Diabetes 1

Prevention and management of type 2 diabetes: dietary components and nutritional strategies

Sylvia H Ley, Osama Hamdy, Viswanathan Mohan, Frank B Hu

In the past couple of decades, evidence from prospective observational studies and clinical trials has converged to support the importance of individual nutrients, foods, and dietary patterns in the prevention and management of type 2 diabetes. The quality of dietary fats and carbohydrates consumed is more crucial than is the quantity of these macronutrients. Diets rich in wholegrains, fruits, vegetables, legumes, and nuts; moderate in alcohol consumption; and lower in refined grains, red or processed meats, and sugar-sweetened beverages have been shown to reduce the risk of diabetes and improve glycaemic control and blood lipids in patients with diabetes. With an emphasis on overall diet quality, several dietary patterns such as Mediterranean, low glycaemic index, moderately low carbohydrate, and vegetarian diets can be tailored to personal and cultural food preferences and appropriate calorie needs for weight control and diabetes prevention and management. Although much progress has been made in development and implementation of evidence-based nutrition recommendations in developed countries, concerted worldwide efforts and policies are warranted to alleviate regional disparities.

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This is the first in a Series of two papers about diabetes

Department of Nutrition (S H Ley PhD, Prof F B Hu MD) **and Department of Epidemiology** (Prof F B Hu), **Harvard School of Public Health, Boston, MA, USA; Joslin Diabetes Center, Boston, MA, USA** (O Hamdy MD); **and Dr Mohan's Diabetes Specialities Centre & Madras Diabetes Research Foundation, Chennai, India** (V Mohan MD)

Correspondence to: Prof Frank B Hu, Departments of Nutrition and Epidemiology, Harvard School of Public Health, 665 Huntington Ave, Boston, MA 02115, USA **frank.hu@channing.harvard.edu**

Introduction

382 million adults (8·3%) worldwide are living with diabetes, and the estimate is projected to rise to more than 592 million by 2035.[1] At least US$147 billion was spent on diabetes health care in Europe, whereas North America and the Caribbean spent $263 billion in 2013.[1] Diabetes has become a major cause of death in people younger than 60 years.[1] Investment in effective diabetes prevention and management has become necessary to battle this global epidemic.

Along with urbanisation and economic growth, many countries have experienced dietary changes favouring a rise in caloric consumption and decline in overall diet quality.[2] Although an unhealthy diet has been regarded as a major contributor to diabetes development for a long time, only in the past two decades has the evidence vastly accumulated from both prospective observational studies and randomised controlled trials (RCTs). In this Series, we examine the role of diet in the prevention and management of diabetes.

Nutrition transition and global dietary trends

At a macrolevel, the type 2 diabetes epidemic has been attributed to urbanisation and environmental transitions, including work pattern changes from heavy labour to sedentary occupations, increased computerisation and mechanisation, and improved transportation. Economic growth and environmental transitions have led to drastic changes in food production, processing, and distribution systems and enhanced the accessibility of unhealthy foods.[3]

Fast food restaurants have experienced exponential global expansion in the past few decades. The increased availability of fast food has contributed to unhealthy diets with a high calorie content; large portion sizes; and large amounts of processed meat, highly refined carbohydrates, sugary beverages, and unhealthy fats. Another key component in the food system transition has been the saturation of large chain supermarkets, which displace fresh local food and farm shops and serve as a source of highly processed foods, high-energy snacks, and sugary beverages in many developed and developing countries.[3]

Parts of the world undergoing epidemiological transition have experienced a livestock revolution, which leads to a rise in the production and consumption of beef, pork, dairy products, eggs, and poultry.[3,4] On the basis of data from the United Nations Food and Agriculture Organization, this change has been especially drastic in Asian countries (figure 1).[4] Another characteristic of nutrition transition is the increased refinement of grain products. Milling and processing of wholegrains to produce refined grains such as polished white rice and refined wheat flour reduce the nutritional content of grains, including their fibre, micronutrients, and phytochemicals.

Dietary factors for the prevention of diabetes

Positive energy balance and excess adiposity

In the past few decades, men and women worldwide have gained weight, largely as a result of changes in dietary patterns and decreased physical activity levels.[4] Excess

Search strategy and selection criteria

We searched PubMed and Google Scholar, mainly for original research articles, meta-analysis or systematic reviews, and organisation recommendations published up to January, 2014. We used the main search terms "type 2 diabetes", "nutrition", "diet", "prevention", and "management" in combination with specific terms on nutrient or dietary pattern. We largely selected publications in the past 5 years but did not exclude frequently referenced and highly regarded older publications. We also searched the reference lists of articles identified by this search strategy and selected those articles that we judged relevant. Review articles and book chapters are cited to provide readers with more details and references.

