth and development are within the normal range.

A number of studies have attempted to determine whether being vegetarian confers any protective effect, in terms of mortality and morbidity, from a range of chronic diseases. Evidence from a few large cohort studies suggests that vegetarians have lower overall mortality ratios than the general population, but this is not the case when vegetarians are compared with similar non-vegetarian groups who follow a health-conscious lifestyle. Vegetarianism has been associated with a reduction in several of the established risk factors for coronary heart disease, including more favourable blood lipid profile, lower body mass index and lower blood pressure. However, some studies suggest that vegetarians and vegans may be at greater risk of having raised plasma homocysteine levels, an emerging risk factor for cardiovascular disease.

Although a high intake of plant-derived foods has been linked with a reduced risk of certain cancers, there are no clear and consistent patterns of cancer incidence and mortality between vegetarians and meat-eaters. Several studies have reported an increased risk of colorectal cancer among those with the highest intakes of meat and the lowest intakes of dietary fibre, but there is no evidence that being vegetarian *per se* confers a protective effect.

More research is needed to establish whether vegetarianism has a role to play in protection against a range of other diseases that are less prevalent amongst vegetarian populations; lifestyle as well as nutritional differences will need to be taken into consideration. Following a vegetarian diet does not automatically equate to being healthier; vegetarians and meat-eaters alike need to be mindful of making appropriate dietary and lifestyle choices.

1 Introduction

There is much interest in the range of dietary practices followed by vegetarians, both in terms of the nutritional content of vegetarian diets, and health and mortality rates among vegetarians. In parallel with this, there is a growing awareness of the potential benefits of plant-based diets (BNF 2003), and even those who include meat in the diet are advised to eat more plant-derived foods.

Vegetarianism has become more popular in recent years, and a body of information is now emerging that provides an insight into the differences between those following an omnivorous diet and those following plant-based diets. Despite the popular opinion that vegetarianism is a healthy option, there are some areas for concern and careful planning is necessary to ensure that the diet is well balanced.

2 Vegetarianism: trends and types

2.1 Contemporary vegetarianism in the UK

Avoiding some, or all, foods of animal origin is not a new concept nor is it simply a contemporary phenomenon. Although the term *vegetarian* was not coined by the Vegetarian Society UK until the mid-19th century, the practice of vegetarianism would seem to date back to early man (Spencer 1994). Palaeontologists in East Africa have unearthed remains of early hominids whose dentition suggests that they were primarily vegetarian, as they had broad, flat teeth that would be unsuited to an omnivorous diet (Wilson & Ball 1999). There have, throughout history, been groups of people who have chosen not to eat meat, often in the context of particular ideologies, and some of these motives, in particular religious reasons for being vegetarian, are still apparent today.

During the 20th century, there was a shift in motives for being vegetarian. In the 1940s and 1950s, avoidance of meat, although uncommon, was often considered to be linked with religious beliefs (see Appendix A for a list of dietary restrictions in religious groups). In the 1960s and 1970s, a person who did not eat meat was often assumed to be part of an antiestablishment (or alternative) movement, using their dietary choices to make a political or other form of statement (Weinsier 2000). Now, vegetarianism is more acceptable to the mainstream population in the UK, with motives including religious, health and animal welfare concerns.

In the UK, the number of vegetarians has increased substantially during the last half century, although estimates vary greatly and are not precise. Figures from the Second World War (1940s) suggest that about 0.2% of the population were vegetarian during times of rationing (Spencer 1994). By 1980, the proportion of vegetarians had risen to 1.8% (Mintel 1995). Recent estimates show that between 3 and 7% of the UK population are vegetarian (Povey *et al.* 2001; Robinson 2001) and in the latest National Diet and Nutrition Survey (NDNS) of adults (Henderson *et al.* 2002), 5% of respondents reported that they were vegetarian. The growth of the vegetarian ready-meals and convenience foods market, and the increased availability of vegetarian options in catering outlets and restaurants in the UK, gives vegetarians a wider choice of foods and makes being vegetarian easier than perhaps 20 years ago.

Vegetarianism is certainly more popular amongst certain groups in the UK. For example, there seems to be a relationship with gender, women being more likely to be vegetarian or meat-avoiders than men (Beardsworth & Keil 1991; Henderson *et al.* 2002). Class differences also exist, although there is no linear trend. Most meat-avoiders being in the C1 group, followed by the A and B groups, and there are considerably fewer meat-avoiders in the lower social groups C2, D and E. In other studies, vegetarians have been identified as more likely to be female, white, middle class, educated to university level and living in the South of England (Realeat 1995; Keane & Willetts 1996).

It is notoriously difficult, however, to obtain an accurate estimate of the number of UK vegetarians because there is no single, accepted definition of 'vegetarian'.

2.1.1 Defining vegetarianism – a range of diets

There are a variety of reasons why people are vegetarian, or choose to avoid some or all animal products, although for the majority of people in the world who do not eat meat, the reasons for having a plant-based diet are economic or geographic in nature (Rottka 1990). In the UK, the reasons cited for being vegetarian commonly include: ethical and ecological reasons (including animal welfare); health concerns; sensory and taste preferences; philosophical reasons (*e.g.* religious teachings such as Buddhism or membership of the Seventh-Day Adventists); cost; family influences; or as a reaction to food safety scares, such as Bovine Spongiform Encephalopathy (BSE), *E. coli*, salmonella or the use of antibiotics or growth hormones in meat production (Richardson *et al.* 1993; Cathro 1994; Sanders & Reddy 1994; Sabate *et al.* 2001).

Consequently, the vegetarian diet adopted by a person may be influenced, to some degree, by their motives, and a range of dietary patterns of professed vegetarians coexist. Table 1 summarises definitions of a range of vegetarian diets. Appendix B lists animal-derived food products avoided by vegetarians and vegans.

The diets followed by vegetarians can vary. According to Sabate *et al.* (2001), a person is considered a vegetarian if flesh (meat, poultry or fish) is eaten less than once a week. Another way of defining the range of vegetarian diets is the vegetarian scale (Fig. 1) devised by Beardsworth and Keil (1991).

Table 1 Types of vegetarian diets

Classification of diet	Description of dietary pattern
Demi-vegetarian (semi-vegetarian)	Occasionally eats meat/poultry/fish.
Pesco-vegetarian	Excludes meat and poultry, but includes fish (and possibly other seafood). May include dairy products and eggs.
Lacto-ovo-vegetarian	Excludes all flesh foods. Includes dairy produce and eggs.
Ovo-vegetarian	Excludes all flesh foods and dairy produce. Includes eggs.
Lacto-vegetarian	Excludes all flesh foods and eggs. Includes dairy produce.
Vegan	Avoids all foods of animal origin.
Macrobiotic	10 dietary regimens of increasing restrictions. Usually vegetarian, but may eat meat or fish if wild/hunted in the lowest (least restricted) dietary regimens. Diet is usually based on brown rice with some fruit, vegetables and pulses. The final stage of the diet consists of wholegrains and limited liquids.
Fruitarian	Diet is usually based on fresh and dried fruits, nuts, seeds and a few vegetables. The diet generally consists only of foods that do not kill the plant of origin.

Adapted from Robinson and Hackett (1995).

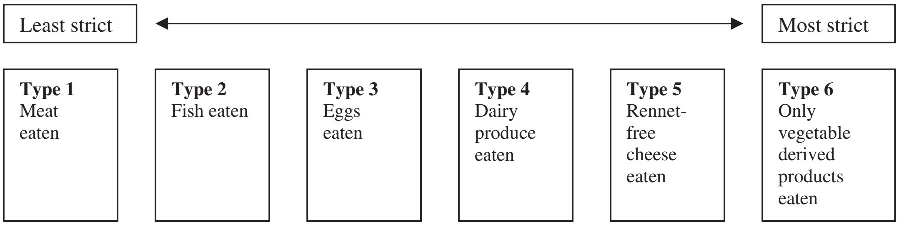

Figure 1 The vegetarian scale. Adapted from Beardsworth and Keil (1991) permission to republish granted by Emerald Group Publishing Limited http://www.emeraldinsight.com.

Beardsworth and Keil suggest that a vegetarian's dietary restrictions may move along the scale, for example eating normally 'forbidden' items at a party if other options are not available. But the further to the right of the scale a person is (most strict), the less likely they are to accept foods far to the left of the scale. Clearly, with such wide-ranging dietary patterns under the umbrella term 'vegetarian', it is impossible to have a definitive categorisation.

For some people, being vegetarian may go no further than selective shopping at the supermarket, whereas for others, being vegetarian does not only mean a set of dietary choices, but also encompasses a system of beliefs and behaviours permeating this whole lifestyle, and this may impact on health and mortality outcome beyond dietary effects (see Section 4). In addition to avoiding meat and/or other animal products, vegetarians may restrict, or abstain from, alcohol, drinks containing caffeine, processed and non-organically produced foods. Non-dietary differences from meat-eaters also exist. For example, vegetarians are more likely not to smoke, more likely to take regular exercise, they use fewer prescription drugs, they tend not to wear fur or leather, they often reject products tested on animals and are more willing to try alternative therapies (Freeland-Graves 1986; Higgs 1995; Johnston 1995; Sabate *et al*. 2001). It is therefore important to remember this complex web of dietary patterns and lifestyle differences when interpreting the results of studies comparing vegetarians with meat-eaters, as such comparisons are not straightforward.

3 Vegetarian nutrition

As indicated in Section 2, the term 'vegetarian' encompasses a spectrum of dietary patterns, some of which are more restrictive than others. Consequently, nutrient intake can vary considerably, depending on which foods are selected. Even within specific subgroups, for example lacto-vegetarians, the diets of individuals may still differ markedly.

Nutritional status is at risk when any group of foods is regularly omitted from the diet, for whatever reason, whether it be an altruistic reason for avoiding meat, or, in response to an allergy to a particular food, such as cows' milk. Whatever the motive for avoiding the food group, care must be taken to ensure that the diet remains balanced and nutritionally complete so as to avoid any deficiencies and to ensure optimal nutritional status.

The most recent survey of the diets of UK adults (Henderson *et al*. 2003a, 2003b) showed that meat and meat products provide a major contribution to a range of nutrients (Table 2).

When meat and meat products, and other animal-derived foods, such as fish, dairy products and eggs, are not eaten, the nutrients which they contain need to be derived from other sources that are naturally rich in those nutrients, or are fortified. The overall effect on the diet of excluding these foods can lead to significant differences in the nutrient intakes of vegetarians and omnivores. There have been some concerns about possible nutritional deficiencies with more restricted vegetarian diets. The most liberal macrobiotic diets, for instance, may provide a variety of nutrients, but are inadequate in

Table 2 Contribution of meat and meat products to daily average intakes of selected nutrients

	Contribution made by meat and meat products (%)	
Nutrient	Males (n = 833)	Females (n = 891)
Energy	17	14
Protein	38	33
Total fat	25	20
Saturated fatty acids	25	19
Monounsaturated fatty acids	30	24
n-3 polyunsaturated fatty acids	19	14
Sodium	28	23
Iron (total)	19	15
Haem iron	87	82
Non-haem iron	15	11
Zinc	36	30
Copper	17	12
Vitamin A (retinol equivalents)	34	22
Niacin	36	33
Vitamin B_{12}	34	24
Vitamin D	24	18

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Table 3 Mean daily nutrient intakes from the EPIC-Oxford cohort

	Meat-eaters	Fish-eaters	Vegetarians*	Vegans
Males (*n* = 12 969)	6 951	1500	3 748	770
Energy (MJ)	9.18	8.90	8.78	8.01
Energy as protein (%)	16.0	13.9	13.1	12.9
Energy as total fat (%)	31.9	31.1	31.1	28.2
Energy as saturates (%)	10.7	9.36	9.37	4.99
Non-starch polysaccharide (g)	18.7	22.1	22.7	27.7
Retinol (μg)	740	337	306	74.2
Vitamin D (μg)	3.39	2.90	1.56	0.88
Vitamin B_{12} (μg)	7.25	5.01	2.57	0.41
Folate (μg)	329	358	367	431
Calcium (mg)	1 057	1081	1 087	610
Iron (mg)	13.4	14.0	13.9	15.3
Zinc (mg)	9.78	8.59	8.44	7.99
Females (*n* = 43 582)	22 962	6931	12 347	1342
Energy (MJ)	8.02	7.75	7.60	6.97
Energy as protein (%)	17.3	14.9	13.8	13.5
Energy as total fat (%)	31.5	30.7	30.4	27.8
Energy as saturates (%)	10.4	9.33	9.33	5.11
Non-starch polysaccharide (g)	18.9	21.6	21.8	26.4
Retinol (μg)	654	308	277	76.6
Vitamin D (μg)	3.32	2.78	1.51	1.00
Vitamin B_{12} (μg)	6.98	4.93	2.51	0.49
Folate (μg)	321	346	350	412
Calcium (mg)	989	1021	1 012	582
Iron (mg)	12.6	12.8	12.6	14.1
Zinc (mg)	9.16	7.94	7.67	7.22

Source: Modified from Davey *et al.* (2003).
*Vegetarians ate no meat or fish but did eat dairy products and/or eggs.

calcium. More restrictive macrobiotic diets, which are considered superior by their supporters, are generally low in energy, protein and other nutrients, and may even be dangerous for children (Zmora *et al.* 1979; Dagnelie *et al.* 1990). The key nutritional issue for vegetarians and vegans is whether the nutrients supplied by meat and fish in an omnivorous diet can be provided in sufficient amounts in foods that are appropriate and acceptable to vegetarians or vegans.

Conversely, compared with omnivorous diets, plant-based diets are reported to contain less saturated fatty acids, animal protein and cholesterol, and more folate, fibre, antioxidants, phytochemicals and carotenoids (Bingham 1999; American Dietetic Association and Dietitians Canada 2003). However, vegans may have low intakes of vitamin B_{12}, vitamin D, calcium and iodine.

The EPIC-Oxford cohort of 33 883 meat-eaters and 31 546 non-meat-eaters provides the most up-to-date data in the UK comparing nutrient intakes of vegetarians and meat-eaters. A selection of some of the nutrient intakes of meat-eaters, fish-eaters, vegetarians and vegans participating in the EPIC-Oxford cohort (Davey *et al.* 2003) is presented in Table 3. More details on the EPIC-Oxford cohort, including preliminary results of the effects of different diets on mortality rates, can be found in Section 5.1.

The average nutrient intakes for the entire cohort, both meat-eaters and non-meat-eaters, are close to current recommendations, although there are wide variations between the dietary groups for several nutrients, most notably for saturates and fibre intake. Furthermore, absorption of nutrients can vary (see later sections on iron and zinc). Vegetarian and omnivorous diets alike clearly need to be well-balanced and varied. An understanding of some of the nutrients of concern in vegetarian diets will help in the selection and planning of a balanced and healthy vegetarian diet (see Appendix C for general guidance).

