Health effects of vegetarian and vegan diets

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Vegetarian diets do not contain meat, poultry or fish; vegan diets further exclude dairy products and eggs. Vegetarian and vegan diets can vary widely, but the empirical evidence largely relates to the nutritional content and health effects of the average diet of well-educated vegetarians living in Western countries, together with some information on vegetarians in non-Western countries. In general, vegetarian diets provide relatively large amounts of cereals, pulses, nuts, fruits and vegetables. In terms of nutrients, vegetarian diets are usually rich in carbohydrates, n-6 fatty acids, dietary fibre, carotenoids, folic acid, vitamin C, vitamin E and Mg, and relatively low in protein, saturated fat, long-chain n-3 fatty acids, retinol, vitamin B_{12} and Zn; vegans may have particularly low intakes of vitamin B_{12} and low intakes of Ca. Cross-sectional studies of vegetarians and vegans have shown that on average they have a relatively low BMI and a low plasma cholesterol concentration; recent studies have also shown higher plasma homocysteine concentrations than in non-vegetarians. Cohort studies of vegetarians have shown a moderate reduction in mortality from IHD but little difference in other major causes of death or all-cause mortality in comparison with health-conscious non-vegetarians from the same population. Studies of cancer have not shown clear differences in cancer rates between vegetarians and non-vegetarians. More data are needed, particularly on the health of vegans and on the possible impacts on health of low intakes of long-chain n-3 fatty acids and vitamin B_{12}. Overall, the data suggest that the health of Western vegetarians is good and similar to that of comparable non-vegetarians.

Vegetarian: Vegan: Health: Mortality

A large number of individuals around the world follow vegetarian diets, but in most countries vegetarians comprise only a small proportion of the population. India is a notable exception because a substantial proportion of the population, perhaps approximately 35%, follows a traditional vegetarian diet and has done so for many generations (International Vegetarian Union, 2005; Refsum *et al*. 2001). The numbers of vegetarians in Western countries are unknown, with estimates based on rather small samples; for example, in a survey of 2251 individuals throughout the UK (Henderson *et al*. 2002) 5% reported being vegetarian or vegan. While the number of vegetarians may be increasing in some of the most affluent countries, there is an opposite picture for other countries around the world, in that meat consumption is increasing greatly in many countries that until recently had a low intake of meat. *Per capita* meat consumption (kg/year) is predicted to increase from 24·2 in 1964–6 to 45·3 in 2030,

with a very large increase in East Asia from only 8·7 in 1964–6 to 58·5 in 2030 (World Health Organization, 2003). Steinfeld (2004) has estimated that world total meat production ($\times 10^6$ tonnes/year) increased from about 92 in 1967–9 to 218 in 1997–9 and will increase further to 376 in 2030, a fourfold increase in 60 years.

Understanding of the health effects of vegetarian and vegan diets is quite good but many uncertainties remain (Fraser, 1999; Key *et al*. 1999*a*; Sanders, 1999*a*; Willett, 2003). The purpose of the present brief overview is to summarize current knowledge on the health effects of vegetarian and vegan diets with an emphasis on recent findings and results from large studies, including the work of the authors' group on the European Prospective Investigation of Cancer and Nutrition (EPIC)-Oxford cohort (Davey *et al*. 2003). Most of the discussion is related to vegetarians in affluent Western countries; the health of vegetarians and individuals with a very low meat intake in

poorer countries is a very important topic and there is some information available, but proper consideration of this topic is outside the scope of the present brief overview.

Dietary characteristics of vegetarian diets

Vegetarians are defined as individuals who do not eat any meat, poultry or fish. Vegetarians are sub-classified as lacto-ovo vegetarians who eat dairy products and/or eggs and vegans who do not eat any animal products. Since vegetarian diets are defined by what they do not contain, the actual composition of vegetarian diets can vary widely. For the purpose of the present review the discussion is largely based on the observed average diet of vegetarians as described in published reports, and mostly for individuals living in affluent Western countries.

Nutritional status of vegetarians

Nutrient intake

Reviews by expert groups such as the American Dietetic Association and Dietitians of Canada (2003) have concluded that a well-planned vegetarian diet is adequate for all stages of the life cycle including infancy, childhood and adolescence. Comparisons of the food intakes of vegetarians and non-vegetarians show that vegetarian diets generally provide relatively large amounts of cereals, pulses, nuts, fruits and vegetables. Together with the differences in intakes of animal foods, these differences in food intake result in several characteristic differences in nutrient intake. Vegetarian diets are usually rich in carbohydrates, *n*-6 fatty acids, dietary fibre, carotenoids, folic acid, vitamin C, vitamin E and Mg, and relatively low in protein, saturated fat, long-chain *n*-3 fatty acids, retinol, vitamin B_{12} and Zn; vegans can have particularly low intakes of vitamin B_{12} and low intakes of Ca (e.g. data from EPIC-Oxford; Davey *et al.* 2003).