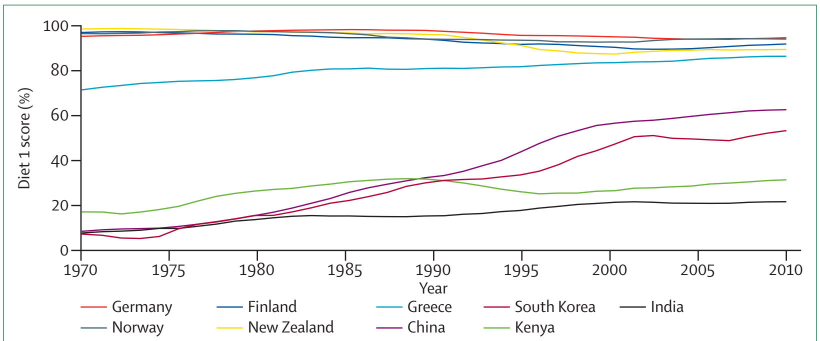

Figure 1: **Changes in global dietary trend over time**

A high diet 1 score indicates a high availability of sugars, meat, animal products, animal fats, milk, eggs, and total calories, in addition to low availability of pulses and cereals based on the United Nations Food and Agriculture Organization food balance sheets.[4]

Nutrients	Number of cohorts
Haeme-iron[21]	4
Glycaemic index[19]	13
Glycaemic load[19]	17
DHA/EPA[17]	16
Vegetable fibre[18]	7
Fruit fibre[18]	8
Alpha-linolenic acid[17]	7
Magnesium[20]	13
Cereal fibre[18]	8
Vitamin D[22]	21

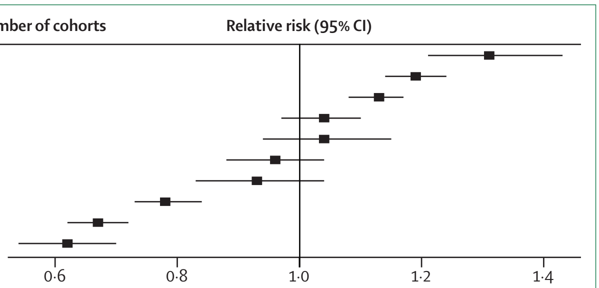

Figure 2: **Summary of meta-analyses of prospective cohort studies of nutrient intake and glycaemic variables and type 2 diabetes**

DHA=docosahexaenoic acid. EPA=eicosapentaenoic acid. Relative risks are a comparison of extreme categories, except for DHA/EPA (per 250 mg per day increase) and alpha-linolenic acid (per 0·5 g per day). All nutrients and glycaemic variables were assessed from dietary intake, except vitamin D for which blood 25-hydroxyvitamin D was used.

See Online for appendix

adiposity shown by a higher body-mass index (BMI) is the strongest risk factor for diabetes, and Asian populations tend to develop diabetes at a much lower BMI than do those of European ancestry.[5] The risk of diabetes rises as excessive body fat increases, starting from the lower end of the normal range of BMI or waist circumference.[6] Findings from a meta-analysis of prospective cohort studies suggest that the risk associated with a higher waist circumference is stronger than the risk associated with a higher BMI.[7] In clinical practice, both BMI and waist circumference should be monitored. Weight gain since young adulthood is another independent predictor of diabetes risk, even after adjustment for current BMI.[5]

Lifestyle intervention with calorie restriction and exercise to promote weight loss, as shown in the Diabetes Prevention Program,[8] significantly reduced conversion to diabetes in high-risk patients with impaired glucose tolerance by 58%. The beneficial effect of lifestyle modification was documented in various populations, including multiethnic American,[8] Finnish,[9] Chinese,[10] and Indian.[11]

Quantity and quality of dietary fat

Although higher total fat intake is thought to contribute to diabetes directly by induction of insulin resistance and indirectly by promotion of weight gain, results from metabolic studies in human beings do not support that high-fat diets per se have a detrimental effect on insulin sensitivity.[12] In several observational studies, total fat intake was not associated with diabetes risk.[13,14] In the Women's Health Initiative,[15] the incidence of diabetes was not reduced in women who consumed a low-fat diet compared with the control group. The quality of fat is more important than total fat intake, and diets that favour plant-based fats over animal fats are more advantageous.[13] Particularly, greater intake of omega-6 polyunsaturated fatty acids (PUFA) was associated with lower diabetes risk in the Nurses' Health Study.[16] Replacement of saturated fat with omega-6 PUFA was related to a lower risk of developing diabetes.[13] However, the association between omega-3 PUFA and diabetes risk has been inconsistent (figure 2, appendix).[17–22]

Quantity and quality of carbohydrates

Prospective observational evidence suggests that the relative carbohydrate proportion of a diet does not appreciably affect diabetes risk.[23] However, a diet rich in fibre, especially cereal fibre, might reduce the risk of diabetes. Findings from a meta-analysis of prospective cohort studies showed an inverse association between fibre from cereal products and the risk of type 2 diabetes (figure 2).[18] Fibre from fruits had a weaker inverse association with risk of diabetes than did cereal fibre.[18]

Carbohydrate quality can be measured by evaluation of the glycaemic response to carbohydrate-rich foods, such as the glycaemic index (GI) and the glycaemic load (GL, a product of GI and the amount of carbohydrates of a food). In meta-analyses of prospective studies, low GI and GL diets were associated with lower risk of diabetes than were diets with a higher GI and GL (figure 2),[19] independent of the amount of cereal fibre in the diet.