3.1 Energy

Whilst meat and meat products provide a substantial amount of energy in the typical British diet (15%)

(Henderson *et al.* 2003a), there is no reason to suggest that energy intakes are compromised by adults following a vegetarian or vegan diet. Both vegetarian and vegan diets may contain foods that are energy-dense such as vegetable oils, nuts, seeds and foods prepared with vegetable oils such as pastries, cakes and biscuits.

Studies have consistently found that vegetarians have similar, or slightly lower, energy intakes than meat-eaters in the same population, for both adults (Sanders 1999a; Leblanc *et al.* 2000) and children (Sanders & Manning 1992; Nathan *et al.* 1996). Vegan diets are generally lower in energy than lacto- and lacto-ovo-vegetarian diets (Davey *et al.* 2003; Spencer *et al.* 2003).

Macrobiotic and raw-food vegetarian diets, however, can be low in energy and especially bulky, making them totally inappropriate for children. Furthermore, an entirely raw-food diet has been shown to cause 9% weight loss within 3 months, despite an apparently adequate energy intake, owing to poor macronutrient absorption (Rauma *et al.* 1993). This may also occur to some degree on a non-macrobiotic vegetarian diet. A study by Levin *et al.* (1986) compared vegetarians with omnivores and reported that the average weight of the vegetarian subjects was significantly lower than that of the omnivores (60.8 kg *vs.* 69.1 kg), but that the vegetarian diet supplied a significantly greater amount of energy than the omnivorous diet (3031 kcal/day *vs.* 2627 kcal/day). The body mass indices (BMIs) of vegetarians and vegans are generally found to be 1–2 kg/m^2 lower than matched omnivores (Appleby *et al.* 1998; Spencer *et al.* 2003).

3.2 Protein

Protein has historically been regarded as one of the critical nutrients in a vegetarian diet. In populations whose diet is predominantly based on cereals and vegetables with minimal consumption of animal products, poorer growth has been observed (Scrimshaw 1996). Conversely, concerns have been raised over the observation that in Western societies, omnivores have protein intakes which are considerably higher than the reference nutrient intakes (Department of Health 1991) and that excessive protein intakes may be associated with potential health risks (Millward 1999). Protein is essential as a source of amino acids for growth and tissue repair and for the synthesis of enzymes and hormones. Care should be taken to ensure that vegetarian and vegan children eat a range of plant sources of protein, for reasons described below. In general, protein intakes of vegetarians tend to be slightly lower than those of omnivores but are still adequate to support nitrogen balance in healthy adults (Sanders 1999a). In a study of London vegetarians (Draper *et al.* 1993), a trend was observed towards lower protein intakes as animal protein intake declined (vegans' protein intakes were 70–75% of the national average protein intake). This trend is reflected among vegetarian and vegan children, but protein intakes still meet requirements and, even in vegan diets, rarely fall below 10% of energy intake (Herens *et al.* 1992; Sanders & Manning 1992). Infants are most likely to be affected by insufficient protein, owing to their relatively high protein requirements for growth (on a body weight basis).

Protein is made up of a series of amino acids. The amino acid profile of a protein is referred to as the quality of the protein. In practice, animal proteins contain a full and sufficient complement of indispensable (essential) amino acids and are referred to as 'high biological value' proteins (see Table 4 for a full list of indispensable amino acids). Indispensable amino acids cannot be synthesised by humans and so they have to be included in the diet for normal growth and repair of tissues to occur. If an indispensable amino acid is present at a low concentration, this is known as a 'limiting' amino acid. Proteins that have limiting amino acids are called 'low biological value' proteins. Most vegetable protein sources are lacking in at least one amino acid. It is argued that soya protein contains sufficient of its limiting amino acids to be considered a complete protein (Young & Pellet 1994), but this is questioned by some nutritionists using other analytical methods. Provided a mixture of plant foods is eaten, the foods that are limiting in one amino acid (cereals, for instance, are

Table 4 Indispensable and dispensable amino acids in humans

Indispensable (essential) amino acids	Dispensable (non-essential) amino acids
Histidine§	Alanine
Isoleucine	Arginine*
Leucine	Aspartic acid
Lysine	Cysteine*
Methionine	Glutamine*
Phenylalanine	Glycine*
Tryptophan	Proline*
Threonine	Serine
Valine	Tyrosine*
	Citrulline†
	Taurine†
	Ornithine†

*Conditionally (in some circumstances) indispensable amino acids. †Non-proteinogenic amino-acids, which have nutritional value in special cases. §Considered to be indispensable in children, but not adults.

typically limited in lysine) will be compensated for by another food. A full range of amino acids will be consumed if (as a general rule) a grain is eaten with a pulse or legume, such as rice and lentils, or beans on toast. The different types of plant proteins should be eaten during the same day, but not necessarily within the same meal, allowing for flexibility in food preferences (Messina & Messina 1997). The improved amino acid profile of mixtures of foods containing protein, in comparison with profiles of single foods, is known as 'complementation'.

In summary, vegetarian diets contain adequate protein, provided that a variety of foods is consumed, but are typically lower in protein than omnivorous diets.

3.3 Fat

3.3.1 Total fat

In the UK NDNS, meat and meat products typically contributed 23% to total fat intake and 22% to saturates intake in 2000/2001 (Henderson *et al*. 2003a) and so it may be reasonable to expect that omitting meat and meat products from the diet could substantially reduce the total fat and saturates in the diet. However, studies comparing vegetarians with meat-eaters have shown that semi-vegetarian and lacto-ovo-vegetarian diets contain similar or only slightly lower amounts of fat, because vegetarian diets can include fat from other food sources (Bull & Barber 1984; Draper *et al*. 1993; Waldmann *et al*. 2003). In both the Oxford Vegetarians Study (Appleby *et al*. 1999) and the EPIC-Oxford cohort (Davey *et al*. 2003), macronutrient intakes were compared by diet group for men and women. The average proportion of energy provided by fat was similar in meat-eaters, fish-eaters and lacto-ovo-vegetarian women, but lacto-ovo-vegetarian men and all vegans obtained a considerably lower proportion of dietary energy from total fat and from saturates compared with the former groups. Other studies have also consistently demonstrated that vegans' intakes of fat (30–35% of energy) reflect more closely the current recommendations for adults in the UK (Sanders & Manning 1992; Sanders & Reddy 1992; Draper *et al*. 1993). For children, very restrictive diets that include little fat (20–25% energy) are unsuitable, because these diets are very bulky and not nutrient-dense, and as a result may lead to delayed growth and development (Dagnelie *et al*. 1989a).

3.3.2 Fatty acids

High dietary intakes of saturated fatty acids can increase serum cholesterol, high levels of which are a major risk factor for cardiovascular disease (CVD). In contrast, mono- and polyunsaturated fatty acids do not raise serum cholesterol levels and may have beneficial effects on other cardiovascular risk factors (Department of Health 1994a). In general, eating fewer sources of animal fats and more vegetable fats results in higher intakes of polyunsaturates and lower intakes of saturates, as demonstrated by the Oxford Vegetarians Study (Table 5).

The diets of vegans in the Oxford Vegetarians Study were considerably lower in saturates and higher in polyunsaturates than those of vegetarians, who include some animal products, *e.g.* milk and/or eggs, meat-eaters and fish-eaters. This is consistent with other UK studies, including the EPIC-Oxford cohort (see Table 2), which indicate that vegans consume 5–8% of energy from saturates (Sanders & Manning 1992; Draper *et al*. 1993; Davey *et al*. 2003). Nevertheless, a vegan diet might contain significantly more saturates if vegetable oils rich in saturates (such as coconut oil or palm oil, which are not commonly eaten in the UK) are eaten in substantial quantities, and less strict vegetarians and meat-eaters alike are advised to limit their intakes of saturates.

One of the main arguments for the perceived healthiness of a vegetarian diet has been the fact that meat and meat products contain saturates (see above). However, not all saturates have a detrimental effect on health. For example, one of the main saturated fatty acids in red meat is stearic acid (C18:0). Stearic acid is not thought

Table 5 Proportions of energy from total fat and saturates and P : S of different dietary groups in the Oxford Vegetarians Study

	Fat (% energy)	Saturates (% energy)	Ratio of polyunsaturates to saturates (P* : S)
Men			
Vegan	33.5	6.2	1.85
Vegetarian	36.4	12.1	0.73
Fish-eater	38.2	12.5	0.73
Meat-eater	38.1	13.2	0.56
Women			
Vegan	36.2	7.4	1.77
Vegetarian	39.6	14.3	0.63
Fish-eater	40.5	13.3	0.75
Meat-eater	38.7	14.2	0.49

Adapted from Appleby *et al.* (1999) with permission by the *American Journal of Clinical Nutrition*. © Am J Clin Nutr. American Society for Clinical Nutrition. *N* = 26 males and 26 females per group. Vegetarians ate no meat or fish but did eat dairy products and/or eggs. *Includes both *n*-3 and *n*-6 polyunsaturated fatty acids.

to raise cholesterol levels at all. Indeed, Kelly *et al.* (2001, 2002) showed that stearic acid in the diet had beneficial effects on thrombogenic (clotting) and atherogenic risk factors in males. However, Hu *et al.* (1999) reported that distinguishing between stearic acid and other saturated fatty acids does not appear to be important in coronary heart disease (CHD) risk, partly because of the high correlation between stearic acid and other saturated fatty acids in the diet (*e.g.* palmitic acid, C16:0, also found in meat). Myristic acid (C14:0) (found in butter, lard and coconut oil) is thought to be the most atherogenic saturated fatty acid and is estimated to have four times the cholesterol-raising potential of palmitic acid (Ullbright & Southgate 1991). By contrast, some of the short-chain saturates in milk fat do not raise plasma cholesterol.

Vegetarians consume similar proportions of monounsaturates to meat-eaters, but a greater proportion of polyunsaturates. This is reflected in the analysis of adipose tissue from omnivores, vegetarians and vegans. The percentage of saturates in vegan adipose stores was significantly less than that in those of vegetarians or omnivores, and the percentage of polyunsaturates, but not monounsaturates, was significantly higher in the adipose stores of vegans and vegetarians (Coulston 1999). The higher amounts of polyunsaturated fatty acids is largely the result of the increased amounts of linoleic acid (C18:2 *n*-6) in vegetarian and vegan diets, as more seed oils, rich in linoleic acid, are consumed (Sanders 1999b). Intakes of alpha-linolenic acid (ALNA; C18:3 *n*-3) are more variable and have been reported to be higher in some studies (Sanders & Roshani 1992) but lower in others (Draper *et al.* 1993) than in omnivores. This may reflect choice of oil as some (*e.g.* rapeseed oil) are higher in ALNA than others. The ratio of alpha-linolenic to linoleic acid is lower in vegetarians than in omnivores, and is particularly low in vegans (Sanders & Roshani 1992). The relative proportions of dietary 18 carbon atom *n*-3 and *n*-6 fatty acids are thought to be potentially important because the two families share common sets of enzymes for their metabolism (elongation and desaturation) and specific fatty acids in each family are precursors for synthesis of molecules known as eicosanoids, which act as local messengers in processes such as inflammation. A shift in the *n*-3 : *n*-6 ratio, by reducing the intake of *n*-3 and increasing *n*-6, may influence the types and potency of eicosanoids formed (BNF 1999), favouring more potent (*e.g.* pro-inflammatory) forms (*i.e.* those produced from *n*-6 fatty acids). However, more recent work suggests that the ratio of *n*-3 : *n*-6 is less important than the actual amounts of specific fatty acids consumed. New recommendations in the US for intakes of fatty acids suggest 17 g and 12 g of linoleic acid per day and 1.6 g and 1.1 g of alpha-linolenic acid per day for men and women, respectively, based on average intakes in the United States [see National Academy of Science http://www.iom.edu/reports.asp (Food and Nutrition Board; Institute of Medicine 2002) for more details].

Long-chain polyunsaturated fatty acids (LCPUFAs), derived from linoleic and alpha-linolenic acids (by introducing double bonds and lengthening the carbon chain, using enzymes), are required for normal development of the retina and central nervous system. The extent to which they can be synthesised from the parent fatty acids is debated (Sanders 1999b). It is argued that synthesis of *n*-3 LCPUFAs, eicosapentaenoic acid (C20:5 *n*-3; EPA) and docosahexaenoic acid (C22:6 *n*-3; DHA) is limited (particularly DHA), so most of our needs must be supplied preformed in the diet. As EPA and DHA are absent from plant foods (with the exception of some seaweeds), the main source being oily fish, intakes from vegetarian and vegan diets may not be optimal. Algal supplements of DHA are also available and these have been shown to enhance blood levels of EPA and DHA (Conquer & Holub 1996). There is no evidence that the capacity to synthesise LCPUFAs is any more limited in vegetarians than among omnivores, although lower concentrations of DHA have been observed in both the plasma and the umbilical cord artery phospholipids of vegetarians, compared to omnivores (Reddy *et al.* 1994).

Lower levels of DHA have also been found in the milk of vegan mothers compared with omnivore mothers (Sanders & Reddy 1992). Studies have shown that infants deprived of DHA show abnormalities in visual and brain function, but it is not yet known whether the reported lower levels of DHA in the milk of vegan and vegetarian mothers is sufficient to result in significant changes in their infants' physiological functioning.

Another LCPUFA is arachidonic acid (C20:4 *n*-6) but, in contrast with DHA, plasma arachidonic acid is higher in vegans and vegetarians than omnivores, and it is thought that sufficient arachidonic acid can be synthesised from the *n*-6 linoleic acid.

Further research is needed to establish the optimum quantities or ratio of *n*-3 to *n*-6 fatty acids in the diet, but Sanders (1999b) suggests that it is prudent to ensure that vegetarian diets do not contain excessive amounts of linoleic acid. The Department of Health has advised an upper limit of 10% of energy from *n*-6 fatty acids and recommends that the proportion of the population consuming more than this should not increase their intakes (Department of Health 1991, 1994a). Proportional intake of *n*-3 fatty acids can be increased by choosing a cooking or salad oil that has a relatively high *n*-3 to *n*-6 fatty acid ratio, such as rapeseed (canola) oil or soybean oil, rather than those which are high in linoleic acid such as sunflower or corn oils, or by including more plant foods rich in *n*-3 fatty acids, such as walnuts. Recent studies have questioned whether plant oils rich in ALNA have the same positive effects on plasma lipid levels as fish oils, which contain the longer chain length EPA and DHA. Supplementation studies with ALNA have shown increased plasma levels of EPA, but not DHA (Sanderson *et al.* 2002) and because conversion is relatively poor, large quantities of ALNA would be required to achieve the plasma levels readily achieved with oily fish. Clearly, if the vegetarian diet selected permits inclusion of fish, then consumption of oily fish such as salmon, herring and sardines, should be recommended, as these are rich sources of preformed EPA and DHA which have been shown to benefit heart health, particularly in secondary prevention studies.