These differences in nutrient intake might have favourable or unfavourable effects on the nutritional status and health of vegetarians. Current knowledge of nutrition suggests that the relatively high intakes of dietary fibre, folic acid, vitamin C, vitamin E and Mg and low intake of saturated fat might all have benefits. In particular, vegetarians are more likely than non-vegetarians to reach the UK Department of Health (1991) targets for fruit and vegetables and the dietary reference values for saturated fatty acids of 10% total energy and NSP of 18 g/d. For example, mean saturated fat intakes expressed as percentage energy are estimated as 10·7 and 10·4 in male and female meat-eaters, 9·4 and 9·3 in male and female vegetarians and 5·0 and 5·1 in male and female vegans (Davey *et al.* 2003). For NSP, mean intakes (g/d) are 18·7 and 18·9 in male and female meat-eaters, 22·7 and 21·8 in male and female vegetarians, and 27·7 and 26·4 in male and female vegans (Davey *et al.* 2003).

The impact on health of the relatively high intakes of carbohydrates and *n*-6 fatty acids and relatively low intakes of protein, retinol and Zn in vegetarians is unclear; mean intakes of these nutrients in vegetarians are probably close to or above the recommended intakes, where applicable (Davey *et al.* 2003), and these nutrients are not discussed further in the present review. For *n*-3 fatty acids and vitamin B_{12}, however, there is substantial recent research relevant to the status of vegetarians in relation to these nutrients and this aspect will be discussed further, together with Fe status.

n-*3 Fatty acids*

Plant foods can provide α-linolenic acid but are devoid of the long-chain *n*-3 fatty acids EPA and DHA (marine algae can provide EPA and DHA and are acceptable to vegetarians but are not considered here as a plant food); eggs and to a lesser extent dairy products contain low levels of EPA and DHA that vary according to the feeding of the animal. Studies of plasma levels of *n*-3 fatty acids have consistently shown that vegetarians have lower levels of EPA and DHA than meat-eaters, with lower levels in vegans than in lacto-ovo-vegetarians (Sanders *et al.* 1978*a*; Sanders, 1999*b*). Recently, it has been shown that plasma levels of EPA and DHA in vegans are not related to the duration of adherence to the diet over periods of ≤20 years, suggesting that the endogenous production of these fatty acids in vegetarians and vegans may result in low but stable plasma concentrations (Rosell *et al.* 2005*c*). Studies using labelled α-linolenic acid have shown that conversion of this fatty acid to EPA and DHA can occur in human subjects but that the rate of conversion is low in females and very low in males (Williams & Burdge, 2006). Vegetarian diets are usually rich in linoleic acid, which may reduce the conversion of α-linolenic acid to EPA and DHA (Davis & Kris-Etherton, 2003), but there is no direct evidence that plasma levels of EPA and DHA in vegetarians can be substantially increased by following a diet low in linoleic acid and high in α-linolenic acid.

It is unknown whether the low levels of EPA and DHA in the plasma of vegetarians have effects on health. In a small uncontrolled trial in which supplements of EPA and DHA were given to ten vegetarians Mezzano *et al.* (2000) observed an increase in the plasma levels of these fatty acids and a reduction in platelet aggregation, a possible risk factor for CVD, but more research is needed to explore this possible effect.

Vitamin B_{12}

Food plants do not contain vitamin B_{12}; therefore, the only reliable sources of vitamin B_{12} for vegetarians are dairy products and eggs, fortified foods and dietary supplements (Herbert, 1988; Dagnelie *et al.* 1991). It has been claimed that some plant foods such as seaweed and tempeh might provide true vitamin B_{12}, but this claim has not been established and much or all the material in these foods that is detected by assays for vitamin B_{12} may be vitamin B_{12} analogues that are either inactive or may antagonize true vitamin B_{12} (Dagnelie *et al.* 1991; Dagnelie, 1997).