Vitamins and minerals

Evidence has supported the associations of specific minerals with type 2 diabetes using assessments of dietary intake or biomarkers, or both (figure 2). In a meta-analysis of prospective studies, magnesium intake was inversely associated with risk of diabetes.[20] This association was more pronounced in overweight than in normal weight participants.[20] Conversely, higher haeme-iron intake was associated with a higher risk of diabetes.[21] Similarly, higher iron stores shown by increased ferritin concentrations were associated with a higher risk of diabetes.[21]

An inverse association was shown between circulating 25-hydroxyvitamin D concentrations and risk of diabetes in a meta-analysis of prospective studies from diverse populations.[22] However, plasma vitamin D might be a marker of an overall healthy lifestyle, including frequent outdoor physical activities and exposure to sunlight. Further, vitamin D supplementations did not improve glycated haemoglobin (HbA_{1C}), fasting plasma glucose, or insulin sensitivity in small RCTs.[24] Ongoing large

RCTs could provide more conclusive evidence for the role of vitamin D in prevention of type 2 diabetes.

Individual foods and food groups

Prospective studies have provided evidence that intake of several individual food items or food groups might play a part in diabetes prevention (figure 3, appendix).[25–34] Wholegrain intake has been consistently associated with a lower risk of diabetes even after adjustment for BMI.[25] Conversely, greater intake of white rice, a processed grain, was associated with an increased risk of diabetes,[26] especially in Asian populations with white rice as a staple food and a main source of calories. Frequent consumption of red meats, especially processed red meats such as bacon, sausages, and hot dogs, was strongly associated with a higher risk of diabetes.[27]

In a meta-analysis of prospective cohort studies, neither fish nor seafood consumption were significantly associated with the risk of diabetes.[17] A difference in the direction of the association between fish or seafood consumption and risk of diabetes was reported between geographical regions.[17] Higher fish or seafood consumption was associated with a higher risk of diabetes in North America and Europe but associated with a lower risk in Asia.[17] The reason for this regional variation is unclear but might be explained by a combination of the differences in the types of fish consumed, cooking methods used, and levels of exposure to pollutants in different locations.

Total intake of fruits and vegetables was not associated with risk of diabetes, but greater intake of green leafy vegetables was associated with a lower risk.[28,29] Further, consumption of specific whole fruits, such as blueberries, grapes, and apples, was significantly associated with a lower risk of diabetes on the basis of findings from three large prospective cohort studies.[35]

Consumption of greater amount of dairy products has been associated with a moderately lower risk of diabetes,[30] and the benefits of yoghurt seem to be more consistent than for other types of dairy products. Consumption of nuts, which are high in PUFA and monounsaturated fatty acids (MUFA), could have beneficial effects on diabetes prevention. Greater nut consumption, especially walnuts, was associated with a lower risk of diabetes.[36,37] In the Prevención con Dieta Mediterránea (PREDIMED) trial, supplementation of mixed nuts significantly reduced incident diabetes in a preliminary analysis from one centre[38] and by a non-significant 18% in the entire cohort.[39] However, the nuts were supplemented in the context of a Mediterranean diet in this trial and, therefore, the beneficial results might not be solely attributed to nut consumption. Despite their high fat and energy contents, regular consumption of nuts was not associated with increased obesity, but instead conferred benefits in weight control.[36]

Beverages

Greater intake of sugar-sweetened beverages has been associated with a higher risk of type 2 diabetes in a meta-analysis[31] and a pooled analysis of European cohorts[32] (figure 3). This association remains significant even after adjustment for BMI, which suggests that the deleterious effects of sugar-sweetened beverages on diabetes are not entirely mediated by bodyweight. Substitution of water, coffee, or tea for sugar-sweetened beverages was associated with a lower risk of diabetes.[40]