3.4 Carbohydrate

Current dietary guidelines suggest that a healthy diet should provide around 50% of energy from carbohydrate, the majority of which should be from complex carbohydrates and from sugars derived from milk, fruit and vegetables. Compared with omnivorous diets, the amount of carbohydrate, or the proportion of energy from carbohydrate, in vegetarian diets is similar or slightly higher (especially for vegans) (Bull & Barber 1984; Thorogood *et al.* 1990; Draper *et al.* 1993; Sanders 1999b; Robinson *et al.* 2002; Davey *et al.* 2003).

Fibre intakes are consistently reported to be higher in vegetarians, especially vegans, in some cases being twice those recorded for omnivores (Davies *et al.* 1985; Sanders & Manning 1992; Davey *et al.* 2003; Waldmann *et al.* 2003). The higher fibre intakes are generally because of a preference for unrefined cereals and greater consumption of fruits, vegetables and pulses. Current dietary recommendations encourage increased intakes of fibre-rich foods and wholegrains for adults. But for children, vegetarian and particularly vegan diets that include very high intakes of fibre may be problematic, as availability of micronutrients, such as zinc, may be compromised by the high content of phytate (see Section 3.6, Micronutrients).

3.5 Alcohol

Alcohol consumption amongst vegetarians largely depends upon a person's reasons for being vegetarian. Seventh-Day Adventists, for example, usually abstain from alcohol, but those following a vegetarian diet because of their concerns about animal welfare may include alcohol.

There is no clear pattern of alcohol consumption amongst vegetarians and few studies have reported on alcohol intake in Western vegetarians, but the available data suggest that alcohol intake is relatively low (Key *et al.* 1999a; Waldmann *et al.* 2003). The Oxford Vegetarians Study (Key *et al.* 1999a) showed that alcohol intake among vegetarians was slightly lower than the national average, although for men, the more restricted the vegetarian diet chosen, the less alcohol they consumed. For women, fish-eaters and vegans consumed more alcohol than the meat-eaters in the cohort. Other studies have shown that vegans consume less alcohol (typically half the amount) than meat-eaters (Carlson *et al.* 1985; Draper *et al.* 1993; Waldmann *et al.* 2003). In a study of dietary practices and health attitudes in Cardiff, those who were vegetarian were more likely to be non-drinkers (28% of vegetarians compared with 11% of omnivores) but vegetarians who did drink typically did so more frequently than meat-eaters (Shickle *et al.* 1989). Current guidelines advocate that if alcohol is consumed, no more than 3–4 units per day should be consumed by males, and no more than 2–3 units per day by females; these guidelines should also be observed by vegetarians and binge drinking should be avoided by vegetarians and meat-eaters alike.

3.6 Micronutrients: intakes and status

As mentioned earlier, meat and meat products, and other animal-derived foods, are excellent sources of certain vitamins and minerals. Red meat, for example, is a good source of iron, zinc, preformed vitamin A and vitamin B_{12}; milk and dairy products are rich in bioavailable calcium and provide useful amounts of a diverse range of other minerals and vitamins; and oily fish is rich in vitamin D. Furthermore, there are components in plant foods that affect the absorption and metabolism of some micronutrients. Phytates, for instance, associated with high intakes of cereal fibre, impair absorption of minerals such as zinc and iron. Taking these factors into account, it is reasonable to question whether diets that exclude meat provide adequate amounts of micronutrients.

3.6.1 Fat-soluble vitamins

Vitamin A (retinol) is needed for the growth and normal development of tissues, vision and healthy skin. It is found in animal foods and in fortified foods, such as

Table 6 Food sources of a selection of nutrients for vegetarians

Nutrient	Food sources
n-3 fatty acids	Linseeds (or flaxseeds), soybean oil, rapeseed oil, tofu, walnuts
Vitamin A (retinol equivalents)	Milk, eggs, yogurt, green leafy vegetables, yellow/orange vegetables or fruits
Vitamin B_2 (riboflavin)	Fortified breakfast cereal, milk, yogurt, cheese, eggs, fortified soya drink, almonds
Vitamin B_{12}	Fortified breakfast cereal, yeast extract, fortified soya drink, eggs, milk
Vitamin D	Fortified breakfast cereal, fortified soya drink, all margarines, other fortified fat spreads, eggs, milk
Calcium	Fortified soya drink, sesame seeds, white/brown bread, fortified fruit juice, dried figs, broccoli, green leafy vegetables (except spinach), molasses, milk, cheese, yogurt, beans and pulses, tofu, soya mince
Zinc	Tofu, legumes (e.g. baked beans, chick peas, lentils), peas, nuts and seeds (e.g. cashew nuts, sunflower seeds) Wholegrain cereals and wholemeal bread, milk, eggs, cheese, yogurt
Iron	Fortified breakfast cereal, wholemeal bread, dried fruit (e.g. apricots, prunes, raisins), green leafy vegetables, beans and pulses, molasses, nuts and seeds (almonds, pumpkin seeds, sesame seeds), tofu
Selenium	Brazil nuts, sunflower seeds, molasses, wholemeal bread
Iodine	Iodised salt, seaweed, milk

fat-spreads and breakfast cereals (see Table 6). Vitamin A can also be synthesised from provitamin A, *e.g.* beta-carotene, which is abundant in green, orange and yellow fruits and vegetables. Although intakes of retinol equivalents (taking carotenoids into account) are consistently observed to be lower in vegetarians and vegans than meat-eaters (all preformed retinol in vegan diets is derived only from fortified foods), vegetarian and vegan diets are typically higher in carotenoids (Sanders & Roshani 1992), partially compensating for lower intakes of preformed retinol and helping to ensure adequate intake. However, beta-carotene bioavailability is variable and is much improved when oil is used during preparation of plant foods or when vegetables (*e.g.* carrots) are cooked (de Pee & West 1996; Southon 2001).

Vitamin D is essential for calcium absorption and optimal bone health. Most individuals can synthesise sufficient vitamin D upon exposure of the skin to sunlight, although dietary vitamin D, found in animal foods (oily fish, eggs and meat) and fortified foods (such as breakfast cereals and fat spreads), contributes to blood levels. Dietary intakes of vitamin D have been reported to be lower in vegetarians compared to omnivores and are lowest in vegans, whose only dietary source is fortified foods (Table 6). Vegans usually avoid consumption of foods fortified with animal-derived vitamin D_3 (cholecalciferol), but vitamin D_2 (ergocalciferol) is acceptable to vegans, although questions have been raised about whether this is less bioavailable than vitamin D_3 (Trang *et al.* 1998). The lower vitamin D intakes are probably without significance in relation to nutritional status for many Caucasian vegetarians, who synthesise adequate vitamin D from sunlight exposure during the summer months, but may be problematic for vegan infants and young children, Asian vegetarians (who have darker skin which is traditionally covered up) and elderly people on a vegetarian diet. Low vitamin D levels and reduced bone mass have been observed in some vegan populations who do not use supplements or fortified foods (Parsons *et al.* 1997). An examination of the serum vitamin D levels of 300 Asians, resident in London, indicated that the levels during the summer months had increased less than expected amongst vegetarian Asians compared to Caucasians, Muslims and non-vegetarian Asians (Finch *et al.* 1992).

In a study of Finnish women, dietary intake of vitamin D was found to be insufficient to maintain blood levels of 25-hydroxy vitamin D and parathyroid hormone (important in bone metabolism) during the winter (Outila *et al.* 2000). The researchers concluded that supplementation or fortification should be routinely recommended to vegans living in northern latitudes, at least during the winter months. Craig and Pinyan (2001) suggest that a 5–10 μg supplement of vitamin D during the winter and early spring would be a safe and appropriate step for vegans.

Macrobiotic diets are also lacking in vitamin D and studies of children under 6 years of age have observed a high prevalence of rickets, a result of vitamin D deficiency (Dwyer *et al.* 1979; Dagnelie *et al.* 1990). A study by James *et al.* (1985) also found that children from Rastafarian families in Britain, who were fed strict vegan diets, were at risk of developing rickets.

In order to optimise vitamin D status, health education focuses on encouraging exposure of some skin (*e.g.* face and arms) to sunlight, consumption of fortified fat spreads and other fortified foods, and the use of vitamin

D supplements. Suboptional vitamin D status is now recognised to be widespread in Britain and it is recommended that young children, pregnant women from Asian families, and elderly people who are housebound or who live in an institution, take a 10 μg per day vitamin D supplement in tablet form, regardless of whether they are vegetarian or not (Department of Health 1998). Lower serum levels of vitamin D are associated with a decreased ability to absorb calcium and consequently predispose the individual to adverse effects on bone health. Prolonged deficiency of vitamin D results in rickets in children and osteomalacia in adults.

Vitamin E intakes are generally adequate and are frequently higher in vegetarians than omnivores (Draper *et al.* 1993). This is because vegetarians and vegans tend to eat more vegetable oils, wholegrain products and nuts, all of which are rich in vitamin E.

Vegetarians and vegans also typically consume more green leafy vegetables than the general population. Green leafy vegetables, such as broccoli, cabbage and lettuce, supply vitamin K, which is needed for bone metabolism. In a study of hip fractures and vitamin K intake, one or more servings of lettuce per day was associated with a 45% reduction in risk of hip fractures in women (Feskanich *et al.* 1999).

3.6.2 Water-soluble vitamins

A vegetarian diet usually, but not always, includes more fruit and vegetables, pulses, nuts and wholegrains, than an omnivorous diet. As a consequence, vegetarians' intakes of vitamin C, folate and thiamin are higher than those of meat-eaters (Carlson *et al.* 1985; Draper *et al.* 1993; Davey *et al.* 2003).

Intakes of riboflavin [found naturally in dairy products and present in various fortified foods (see Table 6), wholegrains, leafy green vegetables and almonds] by Western lacto-ovo-vegetarians are generally lower than in meat-eaters, but intakes are still adequate (Janelle & Barr 1995; Davey *et al.* 2003) and clinical riboflavin deficiency has not been observed in vegans (Larsson & Johansson 2002). Nevertheless, vegans should ensure that they include other foods high in riboflavin, such as fortified breakfast cereals and fortified soya drinks in their diet.

(i) Vitamin B_{12} Vitamin B_{12} is needed for the normal maturation of red blood cells and for the synthesis of sphingomyelins, which are used for making the myelin sheath of nerve tissues. Thus a deficiency in vitamin B_{12} (cobalamin) that results in blood levels of B_{12} dropping to subnormal levels (below 200 picograms/mL), will lead to changes in nerve function and red blood cells will remain as large immature megaloblasts (megaloblastic anaemia).

Vitamin B_{12} is not naturally found in any significant amounts in plant foods (although milk is a good source), therefore vegetarians, and especially vegans, may be at risk of vitamin B_{12} deficiency. Dietary intakes of vitamin B_{12} are consistently reported as being lower in vegetarian diets, and particularly low in vegans (Herbert 1988, 1994). The EPIC-Oxford cohort found very low intakes of vitamin B_{12} by vegan males (0.41 μg/day) and females (0.49 μg/day). Symptoms of B_{12} deficiency may take years to appear in those changing to a vegan diet, if body stores of B_{12} and gut reabsorption of B_{12} were hitherto optimal. The main reason for vitamin B_{12} deficiency is inadequate B_{12} absorption, either because of a lack of B_{12} in the diet, lack of the intrinsic factor produced in the stomach and needed for absorption, or achlorhydria (where the production of acid in the stomach declines) (Craig & Pinyan 2001). Signs of B_{12} deficiency may initially go unnoticed if vegans and vegetarians have very high intakes of folic acid (*e.g.* from supplements), which masks the megaloblastic anaemia. Consequently, presenting symptoms may be neurological, such as abnormal sensations in the limbs, weakness or a range of psychiatric disorders resulting from demyelination in peripheral nerves, the spinal cord and the brain (Craig & Pinyan 2001). Although folic acid intake can prevent or delay the megaloblastic anaemia of B_{12} deficiency, it cannot prevent nerve damage and so a delay in remedying the B_{12} deficiency, with intramuscular B_{12} treatment, may lead to permanent neurological damage. Herrmann *et al.* (2003) have shown that vegans and, to a lesser degree, lacto- and lacto-ovo-vegetarians have biochemical evidence of vitamin B_{12} deficiency based on increased blood levels of homocysteine and methylmalonic acid, although megaloblastic anaemia was not observed.

It is essential that all pregnant and breastfeeding women have adequate B_{12} intakes. B_{12} status can be a problem for those following a vegan diet, if supplements are not taken, as the fetus removes about 0.2 μg of B_{12} per day from the mother's stores and more is secreted in breast milk. Vitamin B_{12} deficiency may develop in the baby if breast milk has a low B_{12} content, and this can lead to persistent neurological defects (Grattan-Smith *et al.* 1997).

Plasma B_{12} concentrations were observed to be lower in infants on a macrobiotic diet than in matched omnivorous infants (Dagnelie *et al.* 1989b) and, in a study of vegan infants, plasma vitamin B_{12} levels were one quarter of normal levels (Shinwell & Gorodischer 1982). Thus, pregnant and breastfeeding women following vegan or macrobiotic diets need to take considerable care about their B_{12} intake.

There is some debate concerning appropriate sources of vitamin B_{12} in vegetarian and vegan diets. Only very small amounts of the vitamin are needed, only less than 2 μg per day. Vitamin B_{12} is found in eggs, milk and meat. There have been some suggestions that vitamin B_{12} is present in fermented soya products (*e.g.* miso and tempeh), shiitake mushrooms and algae (spirulina and nori). Although these products are sometimes sold as excellent sources of B_{12}, they actually contain analogues of the vitamin which have been reported to be inactive and may block the absorption of true vitamin B_{12} when intake is low (Herbert 1988; Dagnelie *et al.* 1991).

In developing countries, faecal contamination of water supplies may contribute to dietary intake. In developed countries, dairy products and eggs can supply some B_{12} for lacto-ovo-vegetarians but, for vegans, B_{12}-fortified foods should be included, particularly fortified meat-substitutes, fortified yeast extracts, fortified soya drinks, fortified breakfast cereals and fortified bread. Provided these foods are consumed regularly, the hazard of B_{12} deficiency is easily avoided.