Early studies of vitamin B_{12} status in vegetarians have shown that, as would be expected, dietary intake and plasma concentrations are lower than those in meat-eaters (Armstrong *et al.* 1974; Sanders *et al.* 1978*b*). Clinical

evidence of vitamin B_{12} deficiency has been reported in some vegans but is apparently uncommon (Antony, 2003). Recent research using more sensitive indicators of vitamin B_{12} status (plasma methylmalonic acid, homocysteine and holotranscobalamin II) has shown that substantial proportions of vegans and even of vegetarians have suboptimal vitamin B_{12} status according to these criteria, both among affluent Western vegetarians and in other countries including India, China and Taiwan (Mann *et al.* 1999; Refsum *et al.* 2001; Hung *et al.* 2002; Kwok *et al.* 2002; Herrmann *et al.* 2003; Koebnick *et al.* 2004). Dietary vitamin B_{12} deficiency is also now recognized to be a serious problem in non-vegetarian populations with a low intake of meat because of poverty (Stabler & Allen, 2004).

Recent work shows that vegetarians must be careful to ensure that they do consume adequate amounts of vitamin B_{12} (Herrmann & Geisel, 2002; Antony, 2003; Stabler & Allen, 2004). The current UK dietary reference values for vitamin B_{12} ($1.5 \mu g/d$ in adults; Department of Health, 1991) were derived partly from studies of vegetarians and vegans that have suggested that intakes of vitamin B_{12} of approximately $0.3 \mu g/d$ are sufficient to prevent anaemia and macrocytosis. However, intakes of $0.3 \mu g/d$ may be probably associated with moderate elevation in homocysteine that might be detrimental to health.

Iron

The Fe content of vegetarian diets is typically quite similar to that of non-vegetarian diets, but the bioavailability of the Fe is lower because of the absence of haem-Fe. Vegan diets are usually higher in Fe than lacto-vegetarian diets because dairy products are low in Fe. For example, in EPIC-Oxford estimated Fe intakes among 43 582 women are 12.6, 12.8, 12.6 and 14.1 mg/d for meat-eaters, fish-eaters, lacto-vegetarians and vegans respectively (Davey *et al.* 2003). Studies of Fe status (for example, see Waldmann *et al.* 2004) have consistently shown that serum ferritin is lower in vegetarians than in non-vegetarians and that Hb levels are similar or slightly lower in vegetarians than in non-vegetarians. Low Fe status is not common in men, but is moderately common among premenopausal women throughout the world, and young female vegetarians need to ensure that their diet includes good sources of Fe with vitamin C to help absorption and that they take supplements if needed.

Growth and development

A well-planned vegetarian diet is considered to be adequate for all stages of the life cycle including infancy, childhood and adolescence (American Dietetic Association and Dietitians of Canada, 2003), but epidemiological data on growth and development in vegetarians are still sparse. Recent data on 390 lifelong vegetarians in EPIC-Oxford (Rosell *et al.* 2005*a*) show no significant differences in height in men or women, or in age at menarche in women, between lifelong vegetarians and those who became vegetarian at age ≥ 20 years.

Obesity

Studies of Western vegetarians have consistently reported that vegetarians have a lower BMI than comparable non-vegetarians, with differences in mean BMI of about $1 kg/m^2$ (Key *et al.* 1999*b*); the proportion of vegetarians who are obese is correspondingly lower than that among non-vegetarians (Key & Davey, 1996). The reasons for this difference are not well understood, but may include differences in the composition of the diet such as a higher fibre intake and a lower protein intake (Spencer *et al.* 2003). Follow-up of body weight among 21 966 individuals in EPIC-Oxford shows a mean body-weight increase of approximately 400 g/year overall, with significantly lower weight gain in vegans, but not in vegetarians, than in meat-eaters (Rosell *et al.* 2005*b*).

Despite these consistently-observed differences in BMI between vegetarians and non-vegetarians, obesity is common among some populations that follow largely vegetarian diets, such as Indians living in the UK (Jebb *et al.* 2004) and in India (Shetty, 2002).

CVD

Plasma cholesterol

Studies have consistently reported that total plasma cholesterol is lower in vegetarians than in non-vegetarians, e.g. by 0.61 mmol/l in the Health Food Shoppers Study, 0.43 mmol/l in the Oxford Vegetarian Study and 0.39 mmol/l and 0.35 mmol/l in men and women respectively in EPIC-Oxford (Key *et al.* 1999*b*). The effect of a vegetarian diet on plasma cholesterol is dependent on the exact composition of the diet, particularly in relation to saturated and unsaturated fatty acids, and Jenkins *et al.* (2003) have shown that a vegetarian diet including a portfolio of cholesterol-lowering foods such as soyabean and nuts reduces serum LDL-cholesterol substantially more than a control vegetarian diet.