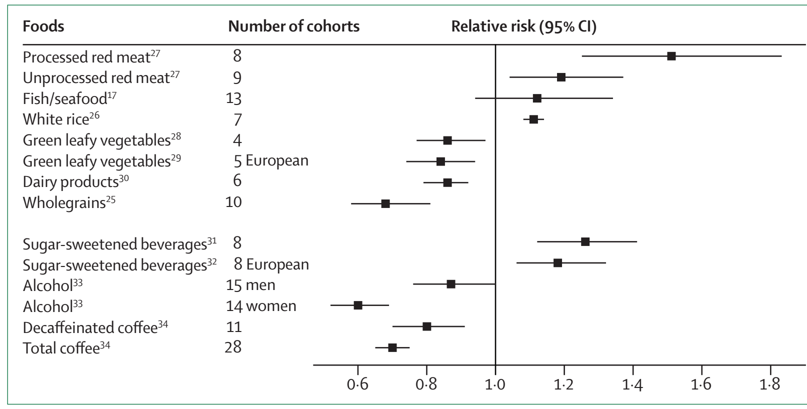

***Figure 3*: Summary of meta-analyses of prospective cohort studies on food and beverage intake and type 2 diabetes**
Relative risks are a comparison of extreme categories, except for processed meat (per 50 g per day increase), unprocessed red meat and fish or seafood (per 100 g per day), white rice (per each serving per day), wholegrains (per three servings per day), sugar-sweetened beverages in European cohorts (per 336 g per day), and alcohol (22 g per day for men or 24 g per day for women with abstainers).

Alcohol consumption is associated with diabetes in a U-shaped fashion (figure 3).[33] On the basis of findings from a meta-analysis, the amounts of alcohol consumption most protective of diabetes were 24 g per day in women and 22 g per day in men, but alcohol became harmful at a consumption level above 50 g per day in women and 60 g per day in men.[33] In a randomised trial,[41] moderate alcohol consumption improved insulin sensitivity.

Coffee consumption has been consistently associated with a lower risk of diabetes (figure 3). In a meta-analysis of 28 prospective cohort studies, coffee consumption was inversely associated with risk of diabetes in a dose-response manner.[34] Furthermore, both caffeinated and decaffeinated coffee intakes were associated with a lower risk of diabetes, which suggests that bioactive compounds other than caffeine might contribute to the benefits.[34]

Dietary patterns and overall diet quality

Instead of considering individual food items in isolation, the application of food pattern techniques has led to a variety of different food patterns related to risk of diabetes (table 1). Mediterranean-style diets have been associated with lower incident type 2 diabetes in prospective cohort studies.[38,39,42,43] In the PREDIMED trial after a 4·1-year follow-up, participants assigned to a Mediterranean diet without calorie restriction had a significant 40% reduction in the risk of diabetes with extra-virgin olive oil supplementation and a non-significant risk reduction of 18% with mixed nut supplementation compared with a low-fat control diet.[39]

	Main components	Diabetes prevention	Diabetes management
Mediterranean diet	High consumption of minimally processed plant-based foods; olive oil as the principal source of fat; low-to-moderate consumption of dairy products, fish, and poultry; low consumption of red meat; and low-to-moderate consumption of wine with meals	Mediterranean dietary patterns were associated with lower risk of type 2 diabetes in prospective cohort studies and RCTs[38,39,42,43]	Mediterranean diets compared with a conventional diet for diabetes management improved glycaemic control and insulin sensitivity, and reduced risk of CVD[43–46]
DASH	Rich in vegetables, fruits, and low-fat dairy products, including wholegrains, poultry, fish, and nuts; lower in saturated fat, red meat, sweets, and sugar containing beverages; and reduced in sodium	Adherence to the DASH diet was associated with lower risk of diabetes[47,48]	The DASH diet with 2400 mg per day sodium restriction had beneficial effects on glycaemic control and CVD risk factors[49,50]
Vegetarian and vegan	Vegan, diets devoid all animal-derived products; vegetarian diets, diets devoid of some animal products including lacto-ovo (consuming dairy or eggs), pesco (consuming fish, eggs, or dairy), semi (consuming all but no red meat and poultry)	Vegan, lacto-ovo, and semi-vegetarian diets were associated with lower risk of type 2 diabetes[51]	Improved glycaemic control or CVD risk was not consistently reported,[52,53] and the effect of vegetarian diets was difficult to isolate because calorie-restriction was often implemented
Dietary guidelines (AHEI)	Indices of the diet quality created on the basis of foods and nutrients predictive of chronic disease risk, including greater intake of vegetables and fruits, wholegrains, nuts and legumes, long-chain omega-3 fatty acids, and PUFAs; lower intake of sugar-sweetened beverages and fruit juice, red/processed meat, trans-fat, sodium; and moderate alcohol consumption	Adherence to high-quality diet assessed by AHEI was strongly associated with lower risk of diabetes[54]	NA
Prudent pattern	Dietary patterns higher in fruits, vegetables, wholegrains, legumes, and vegetable fats and lower in red meats, refined grains, and sugared soft drinks	Prudent dietary patterns over Western dietary patterns were associated with lower type 2 diabetes risk[55–60]	NA
Moderately low carbohydrate diet	Dietary patterns that restrict consumption of carbohydrates by increasing intake of fats and protein from animal or plant food sources	A diet moderately low in total carbohydrate but high in plant-based protein and fat was associated with lower diabetes risk, but a diet low in carbohydrate and high in animal fat and protein was associated with higher risk[14]	Carbohydrate restrictions improved glycaemic control and blood lipids and led to greater weight loss compared to conventional control diets[52]

RCT=randomised controlled trial. CVD=cardiovascular disease. DASH=dietary approaches to stop hypertension. AHEI=alternate healthy eating index. PUFA=polyunsaturated fatty acid. NA=not available.