3.6.3 Minerals

As with any diet, the provision of adequate amounts of nutrients depends primarily on the nature and variety of the foods selected. The amount of animal products consumed (*e.g.* including fish, dairy produce or eggs) will also dictate, to some extent, the mineral content of the diet.

Higher intakes of iron, copper, potassium and magnesium have been observed for vegan diets (Sanders & Manning 1992; Draper *et al.* 1993; Janelle & Barr 1995; Waldmann *et al.* 2003), but vegans have lower intakes of selenium, calcium and iodine than meat-eaters (Draper *et al.* 1993; Judd *et al.* 1997; Lightowler & Davies 1998; Waldmann *et al.* 2003). Compared to omnivores, zinc intakes are similar in male vegetarians and vegans but are typically low in females. People can be particularly vulnerable during the transition period to a vegetarian diet, as it may take some time for the body to adjust to the increased amount of fibre, phytate and oxalate, which impair absorption of some minerals in the vegetarian diet (Draper *et al.* 1993). Supplementation may be helpful during this period.

(i) Iron There is particular interest in the iron status of vegetarians and vegans because, in an omnivorous diet, meat provides a significant amount of highly bioavailable haem iron, and also because of the presence of other unidentified factors in meat (and also in fish and poultry), which promote iron absorption. Burgess *et al.* (2001) showed that in a sample of 50 omnivorous children, meat provided 33% (3.2 mg) of total iron intake and 13–16% of the total (1.3–1.5 mg) was estimated to be in the form of haem iron. In a vegetarian diet, where meat is completely excluded, the iron present is only in the non-haem form (unless fish is included). In addition, absorption may be impaired because vegetarian diets commonly contain dietary inhibitors of iron absorption (see Table 7) such as phytates, as a result of greater consumption of legumes and wholegrains. Non-haem iron is more sensitive to both inhibitors and enhancers of iron absorption. After following a vegetarian diet for 8 weeks, there was 70% lower non-haem iron absorption than from an omnivorous diet followed by the same subjects in a crossover design study (Hunt & Roughead 1999). Despite previous reports of no adaptation in people who have consumed a vegetarian diet for several years (Brune *et al.* 1989), Hunt and Roughead observed some partial physiological adaptation. Absorption of non-haem iron is also enhanced by the presence of vitamin C, intake of which is usually increased when a vegetarian diet is consumed. Also, some food preparation techniques, such as soaking and sprouting beans, grains and seeds, and leavening of bread, can hydrolyse phytate and may improve iron absorption.

In general, iron intakes of vegetarians and vegans are similar to or higher than those of meat-eaters (Alexander *et al.* 1994; Ball & Bartlett 1999; Wilson & Ball 1999; Robinson 2001; Perry *et al.* 2002; Davey *et al.* 2003) for all age groups (see Section 4 for further details). But female vegetarians, in particular, have lower iron stores, as indicated by serum ferritin levels, as the proportion absorbed from the diet may be less in vegetarians and vegans (Reddy & Sanders 1990; Donovan & Gibson 1995; Wilson & Ball 1999). Consequently, they are more prone to iron-deficiency anaemia (Sanders 1999a),

Table 7 Dietary factors impairing and enhancing iron absorption and bioavailability in a vegetarian diet

Impair non-haem iron absorption	Enhance non-haem iron absorption
Phytic acid/Phytate	Fish (if eaten)
Oxalic acid/Oxalate	Vitamin C
Tannins (*e.g.* in tea and red wine)	Possibly alcohol
Calcium	Retinol
Soya protein	Carotenes
Egg yolk (Coffee, cocoa and some spices slightly impair absorption)	

Sources: Hurrell *et al.* (1999) and Hunt (2002).

particularly if menstrual losses are high. Nevertheless, haemoglobin or haemocrit concentrations are generally found to be normal in vegetarians in Western societies and adverse health effects of lower iron absorption have not been demonstrated (Sanders 1999a; Hunt 2002). An exception to this is macrobiotic vegetarians, who consume brown rice, rich in phytates, as their staple food, among whom an increased prevalence of iron deficiency anaemia has been reported (Dagnelie *et al.* 1989b).

Owing to the reduced bioavailability of iron in vegetarian diets, an upward adjustment of the recommended intake has been suggested. Hunt (2002) suggests that the US dietary recommendation for iron (for vegetarians) should be increased by 80%, to compensate for lower bioavailability, resulting in recommendations of 14 mg and 33 mg of iron daily for adult vegetarian men and premenopausal vegetarian women, respectively (the UK Reference Nutrient Intakes (RNIs) for iron are 8.7 mg and 14.8 mg for men and women, respectively) (Department of Health 1991). For premenopausal women this amount is unlikely to be obtained from dietary sources and implies a recommendation for iron supplementation. However, strategies to increase iron intakes must also consider the possible risks of excess dietary iron in terms of heart disease and possibly cancer (Kelly 2002). Furthermore, supplementing with iron may interfere with bioavailability of copper or other minerals. The government's Scientific Advisory Committee on Nutrition (SACN) is currently reviewing dietary recommendations for iron, which is due to report in 2005. In the meantime, those who are most vulnerable to iron deficiency, *i.e.* women with high menstrual blood losses and infants, whether vegetarian or omnivorous, may benefit from monitoring of iron status and ensuring that steps are taken to ensure optimal iron intake and to limit dietary factors which inhibit iron absorption (also see Section 4).

(ii) Zinc Zinc is a constituent of enzymes involved in many metabolic pathways in the body, and is important for cell growth and repair, protein metabolism and immune function. Meat is a rich source of zinc, but there are many other non-meat sources, including dairy products, bread and cereal products, pulses, nuts and seeds. However, many of the plant-derived foods that are rich in zinc are also high in phytic acid, an inhibitor of zinc absorption (Hunt 2002). Small dietary modifications may improve the availability of zinc. For example, zinc bioavailability is greater from leavened bread than unleavened bread, as the leavening process in breadmaking activates phytase, which breaks down phytic acid.

Studies have compared zinc intake in vegetarians and omnivores, with variable findings. Overt zinc deficiency has not been observed in Western vegetarians (Freeland-Graves *et al.* 1980; Alexander *et al.* 1994; Donovan & Gibson 1995) and currently the effects of marginal intakes are poorly understood. Elderly people (vegetarians and meat-eaters) often have a low intake of zinc, predisposing them to an increased risk of zinc deficiency, which may be associated with a change in taste acuity and decreased immune function. A study of elderly Dutch women showed low mean zinc intakes for both vegetarians and meat-eaters (Nieman *et al.* 1989). Another study of elderly Dutch people found lower serum zinc levels in vegetarians than in omnivores (Lowik *et al.* 1996).

Male vegetarians are frequently found to have similar zinc intakes to male omnivores, but lower intakes of zinc have been observed in female vegetarians (Janelle & Barr 1995) and lower average zinc intakes have been reported for adolescent vegetarian females (6.7 mg/day) than meat-eaters (7.8 mg/day) (Donovan & Gibson 1995). Despite lower intakes of zinc, serum levels of zinc were not lower in female vegetarians (Ball & Ackland 2000) and cross-sectional studies have shown that plasma zinc measurements are not significantly different between vegetarians and omnivores (Anderson *et al.* 1981; Latta 1984). This suggests that there is compensation with increased zinc absorption in those with low intakes or status and/or an adaptation to a long-term vegetarian diet, with changes in bioavailability or metabolism (Ball & Ackland 2000). However, there may be a period when people change to a vegetarian diet, or a more restricted vegan diet, when zinc bioavailability is temporarily impaired. In longitudinal studies of the effect of changing to a vegetarian diet, plasma zinc was not changed after 22 days of following a vegetarian diet (Freeland-Graves *et al.* 1980) but other studies showed that plasma zinc was reduced after 8 weeks (Hunt *et al.* 1998), and, in a longer study, after 3 months, with no further reduction after 6 months (Srikumar *et al.* 1992), suggesting that a new equilibrium is reached after some months.

Those responsible for setting dietary reference intakes for zinc in the USA (Food and Nutrition Board; Institute of Medicine 2001) concluded that because of lower absorption of zinc, those consuming vegetarian diets, especially those with a high content of inhibitory phytate, may need as much as 50% more zinc than non-vegetarians.

Low zinc intake is unlikely to be a specific problem for lacto-ovo-vegetarians, but vegans and high-risk groups, particularly elderly people, pregnant women and adolescents, should ensure that mineral-rich foods are included in the diet (see Table 6). Zinc status should also be assessed in high-risk groups and Hunt (2002) suggests that more research is needed to develop sensitive indices to assess zinc status.

(iii) Calcium Calcium is found in a range of foods, most notably in milk and dairy products. Vegetarians and omnivores generally have similar intakes of calcium and some studies have reported a greater calcium intake by lacto-ovo-vegetarians (Drake *et al.* 1998; Weaver *et al.* 1999). The calcium intakes of vegans, who exclude dairy products, are considerably lower than in the general population (Draper *et al.* 1993; Janelle & Barr 1995; Davey *et al.* 2003). Canadian vegan women were found to consume 578 mg calcium/day, compared with 950 mg/day for omnivores and 875 mg/day for lacto-ovo-vegetarians (Janelle & Barr 1995). A study of 20 life-long vegan children recorded intakes of calcium that were 67% of the levels reported nationally for British children (Sanders & Manning 1992). Even lower levels were reported in a study of 44 children following macrobiotic diets, at 40% of the calcium levels reported in national data (Herens *et al.* 1992). Low intakes of calcium are especially problematic for teenagers and during lactation, when requirements for calcium are high (Department of Health 1991); in some cases, supplements containing calcium and calcium-fortified foods (such as fortified soya drink) may be useful.

Calcium status is impossible to assess *via* blood measurements, as levels are controlled to remain within very narrow limits, regardless of dietary intake. However, it is well-recognised that when habitual dietary intakes of calcium are low, and when requirements for calcium are raised, there is an increase in the proportion of dietary calcium that is absorbed, provided vitamin D status is adequate (BNF 1989). Lower intakes of protein typically observed in the vegan diet may also contribute to greater calcium retention, as calcium excretion in urine increases with high intakes of protein (Heaney 1993).

Adequate calcium intake throughout childhood and adulthood (particularly for postmenopausal women) is recognised as important. Vegans, especially, should ensure an adequate calcium intake by consuming high-calcium plant-derived foods (such as beans and pulses, and broccoli), green leafy vegetables, that are low in oxalate (Weaver *et al.* 1999), and calcium-fortified foods. If insufficient calcium-rich or fortified foods are consumed, supplemental calcium may be required.

(iv) Selenium Selenium, which is an integral part of a number of enzymes, including glutathione peroxidase (involved in the body's defence against the damaging impact of free radicals) and is involved in thyroid hormone synthesis, is present in a number of foodstuffs, including meat and meat products (BNF 2001a). The Total Diet Survey in 1997 (Ministry of Agriculture, Fisheries and Food 1999) estimated contribution to selenium intake by meat and meat products at 32%. Small studies have reported low selenium intakes in vegetarians and vegans in the UK (Judd *et al.* 1997), Finland (Rauma *et al.* 1995) and Slovakia (Kovacikova *et al.* 1998). This probably reflects the low soil selenium levels in parts of Europe; the selenium content of plant foods is strongly determined by the selenium content of the soil. Another study found the mean dietary selenium intake of vegetarians to be 28 μg/day, which is lower than in the general population and well below recommendations (Ministry of Agriculture, Fisheries and Food 2000); the UK RNIs for selenium are 60 μg and 75 μg per day for adult women and men, respectively. Srikumar *et al.* (1992) reported that after 3 months of following a prescribed vegetarian diet, dietary selenium intake was 40% lower than at baseline when subjects were eating meat, and plasma and hair concentrations of selenium had decreased. However, after 3 years, selenium status had reverted towards baseline levels, suggesting physiological adaptation. The richest source of selenium is Brazil nuts, but vegetarians may also obtain selenium from sunflower seeds, molasses and wholemeal bread.

The government's advisory committee, SACN, has been asked to review the evidence on UK selenium intakes.

(v) Iodine Iodine is an essential trace element needed for normal mental and physical growth and development. Too little iodine and excessive intakes may both lead to thyroid dysfunction.

Lacto-ovo-vegetarians usually have adequate intakes of iodine, similar to those of meat-eaters, as milk is a major source in the UK diet. Seafood and seaweed are also rich sources of iodine. Vegans do not consume either seafood or milk and are therefore at risk of low intakes of iodine unless they eat seaweed or take supplements. Furthermore, certain foods can alter iodine bioavailability; goitrogenic compounds (these may be destroyed by cooking), which decrease iodine utilisation, occur in nuts, cruciferous vegetables (such as broccoli), millet, sweet potatoes and soya products, and these foods are commonly eaten by vegans (Craig & Pinyan 2001).

Studies have shown that vegans are at risk of both excessive and low intakes of iodine (Lightowler & Davies 1998). Excessive intakes were evident in those consuming seaweed, but for those not consuming seaweed or supplements, intakes of iodine were frequently below the LRNI of 70 μg (Department of Health 1991), *i.e.* likely to be inadequate.

In two further studies, the mean iodine intake of vegans was substantially below recommended levels (Abdulla *et al.* 1981; Draper *et al.* 1993), although Lightowler and Davies (1998) did not find any evidence of clinical iodine deficiency. In a study in Slovakia, 25% of the vegetarians and 80% of the vegans were iodine deficient, compared with only 9% of the meat-eaters, based on iodine excretion measurements (Krajcovicova-Kudlackova *et al.* 2003).

Marginal iodine status increases the level of thyroid stimulating hormone (TSH) in the blood; high levels of TSH may also be an indication of excessive iodine intake. Mean adjusted levels of TSH in British males were 47% higher in a vegan group than in omnivores (Key *et al.* 1992). Three vegans with the highest values of TSH reported that they regularly used kelp (seaweed) tablets or powder, and when these subjects were excluded from analyses, the remaining vegans had mean TSH levels 29% lower than the omnivores, possibly indicating poor iodine status in British vegans not consuming seaweed products.

Consumption of small amounts of iodised salt or seaweed is therefore advisable for those avoiding milk or following a vegan diet, but excessive intakes should be avoided.

(vi) Potassium Potassium is found in body fluids and is essential for the proper functioning of cells, including nerves. It is needed for synthesis of lean tissue as well as being required for homeostasis of sodium, and for renal function (Department of Health 1991). Potassium is present in almost all foods, and is particularly abundant in fruit (especially bananas), potatoes, vegetables and juices.

Currently there is concern that sodium intakes are too high in the UK and, furthermore, the ratio of sodium to potassium is considered to be important in relation to raised blood pressure risk. Vegetarian diets normally supply more than adequate amounts of potassium (Craig & Pinyan 2001). For adults and children, vegetarian diets often provide more potassium than omnivorous diets (Sanders 1999a; Thane & Bates 2000) as vegetarians often consume a wider variety of foods containing potassium on a regular basis.