Hypertension

The main diet-related determinants of hypertension are high salt intake, obesity and excess alcohol consumption (Scientific Advisory Committee on Nutrition, 2003). Some early studies have suggested that vegetarians have a lower blood pressure than similar non-vegetarians, with differences of 2–10 mmHg in systolic or diastolic pressure (Beilin *et al.* 1988). However, analyses of blood pressure among 11 004 men and women in EPIC-Oxford indicate very little difference in blood pressure between vegetarians and meat-eaters (≤ 1 mmHg); blood pressure was observed to be 2–3 mmHg lower in vegans than in meat-eaters, largely associated with the lower BMI of the vegans (Appleby *et al.* 2002). In this study the very small differences in blood pressure between the dietary groups would not be expected to cause a detectable difference in rates of CVD.

IHD

Collaborative re-analysis of five prospective studies, each including a large proportion of vegetarians, has shown the

mortality from IHD to be 24 (95 % CI 6, 38) % lower in vegetarians than in non-vegetarians (Key *et al.* 1999*b*). Results published subsequently are similar; a death rate ratio of 0·75 (95 % CI 0·4, 1·37) in the first analysis of EPIC-Oxford (Key *et al.* 2003) and 0·70 (95 % CI 0·41, 1·18) in the extended follow-up of the cohort in Germany (Chang-Claude *et al.* 2005). In a case–control study among Indians in Bangalore the risk for myocardial infarction in vegetarians compared with non-vegetarians has been reported to be 0·81 (95 % CI 0·46, 1·43; Pais *et al.* 1996).

Law *et al.* (1994) have estimated that a reduction in total serum cholesterol of 0·6 mmol/l would reduce mortality from IHD by 27 %; therefore, the observed differences in cholesterol between vegetarians and non-vegetarians of approximately 0·4 mmol/l would be expected to reduce mortality from IHD by approximately 20 %. The observed difference in mortality of about 24 % is therefore of the magnitude that might be predicted from the difference in serum cholesterol. The lower BMI of vegetarians would also be expected to cause a small reduction in mortality from IHD.

Stroke

The main known risk factor for stroke is high blood pressure. The only data on stroke mortality in vegetarians comes from the five prospective studies, pooled analysis of which shows a death rate ratio for stroke in vegetarians compared with non-vegetarians of 0·93 (95 % CI 0·74, 1·17; Key *et al.* 1999*b*).

Cancer

There are few data on cancer rates in vegetarians but some information is available, particularly for colo-rectal, breast and prostate cancer.

Colo-rectal cancer

The causes of colo-rectal cancer are not well understood but researchers agree that diet is important, and there is substantial, although not conclusive, evidence that diets high in red and processed meat are associated with a moderate increase in colo-rectal cancer risk (Key *et al.* 2004; Norat *et al.* 2005). As well as the absence of meat from their diet, some putative risk factors for colo-rectal cancer are more favourable in vegetarians than in non-vegetarians; for example, vegetarians have a lower proportion of secondary bile acids in their faeces (Reddy *et al.* 1998) and are less likely to have infrequent bowel movements (Sanjoaquin *et al.* 2004*a*). Studies of colo-rectal cancer in vegetarians have suggested that the incidence may be lower than in non-vegetarians (Fraser, 1999; Sanjoaquin *et al.* 2004*b*), but the pooled analysis of mortality among vegetarians and non-vegetarians in five cohorts shows no difference between the dietary groups (Key *et al.* 1999*b*; some of the cases in this analysis of mortality are the same individuals as in the studies of incidence of Fraser (1999) and Sanjoaquin *et al.* (2004*b*).

Breast cancer

Most of the epidemiology of breast cancer can be explained by hormonal factors, and the only definite dietary effects on risk are obesity in post-menopausal women and alcohol. Endogenous oestrogen levels are clearly associated with breast cancer risk in post-menopausal women (Key *et al.* 2002), and there is some evidence that high levels of insulin-like growth factor-I may also increase risk (Renehan *et al.* 2004). Although studies of hormone levels in vegetarians have shown that plasma oestrogen levels are not different from those of non-vegetarians (Thomas *et al.* 1999), they have shown that vegans have lower plasma levels of insulin-like growth factor-I than either meat-eaters or lacto-vegetarians (Allen *et al.* 2002). Vegetarians, and especially vegans, often consume substantial amounts of soyabeans or foods made from soyabeans; soya foods are rich in phyto-oestrogens, which have been hypothesized to reduce breast cancer risk but research on this topic has so far been inconclusive (Peeters *et al.* 2003).

Studies of breast cancer incidence or mortality have not demonstrated any difference between lacto-vegetarians and non-vegetarians (Mills *et al.* 1989*a*; Rao *et al.* 1994; Key *et al.* 1999*b*; Dos Santos Silva *et al.* 2002).