***Table* 1: Summary of observational and intervention studies on dietary patterns for diabetes prevention and management**

Adherence to a high-quality diet assessed by the Alternate Healthy Eating Index (AHEI) was strongly associated with a lower risk of diabetes.[54] Further, adherence to the Dietary Approaches to Stop Hypertension (DASH) diet, which is a dietary plan rich in vegetables, fruits, and low-fat dairy products, was also associated with a lower risk of diabetes.[47,48] Vegetarian diets devoid of animal products were associated with lower risk of diabetes in the Adventist Health Study.[51] Findings from prospective studies using exploratory methods to define dietary patterns further supported that these dietary patterns favouring fruits, vegetables, wholegrains, and legumes at the expense of red meats, refined grains, and sugar-sweetened beverages are beneficial for diabetes prevention.[55–60] A diet moderately low in total carbohydrate but high in plant-based protein and fat was associated with lower diabetes risk, whereas a diet low in carbohydrate but high in animal fat and protein was associated with higher risk.[14]

Major knowledge gaps in the dietary prevention of diabetes

Although much has been learned about the role of various dietary factors in the development of diabetes, further studies are warranted to examine synergistic effects of individual components of various dietary patterns and to understand the biological mechanisms underlying the observed associations. Additional high-quality, large prospective studies are needed to examine the role of different food choices and dietary habits for diabetes prevention in diverse populations and different regions of the world.

Dietary factors for the management of diabetes

Bodyweight loss intervention trials and surgeries

Nutritional therapy recommendations from various organisations for diabetes management support intensive lifestyle interventions to achieve modest weight loss and weight maintenance.[61–64] In the Action for Health in Diabetes (Look AHEAD) trial,[65,66] an intensive lifestyle intervention for weight loss in overweight or obese adults with type 2 diabetes, weight loss was greater in the intervention group than in the control group (8·6% and 0·7% at 1-year; 6·0% and 3·5% at 9·6-year follow-up). The participants randomly assigned to the intervention had health benefits, including reduced sleep apnoea, depression, and urinary incontinence, in addition to improved health-related quality of life and requiring less medication for glycaemic control and management of cardiovascular risk factors.[67–70] However, the Look AHEAD trial did not show a reduction in the rate of cardiovascular events in the intensive lifestyle intervention group compared with the diabetes support and education group.[65,66] This finding might be explained by several factors, including an unbalanced use of cardioprotective medications between the groups and very low event rates, which led to inadequate power for the hard endpoints.[71] The intervention was focused on lowering of caloric and fat intake, which potentially compromised the long-term compliance. In retrospect, improving overall nutritional quality should have been a higher priority.[72]

If diabetes and associated comorbidities are difficult to control with lifestyle and pharmacological therapy, bariatric or metabolic surgeries might be considered in diabetes