3.7 Key points

- The term vegetarian encompasses a wide range of dietary patterns and, consequently, nutrient intakes of vegetarians can vary considerably.
- Meat is a good source of a range of nutrients, including protein, zinc, iron, vitamin A, vitamin B_{12} and vitamin D. When meat (and fish) are not eaten, the nutrients that they contain need to be derived from other sources that are either naturally rich in the particular nutrient or are fortified.
- Compared with omnivorous diets, plant-based diets contain less saturated fatty acids, animal protein and cholesterol, and more folate, fibre, antioxidants, phytochemicals and carotenoids. Vegans may have low intakes of vitamin D, vitamin B_{12}, calcium and iodine.

4 Vegetarian diets through the life cycle

For many healthy adults, it is clear that a well-planned vegetarian diet can provide adequate amounts of all of the nutrients needed by the body, and meet current dietary guidelines. Vegan diets, too, may be nutritionally adequate provided that sufficient care is taken to include sources of nutrients, such as vitamin B_{12}, which are normally lacking in a vegan diet, by including fortified foods or supplements (see Appendix C for more details and guidance on achieving a balanced vegetarian diet).

However, specific subgroups in the population may be more at risk of nutrient deficiencies resulting from poor dietary intakes or particularly high requirements. Extra care should be taken by vegetarians (and by meat-eaters), to ensure that nutrient needs are met at the most vulnerable times in the life cycle, and more restricted diets, containing minimal or no animal-derived foods, require particularly careful planning.

4.1 Infancy and childhood

Babies should be breastfed wherever possible, but if breastfeeding is not an option, an infant formula (either based on cows' milk or soya protein) can be used instead for the first 4–6 months. It is usual practice to begin to introduce solids at around 6 months, but breast milk or infant formula should remain a principal dietary component until at least 12 months (see below).

Recently, there has been some concern about the phytoestrogen content of soya-based infant formulae, which is a lot higher than that in human breast milk. A report on phytoestrogens and health from the Committee on Toxicology (COT) (Committee on Toxicology 2003) reported that it is difficult to draw conclusions on the long-term health effects of soya formula because only one study (Strom *et al.* 2001) has examined the long-term health effects; this study did not find any adverse effects. The COT report concluded that, for the time being, *soya-based infant formulae should be fed to* *infants only when indicated clinically (*i.e. *only used on the advice of a GP or health visitor)*.

Differences in nutrient intakes between omnivore and vegetarian infants have not been widely observed, but regular monitoring of weight should be undertaken to ensure that energy intakes are sufficient to allow normal growth. As infants and young children are less able to control their own food intakes in relation to appetite, weight monitoring should be a principal indication of the adequacy of energy intake. Some vegetarian diets may be relatively low in energy and, where this results in poor growth, the energy density of the weaning diet should be increased by greater use of full-fat dairy products (including cheese), eggs and vegetables cooked in a vegetable oil.

4.1.1 Lacto-vegetarian and lacto-ovo-vegetarian diets

Lacto-vegetarian and lacto-ovo-vegetarian diets can be completely adequate during weaning, so long as carers are aware of how best to meet their child's nutritional needs (Department of Health 1994b). Weaning should follow the same principles as for non-vegetarian babies, and at least a pint per day of infant formula should be consumed when breast milk is no longer given. In addition, some commercial weaning foods may be suitable. It is recommended that all children under 2 years of age (and up to 5 years of age if nutritional status is low) receive supplements of vitamin drops containing vitamins A, C and D. Foods fortified with vitamin B_{12} should be included in a vegan diet and, if necessary, a vitamin B_{12} supplement. Malnutrition and poor growth, and in a few cases death, have been reported among infants and children fed very restricted vegan and macrobiotic diets and these diets are *not* recommended (Roberts *et al.* 1979; Zmora *et al.* 1979; Shinwell & Gorodischer 1982).

The diets of vegan children are typically lower in energy than those of omnivores, and vegan children are frequently smaller and lighter than other children (Sanders 1988). Nevertheless, British breastfed children born to vegan mothers and weaned onto a vegan diet grow and develop normally, but great care is needed to ensure that energy needs are met, and that the diet provides sufficient fat (as a source of essential fatty acids) and amino acids.

4.1.2 Restrictive dietary patterns

Restrictive dietary patterns, such as some macrobiotic diets, are characterised by a reluctance to use proprietary infant formulae, fortified foods and vitamin supplements, and include large quantities of raw or cooked fruits and vegetables, and water-based cereal 'gruels' such as 'kokoh' (a dilute porridge made from ground rice, wheat, oats, beans and sesame flour, which is often used as a weaning food in macrobiotic infant diets). Such foods tend to be bulky and can lead to reduced energy density of the diet, and the presence of high levels of phytate in these foods may have an adverse effect on the mineral content of the diet. There have been several studies investigating the adequacy of a restrictive macrobiotic vegetarian diet in 53 macrobiotic infants in Holland compared with 57 omnivorous infants (Dagnelie *et al.* 1989a, 1989b, 1990). The macrobiotic group showed lower weight gain compared with the omnivorous infants, and slower motor and language development was also observed. Differences in micronutrient status were observed between the two groups of infants; infants fed macrobiotic diets had lower plasma B_{12} levels than omnivorous infants, but plasma folate concentration was higher in the macrobiotic infants. Vitamin B_{12} reserves are likely to be limited in infants compared to adults, and progression into B_{12} deficiency may occur very suddenly in infants and young children (Dagnelie *et al.* 1989b). In another study on the same group of children, symptoms of rickets were reported among 28% of the macrobiotic-fed infants in late summer and among 55% in March/April (Dagnelie *et al.* 1990). Low plasma vitamin D concentrations were observed in these infants, but the authors additionally attributed the manifestation of rickets to poor calcium status [the diets exclude all dairy products and high fibre (and phytate) intakes may have further reduced availability of calcium from the diet]. Low intakes of vitamin B_{12}, vitamin D and calcium need to be addressed to ensure that such diets are nutritionally adequate. Vitamin D supplementation is recommended for all infants and rejection of supplementation, by adherents of the macrobiotic diet, demands the regular inclusion of oily fish (acceptable in less restrictive stages of the macrobiotic diet) in the diets of such infants. The inclusion of dairy products is also highly recommended, and decisions to exclude this food group from the infant diet need to be combined with the use of calcium-fortified products and caution with high-fibre cereal foods. To help ensure adequate vitamin B_{12} intakes, the use of foods fortified with B_{12} and/or B_{12} supplements is strongly advised.

4.1.3 Iron deficiency

Iron deficiency is the most commonly reported nutritional disorder in the general UK population and a high prevalence of anaemia, and low serum ferritin concentrations, has been reported in toddlers (Department of Health 1994b). Vegetarian and meat-eating children alike can be at risk of iron deficiency. Iron status in all infants is of importance because of the possible associations with mental and motor development. In normal (term) infants, iron stores, reflected in serum ferritin levels, are depleted by the age of 6 months. Nutritional advice for the feeding of all infants from 6 to 12 months includes ensuring that dietary sources of minerals should be provided by offering a variety of foods. Specifically for vegetarian infants, where dietary supplies of iron are less well absorbed than the haem-iron present in meat and meat products consumed by omnivorous infants, sufficient intake of vitamin C, cautious use of foods which inhibit iron absorption, *e.g.* tea and high fibre foods (see Table 7) and the use of iron-fortified foods, should be ensured.

In general, intakes of iron are similar between vegetarian and omnivorous children (Nathan *et al.* 1996; Thane & Bates 2000).

Nutrient intakes and nutritional status were generally adequate in a subsample of 51 pre-school children who did not report eating meat, from the NDNS of children aged 1.5–4.5 years, as shown by 4-day dietary records and haematological and biochemical nutrient status indices (Thane & Bates 2000). But serum ferritin levels were significantly lower in vegetarian children (especially in children under 3 years old) compared with omnivores. The vegetarian children also had lower intakes of fat, cholesterol and sodium, and higher antioxidant vitamin intakes and status indices.

In a study of 50 matched ‘pairs’ of vegetarian and meat-eating children (mean age at recruitment: 9 years) (Nathan *et al.* 1996), mean haemoglobin levels were lower for vegetarian children than for meat-eaters (11.9 g/dL *vs.* 12.4 g/dL), suggesting lower availability of iron from the vegetarians’ diets or, conversely, the value of including meat in the meat-eaters’ diets. Further analysis of the data from this study (Burgess *et al.* 2001) showed that 33% of iron intake in the meat-eaters’ diets was from meat and meat products, and 13–16% of total iron intake was estimated to be in the haem form. The authors postulate that the presence of haem iron, which is absent in the vegetarian diet, accounted for the higher haemoglobin values reported in the meat-eaters.

4.1.4 Growth and development

Studies of the growth and development of both UK vegetarian (Nathan *et al.* 1997) and vegan (Sanders & Manning 1992) children have shown that growth and development are within the normal range. In the study by Nathan *et al.* there were significantly lower, but adequate, energy and protein intakes and significantly higher fibre intakes in the vegetarian children, and fat and iron intakes were identical to those of a similar group of meat-eating children participating in the study. Vegetarian children consumed more fat from fat spreads, cheese and vegetarian convenience meals. No differences in either body composition or height were observed between the two groups.

A study of 20 life-long vegan children (mean age: 9 years) found that growth and development was within the normal range, although the children were all exceptionally lean (Sanders & Manning 1992). Furthermore, the vegan children in this study had slower rates of growth, especially up to 5 years of age, but catch-up growth had occurred by 10 years of age. Concerns have been expressed over the low energy density and bulky nature of many vegan diets, but this study showed that intakes of energy and protein were adequate and similar to those reported in children of the same age in the general population. Dietary intakes of most micronutrients were adequate and mean intakes exceeded reference nutrient intakes, with the exception of vitamin B_{12} and calcium. Nine of the 20 subjects regularly received vitamin B_{12} supplements, indicating a reasonable level of awareness of this precautionary measure.

A poorly planned vegan or vegetarian diet may lead to considerable nutrient deficiencies with implications for morbidity and mortality later in life (Jacobs & Dwyer 1988).

4.2 Adolescence

Vegetarianism is becoming more common among adolescents in the UK, especially among girls. The NDNS of 4–18 years olds (Gregory *et al.* 2000) found that 1 in 10 girls aged 15–18 years reported being vegan or vegetarian.

There is an increased requirement of some nutrients during adolescence and it may be difficult to increase intakes of some nutrients sufficiently; for example, adolescent female vegetarians may find it difficult to consume sufficient iron, and male vegan adolescents may fall short of calcium requirements.

In a UK cohort (Thane *et al.* 2003), plasma iron and haemoglobin levels were significantly lower in vegetarians compared with omnivores, but there was no difference in vitamin B_{12} status. In this and other studies, low iron stores were apparent in both vegetarian and non-vegetarian adolescents, particularly in girls (Nelson *et al.* 1994; Gregory *et al.* 2000; Thane *et al.* 2003).

Studies of the dietary intakes of adolescent vegetarians in the USA have found that mean daily intakes of energy and most nutrients are comparable for vegetarians and meat-eaters (Donovan & Gibson 1995). In a study of 4746 adolescents in Minnesota, 5.8% reported being vegetarian, most (73.7%) of whom were girls (Perry *et al.* 2002). Average iron intake was higher among vegetarians in the study, but vitamin B_{12} intake was lower than in the meat-eating adolescents, and most adolescents in both vegetarian (70%) and meat-eating (65%) groups failed to meet the recommended intake for calcium (1300 mg/day in the USA). Conversely, the adolescent vegetarians were more likely to consume more fruit and vegetables and less fat than the meat-eaters.

Iron deficiency anaemia carries implications for both mental and physical performance, and so it is essential that adolescent vegetarians (and meat-eaters) consume iron-rich foods and foods that promote iron absorption (see 3.6.3i and Appendix C).

4.3 Pregnancy and lactation

Women are nutritionally vulnerable during pregnancy and there is an increased requirement for energy (in the last 3 months), protein and some vitamins, such as riboflavin, folate and vitamin D. Increased intake of energy and protein during pregnancy is not likely to pose a problem for vegetarian and vegan women, but increased intakes of some vitamins is likely to be more difficult, especially for vegans. Mean intakes of riboflavin, vitamin B_{12}, calcium and iodine have been reported to be below the RNI in non-pregnant vegan women, and mean dietary intake of zinc was 7 mg/day, exactly meeting the RNI, although the high phytate content of the vegan diet may have subsequently impaired absorption of zinc (Draper *et al.* 1993). In general, pregnant vegetarians should follow the same advice as meat-eaters with respect to food safety (*e.g.* avoid excess vitamin A and unpasteurised cheeses; see http://www.food.gov.uk for current advice). Some types of fish, such as marlin, swordfish and tuna, may contain sufficient mercury to damage the developing nervous system of an unborn infant, and pregnant or lactating vegetarian women (and those who intend to get pregnant) should pay particular attention to the amounts of these fish eaten (current guidelines recommend no more than two 140 g portions of fresh tuna or four 140 g portions of canned tuna and avoidance of shark, marlin and swordfish) (SACN 2004).

4.3.1 Pregnancy outcome

The relatively greater exposure to phytoestrogens on a vegetarian diet (see Soya and Health Briefing Paper, BNF 2002) has raised concerns. The Avon Longitudinal Study of Pregnancy and Childhood (ALSPAC) (North & Golding 2000) found that consuming a vegetarian diet during pregnancy was associated with an increased risk of giving birth to a boy with hypospadias (a birth defect that results from incomplete development of the penis during development in the womb), a condition which is reported to be increasing in prevalence. The authors hypothesised that phytoestrogens have a deleterious effect on the developing male reproductive system and more research is needed to investigate this association.

Outcome of pregnancy has been examined among different groups in the UK population. In a study of the nutrient intake and pregnancy outcomes of lacto-ovo-vegetarians, fish-eaters and meat-eaters, no difference was observed between the three study groups in length of gestation, birth weight, birth length or head circumference (Drake *et al.* 1998). Conversely, Sanders (1995) reported lower birth weights of infants born to white women following vegan diets, and also of infants born to white women consuming macrobiotic diets, compared with the general population. In another study, of Hindu vegetarian women resident in the UK, duration of pregnancy was, on average, 4–5 days shorter, onset of labour was earlier and emergency Caesarean section was more common than in the white UK population (Reddy *et al.* 1994). Birth weight, head circumference and body length were lower in infants born to Asian vegetarians, compared to white omnivores, even after adjusting for confounding factors, such as maternal age and height, gestational age, sex of infant, number of children (parity), and smoking habit. The reverse was found among a cohort of Norwegian Seventh-Day Adventist infants who were almost 1 kg heavier, on average, at birth than the infants of matched meat-eating non-Adventist controls (Fonnebo 1994), however, the difference may be because of the lower number of smokers among the Adventist mothers. It has been suggested that the lower birth weight observed among some infants born to mothers on vegetarian diets may be related to poor nutritional status with regard to iron, or folate and/or vitamin B_{12}, but further research in this area is needed.