Prostate cancer

Hormones are thought to be important determinants of prostate cancer risk, but understanding of these relationships is still poor. There is some evidence that high levels of active androgens and of insulin-like growth factor-I may increase prostate cancer risk (Eaton *et al.* 1999; Renehan *et al.* 2004). No differences in androgens have been found between vegetarians and non-vegetarians but, as in women, vegan men have lower plasma levels of insulin-like growth factor-I than either meat-eaters or lacto-vegetarians (Allen *et al.* 2000).

Studies of prostate cancer incidence or mortality have not demonstrated any difference between lacto-vegetarians and non-vegetarians (Mills *et al.* 1989*b*; Key *et al.* 1999*b*).

Bone health

The bone health of vegetarians has been a topic of interest for many years but few data are available. Ca intake in lacto-vegetarians is similar to that in non-vegetarians, whereas vegans usually have a substantially lower Ca intake unless they consume a lot of Ca-rich plant foods such as dark-green vegetables. It has been suggested that the absence of meat might be beneficial for bone health because of a reduced 'acid load', but whether this factor is important is controversial and overall it is not clear whether the bone health of vegetarians is better or worse than that of comparable non-vegetarians (New, 2004). Early results from EPIC-Oxford show no difference in fracture rates between vegetarians and non-vegetarians, but do show the importance of adequate Ca intake in reducing fracture risk (TJ Key, PN Appleby, EA Spencer, AW Roddam and NE Allen, unpublished results).

Vegetarian athletes

The question of whether vegetarianism is associated with beneficial or detrimental effects on athletic performance has been investigated in some observational studies and a few small trials (Nieman, 1999; Barr & Rideout, 2004). In general, there is little evidence that athletic performance differs much between vegetarians and non-vegetarians, as long as the diet is nutritionally adequate, but more data are needed. Particular care needs to be taken to ensure adequate Fe status, and there is some evidence that the lower muscle creatine concentration in vegetarians may reduce supramaximal exercise performance (Barr & Rideout, 2004).

Total mortality

Total mortality appears to be similar in vegetarians and comparable non-vegetarians; in the pooled analysis of five prospective studies the death rate ratio in vegetarians compared with non-vegetarians is 0·95 (95% CI 0·82, 1·11; Key *et al*. 1999*b*), and a subsequent analysis in EPIC-Oxford shows a death rate ratio of 1·05 (95% CI 0·86, 1·27; Key *et al*. 2003). Calculation of the standardized mortality ratio in the three UK cohorts shows that mortality in the vegetarians is much lower than that in the general population of England and Wales, with standardized mortality ratios (mortality rates expressed as a proportion of the national mortality rates, allowing for the effect of age; %) of 59 (95% CI 55, 63), 51 (95% CI 47, 56) and 40 (95% CI 35, 45) in the Health Food Shoppers study, the Oxford Vegetarian Study, and EPIC-Oxford respectively (Key *et al*. 2003). Low standardized mortality ratios are normally seen in cohort studies of volunteers, but these low values for vegetarians do demonstrate that in general terms their health is good.

Conclusions

Although there are now many publications with data for vegetarians, there are not yet enough data from large studies to allow more than broad conclusions about the health effects of vegetarian diets. In Western countries the health of vegetarians appears to be good compared with national averages and similar to that of non-vegetarians with a comparable background and lifestyle. This outcome is partly because vegetarians tend to be more health conscious than average (for example, by avoiding smoking) and partly because vegetarians have reasonably healthy diets in relation to factors such as fat composition. Vegetarians have consistently been observed to have a lower mean BMI than comparable non-vegetarians. In the available studies vegetarians have been shown to have lower mortality from IHD than comparable non-vegetarians, probably because they have lower blood cholesterol. No clear differences have been shown for other major causes of death such as stroke and cancers of the colo-rectum, breast and prostate. The relatively low blood levels of insulin-like growth factor-I observed in vegans might cause a reduction in risk for cancers of the breast and prostate, but there are no data on the risk for these cancers in vegans; the only data on cancer risk are for vegetarians, mostly lacto-vegetarians, who do not have reduced levels of insulin-like growth factor-I. Vegetarians have low levels of long-chain *n*-3 fatty acids and often have low levels of vitamin B_{12} and raised levels of homocysteine; more research on the health effects of these differences is needed. Overall, the health of vegetarians appears to be good, but as with all dietary patterns care is needed to ensure that the diet is as nutritious and well-balanced as possible according to current understanding.

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