	ADA 2014[61]	CDA 2013[62]	DNSG-EASD 2004[63]
Energy balance	Reducing energy intake while maintaining a healthy eating pattern to promote weight loss for overweight or obese adults	A nutritionally balanced calorie-reduced diet to achieve and maintain a lower, healthier bodyweight in people who are overweight or obese	Reduced caloric intake to loose or maintain bodyweight in people with BMI >25 kg/m²
Macronutrient distribution	Use of individualised assessment because evidence suggests no one ideal distribution for all people	Individualisation within ranges of 45–60% carbohydrate, 15–20% protein, 20–35% fat of total energy	Ranges of 45–60% carbohydrate, 10–20% protein, ≤35% fat of energy
Dietary eating patterns	A variety of eating patterns are acceptable with consideration for personal preferences and metabolic goals	A variety of dietary patterns are acceptable with consideration for personal preferences, values, and abilities	No specific recommendations
Glycaemic index and glycaemic load	Substitute low glycaemic load foods for higher glycaemic load foods may be beneficial	Choose food sources of a low glycaemic index	Low glycaemic index foods are suitable as carbohydrate-rich choices
Dietary fibre and wholegrains	Consume at least the amount recommended for the general public (14 g per 1000 kcal or 25 g per day for women and 38 g per day for men)	Consume higher intake than those for the general public (25–50 g per day or 15–25 g per 1000 kcal)	Consume fibre intake >40 g per day (or 20 g per 1000 kcal per day) with half as soluble; choose cereal-based foods high in fibre and wholegrains
Sucrose and fructose	Limit or avoid intake of sugar-sweetened beverages	Added sucrose or fructose can be substituted for other carbohydrate as a mixed meal up to a maximum of 10% total daily energy intake	Moderate intake of free sugars (up to 50 g per day) recommended without exceeding 10% total energy
Protein	Reducing the amount of dietary protein below usual intake is not recommended for people with diabetes and kidney disease	Usual intake recommended for those without kidney disease, but consider restricting protein to 0·8 g/kg bodyweight for people with diabetes and chronic kidney disease	Insufficient evidence to recommend protein restriction for those with type 2 diabetes and incipient nephropathy
MUFAs and PUFAs	MUFA-rich eating pattern may be beneficial	MUFAs up to 20% of energy and PUFAs up to 10%	10–20% of energy from MUFAs and up to 10% from PUFAs
Omega-3 fatty acids	No support for omega-3 fatty acid supplements	No support for omega-3 fatty acid supplements	No support for omega-3 fatty acid supplements
Saturated fat, dietary cholesterol, and trans fat	Same as recommended for the general public (<10% of energy, aiming for 300 mg dietary cholesterol per day, limiting trans-fat as much as possible)	No more than 7% of energy from saturated fats; limit intake of trans fatty acids to a minimum	Under 10% of energy from saturated and trans fatty acids (<8% if LDL cholesterol is elevated); below 300 mg per day cholesterol
Micronutrient supplements	No support for vitamin or mineral supplements	Routine vitamin and mineral supplementation is generally not recommended	No recommendation for vitamin and mineral supplements
Alcohol	Advised to drink in moderation with consideration for managing delayed hypoglycaemia	Same precautions as in the general public with additional consideration for risk of hypoglycaemia and weight gain	Moderate use of alcohol is acceptable with consideration for prolonged hypoglycaemia and weight control
Sodium	Reduce sodium intake less than 2300 mg per day in general, and further reduction in sodium is to be individualised	No specific cutoffs recommended for people with type 2 diabetes	Restrict salt intake under 6 g per day

ADA=American Diabetes Association. CDA=Canadian Diabetes Association. DNSG-EASD=Diabetes and Nutrition Study Group of the European Association for the Study of Diabetes. BMI=body-mass index. MUFA=monounsaturated fatty acid. PUFA=polyunsaturated fatty acid.

***Table 2*: A comparison of nutrition therapy main recommendations for patients with type 2 diabetes from various organisations**

patients with BMI of 35 kg/m² or greater.[73] Findings from a meta-analysis showed that bariatric surgery led to greater bodyweight loss (mean difference: 26 kg) and higher partial or complete remission rates of diabetes than did non-surgical treatments.[74] Further, participants in the Swedish obese subjects[75] study who underwent bariatric surgery had lower cardiovascular events than did those who received a conventional treatment.

Macronutrient distributions

Organisations vary in their recommendations for optimum macronutrient distributions for diabetes management. In present guidelines, a transition to favouring individualised goals and focusing on the quality of macronutrient intake was provided (table 2).[61–63] The 2014 American Diabetes Association (ADA) position statement recommends the individualisation of macronutrient distribution on the basis of current eating patterns, preferences, and metabolic goals.[61] Although the 2013 Canadian Diabetes Association (CDA) provides ranges of ideal macronutrient distribution for the management of diabetes, the guidelines also emphasise the importance of individualised dietary goals and quality of specific macronutrients.[62]

Quality of carbohydrates

In a meta-analysis of RCTs with interventions greater than 4 weeks in people with diabetes, participants on a low-GI diet had a more significant reduction in HbA_{1C} than did those on a high-GI diet.[76] Education of a person with diabetes to use GI and GL as guides is generally supported by various organisations to improve glycaemic control.[61–64] However, the published work regarding GI and GL is difficult to isolate from the benefits of dietary fibre because studies often investigate high-fibre and low GI foods in combination.[61] In practice, GI values of individual foods should be considered together with other factors, such as the amount of dietary fibre and added sugar.

Soluble fibre interventions have been shown to reduce HbA_{1C} and fasting plasma glucose in people with diabetes.[77] Several organisations recommend increasing fibre intake for diabetes management (table 2).[62,63] However, the latest ADA guidelines did not recommend increasing fibre above the level already recommended for the general public because the amount of fibre needed was unrealistically high (>50 g per day) to modestly lower HbA_{1C} and preprandial glucose.[61]

Reduction of intake of added sugars or sugar-sweetened beverages has been recommended for diabetes management by various organisations (table 2).[61–63] Overconsumption of high fructose-sweetened beverages has adverse effects on selective deposition of visceral fat, lipid metabolism, blood pressure, insulin sensitivity, and de-novo lipogenesis especially in overweight and obese people.[78] Naturally occurring fructose from whole fruits is unlikely to be deleterious because of its relatively slow digestion and absorption. However, regular consumption of fruit juices is not recommended.