4.3.2 Lactation

During lactation, there is an increased requirement for a number of nutrients, such as calcium, zinc, vitamin B_{12} and vitamin D. Guidelines on what to eat during lactation are essentially the same for vegetarians as for meat-eaters. Provided that a varied vegetarian diet is consumed, adequate amounts of most nutrients should be available. For vegans, extra care must be taken to ensure that supplements of vitamin B_{12} or B_{12}-fortified foods are consumed. A number of cases of deficiency, and extremely low B_{12} stores at birth, have been reported in infants born to mothers who had used no animal products for some time, and whose infants were exclusively breastfed (Specker *et al.* 1990; Michaud *et al.* 1992). In a study of lactating women following macrobiotic diets (Specker 1994), dietary supply of calcium was low (486 mg/day *vs.* 1038 mg/day in lactating women on omnivorous diets), but this did not result in lower breast milk concentrations of calcium, presumably because calcium was diverted from the mother's own stores in the skeleton. However, breast milk concentrations of vitamin B_{12} were lower than in breast milk samples from omnivorous women, and this may result in poorer vitamin B_{12} status in the infants of women following a macrobiotic diet. Vitamin B_{12} deficiency in infancy has serious implications for growth and development.

The profile of fatty acids in breast milk is influenced by the dietary intake of the mother, and by the composition of her adipose stores. The amounts of linoleic acid (*n*-6) and alpha-linolenic acid (*n*-3) are both higher in the milk of vegetarian women and highest in the milk of vegan women (Sanders *et al.* 1978; Sanders & Manning 1992). Lower levels of the long-chain derivatives of alpha-linolenic acid, such as DHA (see Section 3.3.2), have been observed in the breast milk of vegetarians compared with omnivore controls, with the lowest levels in the breast milk of vegan women; the breast milk of vegan mothers contained nearly two-thirds less DHA than that of the omnivore control group (Sanders & Reddy 1992, 1994). It has been suggested that very high intakes of linoleic acid in some vegetarian diets may interfere with the production of DHA, and consequently the DHA content of breast milk (Birch *et al.* 1998). The implications of the differences in fatty acid profile of breast milk in relation to infant development are not clear, although infant growth does not appear to be affected. Nevertheless, according to Sanders (1999b), both term and preterm infants deprived of DHA show abnormalities in visual and brain functions, but it is uncertain whether the reported changes result in changes in physiological functioning.

4.4 Athletes

Ancient Greeks considered eating large amounts of meat to be important in enhancing athletic performance (Ratzin 1995), but very high protein diets are no longer favoured by athletes; carbohydrate-rich diets are usually preferred to optimise glycogen stores for those athletes involved in sports that require endurance (BNF 2001b). Long bouts of strenuous exercise deplete much of the glycogen stored in the muscles, leading to fatigue. Vegetarian diets are usually, although not necessarily, higher in carbohydrate than omnivorous diets and so are considered by some to be preferable. But the effect of a vegetarian diet or elimination of animal products remains unclear.

Hanne *et al.* (1986) compared the fitness of vegetarian athletes and non-vegetarian athletes and found no differences. But vegetarian women had a significantly lower percentage body fat than non-vegetarian women, and vegetarian women also had lower haemocrit (red blood cell percentage) values than controls, although haemoglobin was similar.

The iron content of a vegetarian diet and studies of iron status in vegetarians have been discussed previously (see Sections 3.6.3i and 4). Iron plays a critical role in energy metabolism and is it therefore essential that athletes have adequate iron stores. There is evidence that female athletes who limit their intake of meat have lower iron stores despite similar iron intakes to women who eat an omnivorous diet (Snyder *et al.* 1989).

Amenorrhoea has also been shown in the past to be more common in vegetarian female athletes than meat-eaters (Brooks *et al.* 1984; Slavin *et al.* 1984), although the reasons for this remain unclear. Amenorrhoea, a feature of the female athlete triad (disordered eating, amenorrhoea and loss of bone mineral), has a significant detrimental effect on long-term bone health. No significant differences in bone density have been observed between vegetarian and non-vegetarian women and vegetarianism *per se* is not a risk factor for the female athlete triad, but it may be considered a factor if an athlete is amenorrhoeic as a result of her vegetarian eating pattern (Benson *et al.* 1996). Inappropriate eating habits among vegetarian athletes, particularly female athletes involved in sports where body image is important (such as gymnastics), are of concern. Adherence to a vegetarian diet, or other restricted diet, may be used as an excuse for disordered eating patterns, as vegetarianism may be perceived, wrongly, to be 'slimming'.

In summary, whilst a vegetarian diet that is high in carbohydrate can have an advantageous effect on athletic performance, due to the increase in muscle glycogen levels, there is currently no evidence to suggest that simply being vegetarian can enhance performance, and a poorly planned vegetarian diet can have an adverse effect on physical performance as well as long-term health.

4.5 Elderly people

A well-balanced vegetarian diet can easily provide all of the nutrients required by elderly people. Nevertheless, extra care should be taken to ensure that the diet contains adequate amounts of some key nutrients.

Calcium absorption is reported to decline with age (WHO 2002) and elderly vegetarians and, more importantly, vegans should ensure that adequate calcium is included in the diet. Mineral adequacy is particularly of concern as foods high in phytate reduce the availability of minerals such as iron, copper and zinc (see Section 3.6.3ii), although vegetarian diets that are relatively high in fibre may benefit older people who suffer from constipation.

The NDNS of people aged 65 and over showed that a high proportion of elderly people in the UK had selenium intakes below recommended levels (Bates *et al.* 2002). This survey did not examine selenium intakes and status of elderly vegetarians specifically, but other studies have shown that vegetarian adults typically have a lower dietary intake of selenium than the general population.

A raised level of plasma homocysteine is recognised as a risk factor for vascular disease and stroke, and has also been linked to certain cancers, most notably colon cancer, and also to Alzheimer's disease. Homocysteine levels are also known to be inversely associated with blood levels of vitamins B_6, B_{12} and folate; marginal folate deficiency is associated with raised plasma homocysteine. In a major European study called SENECA (Survey on European Nutrition and the Elderly: A Concerted Action) (Quinn & Basu 1996), folate status was generally adequate, but elderly people living in residential homes may be at risk of marginal folate deficiency as a result of foods being kept warm for long periods which reduces folate levels. Vegetarians' intakes of folate are usually adequate, but those who provide food for elderly vegetarians living in institutions should ensure that good sources of folate, or folic acid fortified foods, are consumed. Also, all elderly vegetarians, particularly vegans, should ensure that their intakes of vitamins B_6 and B_{12} are sufficient to meet requirements, including fortified foods and supplements of B_{12} where necessary.

The NDNS survey of people aged 65 and over also found low vitamin D status amongst those living in institutions, such as nursing homes (Finch *et al.* 1998). Deficiency of vitamin D is a major risk factor for hip fractures, a major public health problem in this age group. The main source of vitamin D is from the action of sunlight on the skin, and so to ensure normal vitamin D status, older people are advised to expose some of their skin (*e.g.* face and arms) to sunlight for a short time (avoiding exposure when the sun is strongest, between 11AM and 3PM) during the summer months. Vitamin D supplements may be needed by people who are rarely outside, such as those who are housebound (Department of Health 1998). Dietary intakes of vitamin D are lower in vegetarian and vegan adults than in omnivores (Draper *et al.* 1993) and so it is particularly important that elderly vegetarians and vegans, who are housebound or live in an institution, include foods that are fortified with vitamin D (see Appendix C) and supplementation may be required; currently older people are advised to take a 10 μg supplement of vitamin D (see http://www.dh.gov.uk for more information).

4.6 Key points

- For healthy individuals, a well-balanced vegetarian diet can provide adequate amounts of all of the nutrients required by the body throughout the lifecycle. However, more attention and careful dietary planning may be required for specific vulnerable subgroups in the population.
- Lacto- and lacto-ovo-vegetarian diets can be completely adequate during infancy and childhood. Weaning should follow the same principles as for non-vegetarian infants. Careful dietary planning is needed for infants who are weaned onto vegan diets to ensure that adequate energy, essential fatty acids, protein, calcium and foods fortified with vitamin B_{12} (or supplements), are included.
- Restrictive dietary patterns, such as some extreme macrobiotic diets, have been found to lead to poor growth and malnutrition; such diets are not recommended for infants and children.
- Particular attention to dietary requirements for vitamins and minerals is needed during pregnancy and lactation. Guidelines on what to eat during pregnancy and lactation are essentially the same for vegetarians as for meat-eaters, but women on restricted diets may need to consume supplements or fortified food in order to meet these.
- There are few data on the effects of a vegetarian diet on athletic performance. It is important for female vegetarian athletes to eat sufficient iron-containing foods and foods that promote absorption of iron. A poorly planned vegetarian diet can have an adverse effect on physical performance and long-term health.
- A well-planned vegetarian diet can easily provide all the nutrients needed by elderly people. Particular attention should be paid to mineral adequacy, folate, vitamin

B_{12} and vitamin D, especially for elderly vegetarians and vegans who are housebound or living in an institution.

5 Health implications of vegetarian diets

5.1 Mortality rates among vegetarians

A small number of major studies of Western vegetarians have been set up to examine the long-term health and causes of death amongst UK vegetarians: the Health Food Shoppers Study; the Oxford Vegetarians Study; and the Oxford cohort of the European Prospective Investigation into Cancer (EPIC). Other studies have been set up in Germany and California. These studies are summarised in Table 8.

In summary, three out of the six studies indicate a decrease in all-cause mortality risk for very low or zero intake of meat relative to higher intake of meat (the German study and Adventists studies reached statistical significance).

Appleby *et al*. (2002a) pooled the data from the UK studies to compare the mortality rates of British vegetarians and non-vegetarians. Analyses showed that both vegetarians and non-vegetarians in these studies had lower overall standardised mortality ratios than the general UK population, illustrating the 'healthy volunteer' effect. Mortality rate was not significantly lower in vegetarians than non-vegetarians for any of the causes of death studied, although the results were consistent with a moderate reduction in mortality from CHD. Furthermore, the authors reported a higher mortality rate amongst vegetarians for neurological and mental diseases and amongst vegetarian women for breast cancer. Appleby *et al*. concluded that British vegetarians in these studies have low mortality rates compared with the general population, but that their death rates are similar to those of comparable non-vegetarians. This suggests that the lower death rates observed in vegetarians than in the general population may be attributed to non-dietary lifestyle factors, such as not smoking and higher socio-economic status, or dietary factors other than the avoidance of meat or fish.

Cohort studies have also enabled specific analyses of mortality rates from CHD and cancer to be carried out. Data from the Oxford Vegetarians Study and the Health Food Shoppers Study suggest that there is a moderate (but non-significant) reduction in CHD mortality among vegetarians. The death rate ratios (DRR) for CHD were 0.86 [95% CI 0.67, 1.12] in the Oxford Veg-

Table 8 Major cohort studies of Western vegetarian populations

Study name	Country	Cohort size	Follow-up years	Adjusted mortality ratio (vegetarian vs. meat-eater) [95% CI] *	Comments
Oxford Vegetarians Study	UK	11 000	12	1.01 [0.89, 1.14]	6000 vegetarians, 5000 non-vegetarians of similar social class and lifestyle
Health Food Shoppers Study	UK	10 771	18	1.03 [0.95, 1.13]	43% were 'self-reported' vegetarians at baseline, but a later substudy revealed that amongst those classified as vegetarian, 66% consumed meat or fish less than once per week
Oxford-EPIC cohort	UK	56 000	6	1.05 [0.86, 1.27]	17 774 vegetarians and 37 267 non-vegetarians, results adjusted for age, sex and smoking habit
German Vegetarians Study	Germany	1 904	11	Males: 0.44 [0.36, 0.53] Females: 0.53 [0.44, 0.64]	Subjects classified as strict vegetarian (no meat or fish consumed) or moderate vegetarian (low intake of meat or fish)
Adventists† Mortality Study\	USA	34 198	26	0.88 [0.82, 0.93]	7918 subjects who reported eating no meat and were on the California SDA census in 1958
Adventists Health Study	USA	27 530	12	0.85 [0.76, 0.93]	7191 subjects who reported eating no meat and were on the California SDA census in 1976

*The nature of the comparative control groups varied for each of the cohorts. The Oxford Vegetarian Study vegetarians were compared to 'matched' meat-eaters; the Health Food Shoppers Study vegetarians were compared to non-vegetarian subjects from the same cohort; the German vegetarians were compared to the general population; and both of the Adventists studies compared vegetarians (eating zero meat) with Adventists who ate meat once or more per week. †The Seventh Day Adventist (SDA) Church prohibits use of tobacco and alcohol and pork consumption, and recommends the omission of meat from the diet, although not all SDA members are vegetarians.

Sources: Data from Health Food Shoppers Study, Oxford Vegetarians Study and EPIC-Oxford reported by Key *et al*. (2003); data from German Vegetarians Study, Adventists Mortality Study and Adventists Health Study reported by Key *et al.* (1998).

etarians Study and 0.85 [95% CI 0.71, 1.01] in the Health Food Shoppers Study, *i.e.* both lower but non-significantly different from meat-eaters (Appleby *et al.* 2002a). However, the vegetarians in the Adventist studies and the German study showed a greater reduction in CHD mortality. In a pooled analysis of five of the cohort studies outlined in Table 8 (excludes Oxford-EPIC cohort), vegetarians had a 24% lower mortality rate from CHD compared with meat-eaters (0.76 [95% CI 0.62, 0.94]) (Key *et al.* 1998). Furthermore, when 'semi-vegetarians' (those in the cohort who ate meat less than once a week) were separated out from the regular meat-eaters, who were then used as a reference group, and fish-eaters, the reduction in risk of mortality from CHD was 20% in occasional (less than one serving per week) meat-eaters (0.80 [95% CI 0.69, 0.93]), 34% in the fish-eaters (0.66 [95% CI 0.48, 0.90]) and 34% in the vegetarians (0.66 [95% CI 0.52, 0.83]). For vegans, there was no significant difference, however, the number of vegans was small. The pooled analysis by Key *et al.* (1998) also examined mortality data for the five most common cancers in Western countries: lung, colorectal, breast, prostate and stomach cancers. Analyses showed that mortality did not differ significantly between the vegetarian and non-vegetarian subjects. However, studies of British vegetarians have shown that mortality from female breast cancer was higher in vegetarians than non-vegetarians in the Health Food Shoppers Study, although this was not reflected in the Oxford Vegetarians Study (Appleby *et al.* 2002a). On the other hand, the Adventist Health Study reported significantly lower breast cancer death rates among vegetarians (Key *et al.* 1999b).