Non-nutritive sweeteners could reduce overall calorie and carbohydrate intake.[61] Short-term studies have shown that replacement of added sugar with non-nutritive sweeteners reduces bodyweight and improves glycaemic control, but the long-term effects need to be investigated.[79]

Protein

The current nutrition recommendations for adults with type 2 diabetes do not indicate prescription of a protein restriction.[61,62] For people on energy-reduced diets for weight loss, however, an increased protein intake as percentage of calories is important because use of a fixed percentage of total calories to estimate a protein requirement might result in inadequate protein intake and lean muscle loss.[62]

For people with diabetic kidney disease, either microalbuminuria or macroalbuminuria, recommendations for protein intake vary among organisations (table 2).[61–63] The European Association for the Study of Diabetes (EASD) states that there is insufficient evidence to make a firm recommendation.[63] The CDA recommends to consider prescribing a protein restriction.[62] The ADA, meanwhile, recommends against a protein restriction.[61] Findings from a meta-analysis of RCTs did not show beneficial renal effects from low-protein diets in patients with diabetes.[80]

Fats

Evidence indicates that the type of fat consumed is more important than the total fat intake to support metabolic goals.[61,44] Although the specific recommendations for distributions of fat composition vary, organisations generally support a reduction in the intake of saturated fat and trans fat from industrial hydrogenation to reduce cardiovascular disease risk (table 2).[61–63] In a cohort study of women with diabetes, a greater intake of saturated fat and cholesterol was associated with a higher cardiovascular disease risk,[81] and a greater intake of fish and long-chain omega-3 PUFA from food was associated with a lower incidence of coronary heart disease.[82] However, omega-3 PUFA supplementation did not reduce the risk of all-cause mortality, cardiovascular disease mortality, or cardiovascular disease events in a meta-analysis of RCTs.[83] In the Outcome Reduction with an Initial Glargine Intervention (ORIGIN) trial[84] of 12 536 people with hyperglycaemia, supplementation of omega-3 PUFA did not show a cardiovascular disease or mortality benefit. Omega-3 PUFA supplementation is not recommended for people with diabetes,[61–63] but an increase in foods containing omega-3 PUFA is recommended as it is for the general public.

In a meta-analysis of RCTs, a high MUFA diet (>12% of energy) was associated with reduced fat mass and improved systolic and diastolic blood pressure.[85] When MUFA was substituted for carbohydrates or saturated fats in people with diabetes, those who consumed a higher amount of MUFA in the context of a Mediterranean-style diet had better glycaemic control after a 2-year intervention compared with the control group.[45]

Dietary patterns

Several dietary patterns consisting of combinations of different foods or food groups are beneficial for diabetes management (table 1). Organisations have recommended use of these dietary patterns with consideration for personal preferences and metabolic goals.[61,62]

In a systematic review of five RCTs in people with type 2 diabetes,[43] improvement in glycaemic control and insulin sensitivity was greater in participants on a Mediterranean diet than other frequently used diets, although the magnitude of results needs to be interpreted with caution because energy restriction was also included in a few RCTs[45,46]A Mediterranean diet reduced the need for antihyperglycaemic medications in overweight patients with newly diagnosed diabetes compared with those on a low-fat diet.[46] In a subgroup of moderately obese participants with diabetes from the Dietary Intervention Randomized Controlled Trial (DIRECT),[45] a calorie-restricted Mediterranean diet resulted in more favourable fasting plasma glucose and insulin concentrations at 2-year follow-up than did a low-fat diet. In a subgroup of the PREDIMED trial participants with diabetes, Mediterranean diet interventions supplemented with extra-virgin olive oil or nuts, without calorie-restriction, significantly reduced the incidence of major cardiovascular disease events after a median 4·8-year follow-up.[44]

The DASH diet has been shown to lower blood pressure in people without (or with controlled) diabetes.[86,87] In a small 8-week RCT in people with diabetes, the DASH diet, including the 2400 mg per day sodium restriction, had favourable effects on glycaemic control, HDL and LDL, cholesterol, blood pressure, and inflammatory biomarkers.[49,50] In one observational study, low sodium intake was associated with increased mortality in people with diabetes,[88] but reverse causation might explain this result. The current sodium intake recommendation for diabetes management from the ADA is 2300 mg per day or less,[61] and table 2 summarises other organisations' recommendations.

Several trials of vegetarian or vegan diets have been done in people with diabetes,[52] but improved glycaemic control or cardiovascular disease risk was not consistently reported in these studies.[52] The effect of vegetarian diets might have been difficult to isolate because many trials implemented calorie restriction. In a 74-week intervention trial, a vegan diet, without energy restriction, resulted in weight loss and improved fasting glucose, triglyceride, and LDL cholesterol, and the vegan diet was more beneficial than a conventional diet after control for medication changes.[53]

Findings from a meta-analysis of RCTs suggested that various dietary patterns, such as low-carbohydrate, low-GI, Mediterranean, and high-protein diets, were effective in improving glycaemic control and cardiovascular disease risk factors compared with control diets in patients with diabetes.[52] These results provide a range of dietary options for diabetes management, paying attention to overall diet quality, treatment goals, and personal and cultural food preferences. However, highly restricted low carbohydrate and high protein diets tend to have low adherence in the long term. To improve long-term cardiovascular disease outcomes, the healthy types of fat and protein should be emphasised.

Vitamin and mineral supplementation

Present nutrition therapy recommendations do not support vitamin or mineral supplementation in people with diabetes who do not have underlying deficiencies (table 2).[61–63] However, people with diabetes should be informed about the importance of acquiring daily vitamin and mineral requirements through a well balanced diet because people with poorly controlled diabetes often have micronutrient deficiencies.[61] Select populations with diabetes, including elderly people, pregnant and lactating women, vegetarians, and those on calorie-restricted diets, should be aware of additional supplemental needs specific to their circumstances.

Alcohol

Organisations from North America and Europe recommend moderate alcohol consumption for people with diabetes, as for the general public with consideration of risk of weight gain and hypoglycaemia, especially if taking insulin or insulin secretagogues.[61–63] Similar to the general public, moderate alcohol consumption has been associated with a lower risk of mortality and coronary heart disease in people with diabetes.[89] In a metabolic study, people with type 2 diabetes did not have delayed hypoglycaemia when alcohol was consumed with food.[90] However, the recommendations need to be delivered in a culturally appropriate context because excess alcohol drinking is one of the leading causes of disease burden in eastern Europe and Latin America, and alcohol consumption is increasing steadily in many Asian countries.[4]

Major knowledge gaps in the dietary management of diabetes

Larger and longer-term RCTs are needed to compare relative efficacy and effectiveness of various dietary approaches in diabetes management. Personalised nutrition therapy tailored according to individuals' metabolic profile or genetic background, a promising concept, is yet to be investigated in the context of diabetes management. High-quality, large sample size intervention and observational studies, and region-specific recommendations are lacking from diverse populations and cultures.

Summary and global perspectives

Economic growth and globalisation of trade have led to drastic changes in food production, processing, and distribution systems and have increased the accessibility of unhealthy foods.[3] With nutrition transitions, men and women worldwide have experienced excess bodyweight gain accompanied by increased diabetes incidence and complications.[4]

In the past two decades, evidence from prospective cohort studies and RCTs has shown the importance of individual nutrients, foods, and dietary patterns in type 2 diabetes prevention and management. The convergence of dietary factors for prevention and management of diabetes was recorded, and healthy dietary patterns for diabetes prevention and management were typically rich in wholegrains, fruits and vegetables, nuts, and legumes; moderate in alcohol consumption; and lower in refined grains, red or processed meats, and sugar-sweetened beverages. To achieve long-term adherence to this diet plan, individuals can have flexibility in food choices without compromising overall diet quality.

Almost all present knowledge of dietary prevention and management of diabetes has been derived from developed countries. To undertake original investigations in other populations with different disease susceptibility and eating habits is crucial. Evidence-based nutrition therapy recommendations have been developed and implemented in many developed countries.[61–63] However, further development of region-specific guidelines is needed to provide practical educational instruments, which consider variation in dietary patterns, accessibility to foods, and agriculture in different regions and cultures.

Global public health policies are warranted across several sectors to create a healthy food environment and promote corporate social responsibility. Potential strategies include nutrition and agricultural policies that favour the production and distribution of healthy food—eg, instituting agricultural subsidies that increase accessibility and affordability of fruits, vegetables, wholegrains, legumes, and nuts. Increasing taxes on sugar-sweetened beverages and other unhealthy products can reduce consumption of these foods and improve overall diet quality. Global efforts, such as standardisation of front-of-package nutrition labels and nutrition facts in conjunction with public health campaigns and sound agricultural and food policies, could reshape the trajectory of nutrition transition and improve the global food supply, which might help to curb the type 2 diabetes epidemic.

Contributors

SHL searched for and assessed the literature, wrote the first draft, and revised the review. OH and VM prepared several references and revised the review. FBH planned and revised the review.

Declaration of interests

OH reports personal fees from Abbott Nutrition Inc, personal fees from Merck Pharmaceutical, and grants from Neurometrix, outside the submitted work. FBH reports grants from Merck, grants from California Walnut Commission, personal fees from Novo Nordisk, and personal fees from Bunge, outside the submitted work. SHL and VM declare no competing interests.

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