The European Prospective Investigation into Cancer and Nutrition (EPIC) (http://www.iarc.fr/epic) aims to provide a greater insight into the potential links between diet and cancer mortality. The EPIC study, initiated in 1992, was designed to investigate the relationships between diet, nutritional status, lifestyle and environmental factors and the incidence of cancer and other chronic diseases. EPIC is the largest study of diet and health ever undertaken, having recruited over *half a million people* in 10 European countries, including the UK. The UK's Oxford cohort of EPIC participants (EPIC-Oxford) intentionally recruited a high proportion of non-meat-eaters, which included a large number of vegans. This has enabled the differences in mortality and morbidity, and the contribution of major lifestyle and dietary factors to these, to be assessed between different diet groups. Preliminary results from the EPIC-Oxford cohort (in which subjects are followed up by record linkage with the National Health Service Central Register to provide information on cancer diagnoses and deaths) show that standardised mortality rates are lower than for the general population for both vegetarians and non-vegetarians in the study. Of the 558 deaths reported in the preliminary results, comparisons of all cause death rates between vegetarians and non-vegetarians showed no significant differences. Higher mortality rates from cancer and reduced mortality from CHD among vegetarians was reported but the findings were not statistically significant (Key *et al.* 2003). The small number of deaths from individual causes in EPIC-Oxford reduces statistical power, but future analyses may provide clearer patterns.

In summary, vegetarians have lower mortality rates than the general population, particularly from CHD, but non-vegetarians who follow a healthy lifestyle also have favourable mortality rates compared with the general population. Therefore, the reduced risk cannot be directly attributed to the vegetarian pattern of eating *per se*. Mortality rates from other causes have shown no clear and consistent trend.

5.2 Cardiovascular disease and vegetarian diets

Globally, CVD is a major cause of illness and death. It is now known that a number of factors are implicated in the aetiology of CVD and diet is thought to influence many of these. This is the subject of a new BNF Task Force report which has recently been published (BNF 2005).

Vegetarian diets have been associated with reduced risk of mortality from CHD, and reduced risk from some of the established risk factors for the disease, such as raised blood pressure, unfavourable blood lipid profiles, obesity and changes in haemostatic factors (such as raised plasma levels of fibrinogen and platelet adhesiveness). Furthermore, vegetarians are less likely than meat-eaters to smoke or consume too much alcohol and are generally more active than comparable non-vegetarians (Key *et al.* 1999a). The difference in mortality and morbidity from CHD between vegetarians and meat-eaters is likely to be attributable to lifestyle as well as diet, but it remains unclear to what degree these factors explain the observed differences referred to in Section 5.1).

Anthropometric measurements favouring lower risk of CHD are more common in vegetarians and changing to a vegetarian diet may lead to a change in body composition (Phillips *et al.* 2004). Vegetarian adults are often, although not always, leaner than comparable non-vegetarians, typically having a BMI approximately 1–2 kg/m^2 less than that of non-vegetarians (Chang-

Claude *et al.* 1992; Thorogood *et al.* 1994; Appleby *et al.* 2002b) and vegans tend to have a lower BMI than both meat-eaters and vegetarians (Sanders & Manning 1992; Appleby *et al.* 2002b). The lower BMI observed among vegetarians may be, in part, the result of a more active lifestyle, but may also be explained by differences in macronutrient intakes, higher fibre consumption and greater consumption of vegetables, which have a lower energy density.

Blood lipid levels tend to show a more favourable profile in vegetarians and vegans than meat-eaters (Sanders & Reddy 1994; Thorogood 1995). Furthermore, changing to a vegetarian diet has been shown to lead to favourable changes in blood lipid profile (Robinson *et al.* 2002). The Oxford Vegetarians Study showed that, on average, total cholesterol was 0.43 mmol/L lower in vegetarians than in meat-eaters and most of this is explained by lower low density lipoprotein (LDL) cholesterol (see Table 9). The EPIC-Oxford cohort found that, compared with non-vegetarian subjects, total serum cholesterol concentrations were 0.39 mmol/L and 0.35 mmol/L lower in male and female vegetarians, respectively (Key *et al.* 2003). The favourable blood lipid profile seen among vegetarians is partly explained by the lower BMI in these groups, as obesity is associated with increased serum total cholesterol and lower high density lipoprotein (HDL) cholesterol. But Sacks *et al.* (1975) observed that even when vegetarians were heavier than non-vegetarians, the lower cholesterol levels observed among vegetarians persisted.

Raised blood pressure is another major risk factor for CVD. It has been estimated that a 5 mmHg increase in diastolic blood pressure increases stroke risk by 34% and heart disease risk by 21% (MacMahon *et al.* 1990). Several studies have reported lower systolic and diastolic blood pressure, of the order of 5–10 mmHg, in vegetarians compared with non-vegetarians (Ophir *et al.* 1983; Melby *et al.* 1985). The EPIC-Oxford study reported lower systolic (4.2 mmHg and 2.6 mmHg lower in men and women, respectively) and diastolic blood pressures (2.8 mmHg and 1.7 mmHg lower in men and women, respectively) and a lower prevalence of hypertension among vegans compared to meat-eaters, but this was largely attributable to differences in BMI between the groups (Appleby *et al.* 2002b). Trials have shown that changing to a prescribed vegetarian diet was associated with small, but clinically useful, reductions in blood pressure (Margetts *et al.* 1987; Sciarrone *et al.* 1993; Beilin 1994) and a recent international study of macronutrients and blood pressure (INTERMAP) (Stamler *et al.* 2003) reported that lower intake of vegetable protein was one of the dietary factors associated with adverse blood pressure levels, although this study did not differentiate between vegetarians and meat-eaters. A vegetarian diet *per se* is not necessarily protective against the development of hypertension, however, vegetarians are less likely to be obese, and less likely to smoke and drink alcohol to excess, and this may be key in reducing the risk of hypertension.

It is clear that not all aspects of vegetarian diets are in accordance with reduced risk of CVD. It is now recognised that high plasma homocysteine concentration may be a risk factor for CVD and plasma homocysteine is inversely related to B vitamin status (Hankey & Eikelboom 1999). Although vegetarians have higher intakes of folate than, and similar intakes of vitamin B_6 to, the general population, vegetarians (particularly vegans), have lower intakes of vitamin B_{12}. Vegetarians are therefore at risk of B_{12} deficiency, which may influence plasma homocysteine levels. Mezzano *et al.* (1999) reported that 21 out of 26 vegetarians had low serum B_{12} concentrations and plasma homocysteine was 41% higher in vegetarians than comparable meat-eaters in the study. Similar findings were evident in another study (Bissoli *et al.* 2002) and in a third, vegans were found to have the highest concentrations of homocysteine (12.8 mmol/L) compared with other groups (Obeid

Table 9 Blood lipid profiles of participants in the Oxford Vegetarians Study

Diet group	*n*	Total cholesterol (mmol/L) Mean (SE)	LDL-cholesterol (mmol/L) Mean (SE)	HDL-cholesterol (mmol/L) Mean (SE)
Vegan	114	4.29 (0.140)	2.28 (0.126)	1.49 (0.140)
Vegetarian (diet may include dairy and/or eggs)	1550	4.88 (0.100)	2.74 (0.090)	1.50 (0.140)
Fish-eater	415	5.01 (0.109)	2.88 (0.098)	1.56 (0.140)
Meat-eater	1198	5.31 (0.101)	3.17 (0.091)	1.49 (0.140)

Source: Thorogood *et al.* (1987) *British Medical Journal* 295: 351–353; reproduced with permission from the *BMJ* Publishing Group.
LDL, low density lipoprotein; HDL, high density lipoprotein.

et al. 2002). The German Vegan Study of strict ($n = 98$) and moderate ($n = 56$) vegans (Waldmann *et al.* 2003) reported vitamin B_{12} deficiency in 37% of strict vegans and 7% of moderate vegans and also found a high prevalence of hyperhomocysteinaemia (42% of strict vegans and 24% of moderate vegans). These studies suggest that raised plasma homocysteine levels may be common in vegans and strict vegetarians and that an adequate intake of vitamin B_{12} is necessary to avoid hyperhomocysteinaemia. Herrmann *et al.* (2003) suggest that vitamin B_{12} status should be monitored in strict vegetarians with more emphasis on supplementation.

It has been suggested that the lower CHD mortality observed among vegetarians in the Oxford Vegetarians Study is partly explained by differences in dietary saturated fatty acids and dietary cholesterol (Mann *et al.* 1997). High consumption of cheese, eggs, total animal fat and dietary cholesterol were strongly associated with CHD mortality, but no effects were observed for consumption of fibre, fish or alcohol, and frequency of meat consumption was not significantly related to CHD mortality. The Adventists Health Study found different associations: wholewheat bread consumption and frequent nut consumption were both associated with a reduction in CHD risk (Key *et al.* 1998). Vegetarians are also more likely to consume more soya products than the general population, and consumption of over 25 g of soya protein per day (a substantial amount) has been estimated to modestly reduce cholesterol levels by an average of 0.23 mmol/L (Anderson *et al.* 1995) (see BNF 2002 and http://www.jhci.org for more information on claims regarding soya protein). Evidence from prospective cohort studies also indicates that a high consumption of plant-based foods, such as fruit, vegetables, nuts and wholegrains, is associated with reduced risk of CVD (Hu 2003). Plant-derived foods contain a wealth of potentially protective phytochemicals, such as phytoestrogens, carotenoids and glucosinolates, but the mechanisms of action of these compounds are still being investigated. For a thorough review of the role of plant-derived foods in health see BNF (2003). It is thought that the protective effects of plant-derived foods are probably mediated through a combination of beneficial nutrients and phytochemicals. Therefore, diets based on plant-derived foods, including vegetarian diets, may be expected to contain more of these beneficial components, conferring some protection from CVD.

In summary, current evidence suggests that vegetarians have a lower risk of CVD (and, in particular, CHD) than the general population. Some dietary factors have been suggested to be protective, including a lower intake of saturated fatty acids and increased nut consumption, and lifestyle factors and a lower BMI are likely to make a considerable contribution to the difference in CVD risk between vegetarians and meat-eaters. More work is still needed to establish which aspects of the diet are of importance: omission of animal-derived foods, inclusion of more (or specific) plant foods, or a combination of the two.

5.3 Cancer and vegetarian diets

Second to smoking, diet is probably the most important modifiable risk factor for cancer. A high intake of plant-derived foods has been linked with a reduced risk of certain cancers, although the mechanisms are not clear (see BNF 2003 for a detailed review). Vegetarians and vegans would be expected to consume more plant-derived foods than meat-eaters and it has been suggested by some, but not all studies, that cancer mortality patterns differ between vegetarians and meat-eaters (see Section 5.1).

In a review of the epidemiological evidence of the protective effect of fruit and vegetables on cancer risk, Riboli and Norat (2003) reported that case–control studies show a significant reduction in the risk of cancers of the oesophagus, lung, stomach and colorectum with increased consumption of fruit and vegetables. Breast cancer risk was lower with increased consumption of vegetables, but not fruit. Prospective studies, which are generally regarded as more robust, have shown weaker evidence than case–control studies (see Riboli & Lambert 2002, for a review of nutrition and lifestyle factors involved in cancer prevention).

As a consequence of higher intakes of plant-derived foods, vegetarians are also likely to have higher intakes of phytochemicals, which may have protective effects and work *via* a range of mechanisms (see BNF 2003). In general, studies examining differences between vegetarians and non-vegetarians, in breast cancer incidence and mortality, are inconsistent in their conclusions, indicating that any dietary association is likely to be weak. For example, pooled data from five prospective studies of vegetarians (Key *et al.* 1998) showed that breast cancer mortality was significantly lower among vegetarians in the Adventist Health Study, but overall the pooled data showed no significant difference for breast cancer.

The colonic environment of vegetarians and vegans is different to that of meat-eaters. Vegans have considerably lower levels of potentially carcinogenic secondary bile acids compared to vegetarians, who, in turn, have lower levels than meat-eaters (van Faassen *et al.* 1993). Vegetarians also have fewer intestinal bacteria able to convert the primary bile acids into secondary bile acids

(Finegold *et al.* 1977). Secondary bile acids have been positively associated with dietary intakes of saturates and negatively associated with intake of fibre and starch (Reddy *et al.* 1998), intakes of which differ between vegetarians, vegans and meat-eaters. Faecal variables associated with colon cancer risk have been examined, before and after changing to a Scandinavian lacto-ovo-vegetarian diet (Johansson 1990)\. Twenty subjects participated for 12 months and, after 3 months, significant reductions were observed in the faecal content of deoxycholic acid and bacterial enzymes, and a significant increase was observed in faecal weight. The increase in faecal weight was explained by a higher water content, which diluted the faecal bile acids and enzymes and appeared to result from a significantly higher fibre intake. The EPIC study has also shown that dietary fibre is inversely related to large bowel cancer (Bingham *et al.* 2003). The adjusted relative risk was 0.75 [95% CI 0.59, 0.95] for the highest *vs.* the lowest quintiles of intakes and the authors suggest that in populations who consume a low fibre diet (approximately 12 g/day or less), doubling fibre intake could reduce the risk of colorectal cancer by as much as 40%. The Adventists Health Study reported that, after controlling for age, sex and smoking, non-vegetarians had an 88% increased risk for colorectal cancer (Fraser 1999). Allen *et al.* (2000) reported lower levels of serum insulin-like growth factor-1, which is thought to be involved in the aetiology of several cancers, including colorectal cancer, in vegans, compared with non-vegetarians and lacto-ovo-vegetarians.

In terms of meat consumption, there is some suggestion that a high consumption of processed meats (*e.g.* bacon, salami, sausage) increases the risk of colorectal cancer. No consistent associations have been made with red meat *per se* (Hill 1999). High temperature cooking (*e.g.* barbecuing, grilling and frying) has also been associated with raised cancer risk (Knize *et al.* 1999) because these cooking methods are thought to produce potentially carcinogenic substances (such as heterocyclic amines). In spite of all of these potentially protective dietary factors, major studies of vegetarians have failed to show a consistent effect on colorectal cancer. Key *et al.* (1998) reported that mortality from colorectal cancer was almost identical in vegetarians and non-vegetarians in the pooled analysis of five prospective studies (death rate ratio = 0.99 [95% CI 0.77, 1.27]) regardless of the length of time for which people had been vegetarian. Results from EPIC are likely to provide some of the answers.

In summary, although some studies have reported lower rates of cancers in vegetarians compared with the general population, these differences are not so apparent when vegetarians are compared with similar non-vegetarians. Nevertheless, a diet based on a high intake of plant-derived foods, whether meat is included or not, seems to be associated with reduced risk of several types of cancer, although more research is necessary to understand the mechanisms involved.

5.4 Osteoporosis and bone health in vegetarians

Osteoporosis is a complex disease that is characterised by low bone mass and deterioration of bone tissue, leading to increased bone fragility and greater risk of fracture.

Studies examining the association between vegetarianism and bone density have found conflicting results. Several studies conducted prior to 1990 (Marsh *et al.* 1980, 1988; Tylavsky & Anderson 1988; Hunt *et al.* 1989) found bone mineral density to be higher among vegetarians than meat-eaters, but confounding lifestyle factors were apparent for many of these. For example, differences in caffeine and alcohol consumption, smoking habits and activity levels were found, all of which independently affect bone mineral density. Subsequent studies have shown no difference in bone mineral density between meat-eaters and vegetarians (Lloyd *et al.* 1991; Tesar *et al.* 1992; Lau *et al.* 1998).

Overall, there is little evidence to suggest that bone mineral density differs markedly between Western vegetarians and meat-eaters.

5.5 Other diseases

A range of other diseases [from gallstones (Pixley *et al.* 1985) and rheumatoid arthritis (Muller *et al.* 2001) to diverticular disease (Gear *et al.* 1979; Nair & Mayberr 1994) nephrotic syndrome (D'Amico *et al.* 1992) and dementia (Giem *et al.* 1993; Snowdon *et al.* 2000)] has been investigated to examine whether vegetarian diets may be associated with reduced risk. However, the small number of studies conducted makes it difficult to draw firm conclusions.

In summary, a range of potential beneficial health effects have been associated with a vegetarian diet, but it is not clear whether these effects result from the omission of meat from the diet, or some other dietary factor such as eating more fruit and vegetables. Nor is it clear whether there are similar benefits to be gained by meat-eaters who include a larger amount of plant-derived foods in their diet, alongside animal-derived foods. Non-dietary lifestyle factors are also likely to be relevant. For vegetarians and meat-eaters alike, the need for dietary balance is key to good health.

5.6 Key points

• Evidence from cohort studies in the UK, USA and Germany suggests that vegetarians have lower overall standardised all-cause mortality ratios than the general population.

• Specific analyses of mortality rates from CHD have shown that there is at least a moderate reduction in mortality from CHD among vegetarians compared with meat-eaters, in general. However, meat-eaters who follow a healthy lifestyle also have favourable mortality rates compared with the general population.

• Vegetarian diets have been associated with a reduction in several of the established risk factors for CHD; these include more favourable lipid profiles, lower BMI and lower systolic and diastolic blood pressures. However, studies suggest that some vegetarians and vegans may be at greater risk of raised plasma homocysteine levels, an emerging risk factor for CVD, perhaps in association with a low vitamin B_{12} intake.

• A high intake of plant-derived foods has been linked with a reduced risk of certain cancers, but there are no clear and consistent patterns of cancer incidence and mortality between vegetarians and meat-eaters.

• Several studies have reported increased risk of colorectal cancer amongst those with the highest intakes of meat and the lowest intakes of dietary fibre, but there is no consistent evidence to show that vegetarianism *per se* is protective against colorectal cancer.

• Vegetarianism has been associated with some factors that result in lower bone density and, consequently, osteoporosis, but studies examining vegetarianism and bone density have found conflicting results. Overall, there is little evidence to suggest that bone mineral density differs markedly between Western vegetarians and meat-eaters.

6 Conclusions

The number of people claiming to be vegetarian has increased in the last 50 years, although vegetarianism has been practised for centuries. There is no single dietary pattern that characterises vegetarianism; several dietary patterns have been identified, from inclusion of some meat products or fish eaten occasionally to extreme avoidance of all animal products. In addition to dietary differences between meat-eaters and vegetarians, a range of lifestyle differences have also been identified. It has been suggested that these lifestyle factors may account for some of the differences in health outcomes that have been reported between vegetarians and meat-eaters.

There is now evidence that vegetarians have lower rates of mortality than the general population, but similarly favourable mortality rates have been identified amongst health-conscious meat-eaters. However, analyses have shown that there is a moderate reduction in mortality from CHD among vegetarians compared to meat-eaters. This is further supported by evidence that a number of established risk factors, including blood lipid profiles, blood pressure and BMI, are all more favourable in vegetarians and vegans. There are no clear and consistent differences in patterns of cancer incidence and mortality between vegetarians and meat-eaters. Further well-controlled studies are needed to establish whether a vegetarian diet can provide any other long-term benefits to health.

In terms of nutrition, vegan and vegetarian diets can be nutritionally adequate, provided they are carefully planned; both the British Dietetic Association and the American Dietetic Association provide guidelines for a healthy vegetarian diet (see Appendix C). Dietary differences between vegetarians and meat-eaters are characterised not only by meat and/or fish being excluded from the diet, but by the foods which are eaten in greater amounts by vegetarians. For vegetarians and meat-eaters alike, the key to a nutritionally adequate diet is balance and ensuring that, where foods are specifically omitted, suitable alternatives are included so that dietary quality is not compromised.

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Appendix A: Typical dietary restrictions of selected religious groups in the UK that relate to meat and fish consumption

	Pork	Beef	Lamb	Chicken	Fish
Hindu	X	X	S	S	S
Muslim	X	Halal only	Halal only	Halal only	S
Sikh	X	X	S	S	S
Jewish	X	Kosher only	Kosher only	Kosher only	S
Buddhist (strict)	X	X	X	X	X
Seventh-Day Adventist	X	X	X	S	S
Rastafarian	X	X	X	X	X

X – foods avoided; other dietary guidelines may also exist.
S – special criteria for inclusion/exclusion (see Thomas 2001 for more details).

Appendix B: Foods of animal origin avoided by vegetarians and vegans

Type of vegetarian diet	Foods of animal origin usually avoided
Pesco vegetarian	Meat, game and poultry
Lacto-ovo-vegetarian	As above, but additionally avoids fish, seafood and fish-derived products, Worcester sauce (if made from anchovies), glycerine (if animal-derived), gelatine, cochineal (E120), beers and wines produced using animal-derived finings (to clarify the drink), e.g. isinglass and chitin. May only eat eggs (and associated products) that are guaranteed 'free-range'.
Lacto-vegetarian	As above, but additionally avoids eggs and egg-derived products
Vegan	As above but additionally avoids all milk and dairy products, may also avoid honey.

Source: Vegetarian Society UK (http://www.vegsoc.org).

Not all of these foods are routinely avoided, and some individuals may be more prudent in following a vegetarian diet than others. In addition, animal-derived clothing or cosmetic products may also be avoided. For a more comprehensive list, visit the Vegetarian Society UK website http://www.vegsoc.org

Appendix C: Choosing a balanced vegetarian or vegan diet and sources of micronutrients

In the UK, current guidelines for a balanced diet are summarised by the plate model of the '*Balance of Good Health*' (see below). Vegetarian and vegan diets can easily fit into the plate model, although care must be taken to ensure that a range of suitable foods are chosen from the 'meat and alternatives' section of the plate. For example, this section includes soya, pulses and nuts, all of which provide a range of nutrients and are good sources of protein. Clearly, advice to choose at least 5 portions of fruit and vegetables per day, and to base the diet on wholegrain starchy staples, applies to vegetarians and meat-eaters alike. Foods high in fat and sugar may also be included by vegetarians and vegans in small amounts or infrequently.

Source: British Nutrition Foundation. Reproduced with kind permission of the Food Standards Agency.

Lacto-ovo- and lacto-vegetarians include some dairy foods, such as low-fat milks and yogurt. For vegans, calcium fortified soya drink, oat or rice drink, and soya desserts can be useful alternatives to dairy foods.

The British Dietetic Association gives some general advice on vegetarian diets and this is summarised in Table C1 (see also Table 6 in Section 3.6).

Table C1 General advice on vegetarian diets from the British Dietetic Association

Food Group	Dietary Guidelines
Bread, other cereals and potatoes	These foods should form the basis of every meal
Fruit and vegetables	Aim for at least five servings each day
Alternatives to meat	Choose a range of foods and eat these in combination with a grain food (e.g. rice or bread) Suitable suggestions include: • Soya-based foods (e.g. tofu) • Beans, lentils, chick peas (dried or canned) • Seeds, nuts and nut butters • Eggs (if eaten)
Dairy foods or alternatives	Include some dairy foods, but if these are excluded, suitable alternatives high in calcium include: • Calcium-fortified soya drink and fortified fruit juice • Tofu • Brown or white bread (made with calcium-fortified flour) • Dried fruit (e.g. apricots) • Green leafy vegetables (except spinach) • Nuts and sesame seeds • Tinned salmon and sardines (if fish is eaten)

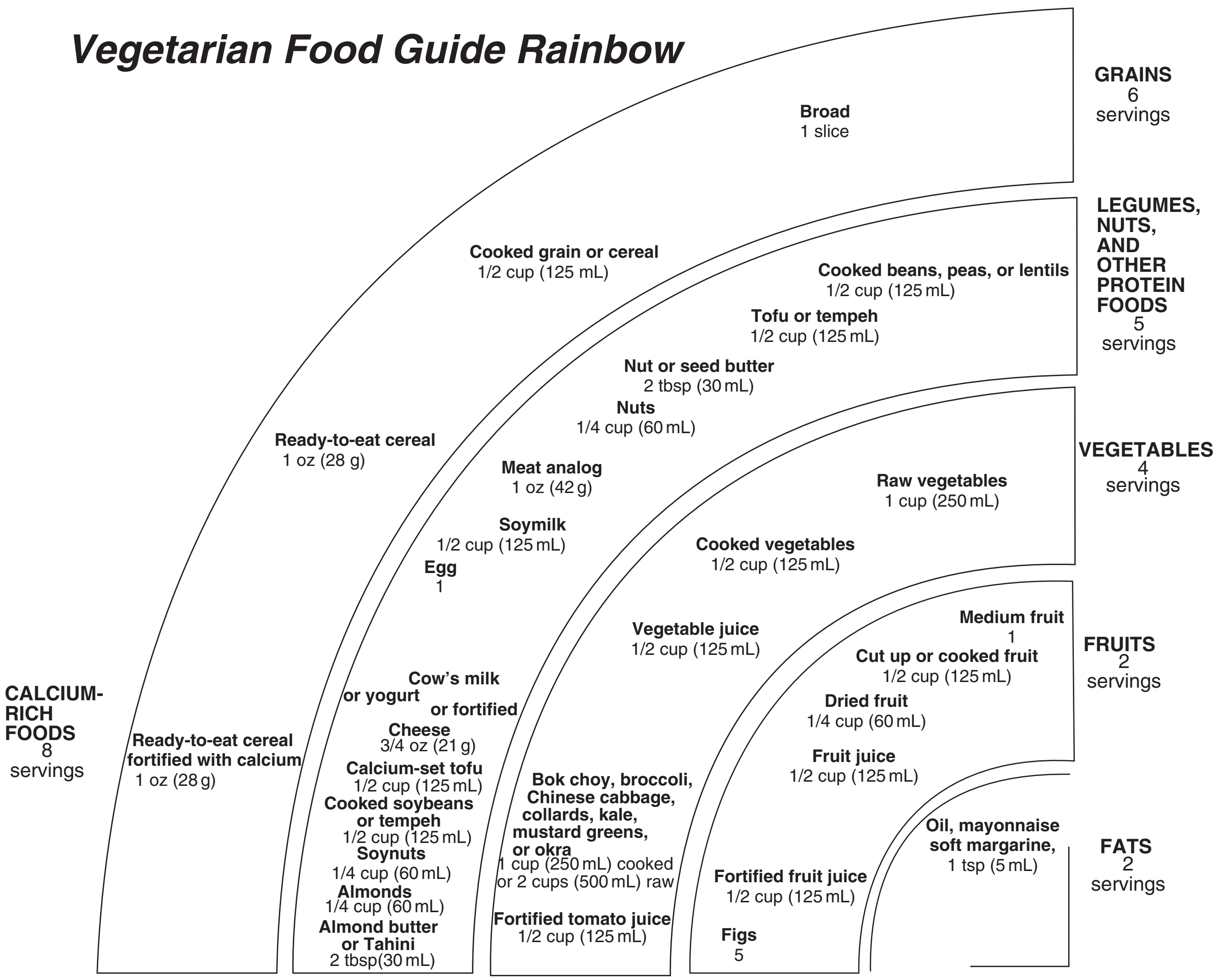
Other key points to ensure a balanced diet:
- If you rarely or never eat animal-derived foods, include foods fortified with vitamin D, B_2 and B_{12}, or consider a supplement
- If you are vegan, include small amounts of iodised salt or seaweed

Source: http://www.bda.uk.com.

In addition, the UK Vegetarian Society (http://www.vegsoc.org) recommends that a balanced vegetarian diet should include the following foods daily:

- 3 to 4 servings of cereals/grains or potatoes
- 4 or 5 servings of fruit and vegetables
- 2 or 3 servings of pulses, nuts & seeds
- 2 servings of milk, cheese, eggs or soya products
- A small amount of vegetable oil and margarine or butter.
- Some yeast extract such as Marmite, fortified with vitamin B_{12}

More detailed dietary guidelines are provided by the American Dietetic Association (ADA) and Dietitians Canada (DC) (American Dietetic Association and Dietitians Canada 2003). The vegetarian food guide pyramid and the food guide rainbow are useful resources, especially for those in the earliest stages of a vegetarian diet, as specific quantified guidelines are given. The vegetarian food guide rainbow is illustrated below.



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http://www.dietitians.ca/news/downloads/vegetarian_ position_paper_2003.pdf and http://www.dietitians.ca/news/downloads/Vegetarian_ Food_Guide_for_NA.pdf

In addition, the American Dietetic Association and Dietitians Canada recommend the following:

• Choose a variety of foods
• Include 2 servings every day of foods that supply *n*-3 fats (*e.g.* linseeds, soyabean oil, walnuts)
• Ensure adequate vitamin D from sunlight exposure or through fortified foods or supplements
• Include at least 3 good sources of vitamin B_{12} every day (*e.g.* fortified foods, milk or yogurt, egg)
• If sweets or alcohol are included, consume these in moderation.

For more information on the North American vegetarian food guide, go to the website: http://www.dietitians.ca