Treatment of Diabetes with Lifestyle Changes: Diet

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Contents

Abstract

The present chapter critically reviews scientific evidence on the impact of the diet and its components on the metabolic control, cardiovascular risk factors, and morbidity/mortality in diabetic patients.

Three main topics are included in this chapter: (1) the effects of dietary treatment on body weight control in diabetic patients; (2) the optimal dietary composition in order to achieve blood glucose control and reduce other cardiovascular risk factors associated with type 2 diabetes; (3) the effects of lifestyle modifications and dietary changes on the risk to develop type 2 diabetes.

The overall body of evidence seems to confirm the efficacy of current recommendations for diabetes management. However, although dietary strategies based on structured interventions are often successful, particularly in relation to body

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weight control, they are not easily applicable in clinical practice and, therefore, more feasible strategies should be identified.

In addition, further intervention studies focused on the effects of lifestyle on hard endpoints in diabetic subjects are needed to definitively prove the role of diet in the prevention of both cardiovascular and microvascular complications in these patients over and above their impact on weight reduction.

Keywords
Healthy diet · Diabetes · Body weight control · Dietary fat · Fiber · Glycemic index

List of Abbreviations

BMI	Body Mass Index
CVD	Cardiovascular diseases
DPS	Diabetes Prevention Study
EASD	European Association for the Study of Diabetes
T2D	Type 2 diabetes
HDL-chol	High density lipoprotein-cholesterol
MedD	Mediterranean diet
NHANES	National Health and Nutrition Examination Survey

Dietary Treatment of Type 2 Diabetes

Weight Loss

Weight gain is a major problem for people with type 2 diabetes. The results of the *Third National Health and Nutrition Examination Survey* (NHANES III) have indicated that the 85.2% of diabetic people were overweight or obese, and the 54.8% were obese, during the years 1999–2002 (Flegal et al. 2002); so, most adults with diabetes are overweight or obese. In addition, it is important to underline that body weight increases with age, and widely prescribed oral hypoglycemic drugs facilitate weight gain. Therefore, encouraging patients to achieve and maintain a healthy weight should be a priority for all diabetes care programs.

In overweight and obese patients with type 2 diabetes, modest and sustained weight loss has been shown to improve glycemic control (by reducing insulin resistance) and plasma lipid, and to reduce blood pressure levels, the need for glucose-lowering, blood pressure, and lipids medications, and cardiovascular mortality (UK Prospective Diabetes Study 1990; Goldstein 1992; Pastors et al. 2002; Wing et al. 2013; Look AHEAD Research Group 2014).

In particular for mortality, an observational study conducting in the United States and involving 4970 overweight people with diabetes (body mass index – BMI $\geq$27 kg/m^2) has showed that an intentional weight loss is associated with a reduction in total mortality of 25% and in diabetes-related and cardiovascular mortality of 28% (Williamson et al. 2000). But, in the same study, the authors also report an U-shaped relationship between mortality and weight loss; more in detail, the authors show that a body weight reduction ≥30% is associated with slightly increased of mortality (Williamson et al. 2000).

In order to improve blood glucose control and reduce body weight and waist circumference, some studies have demonstrated that an intensive dietary intervention, based on the nutritional recommendations for people with diabetes, is more effective than usual care, in particular in diabetic patients not adequately controlled despite an optimized hypoglycemic drug treatment (Coppell et al. 2010). However, it is important to underline that among overweight or obese patients with type 2 diabetes and inadequate glycemic, blood pressure, and lipid control and/or other obesity-related medical conditions, lifestyle changes that include diet, exercise, and daily/weekly contacts with health professionals are the most effective interventions, as demonstrated by the Look AHEAD trial (Look AHEAD Research Group 2010 and 2014). The Look AHEAD trial is the first study that has investigated the effects of a moderate body weight reduction, obtained by an intensive lifestyle intervention combining a moderate energy restriction with a significant increase of the habitual physical activity, on cardiovascular risk factors and the incidence of cardiovascular events and mortality in a large cohort of overweight and obese individuals with type 2 diabetes. In relation to the cardiovascular risk factors, this study has shown that an intensive lifestyle intervention, compared with an usual education program, represents a good strategy to reduce body weight, improve significantly blood pressure and blood glucose control also in long-term (4 years of follow-up) (Look AHEAD Research Group 2010 and 2014). In addition, in a small number of patients, the intervention has been able to induce a partial or total remission of diabetes. Particularly remarkable is the effect on HDL-cholesterol (HDL-chol), with an increase greater at 4 years than at 1 year. More in detail, in the lifestyle group the HDL-chol was approximately 8–9% higher at each year than the baseline levels, whereas in the control group it remained at 3–6% above baseline. Interestingly, although severely obese participants did not reach their ideal body weight, a significant reduction of blood pressure, plasma glucose, HbA1c, and triglycerides was achieved, confirming the benefits of moderate weight loss (7–10% of initial body weight) in the management of diabetes (Look AHEAD Research Group 2010 and 2014).

Although this approach is clinically meaningful, it is not easily applicable in clinical practice for the great investments in terms of economic and professional resources; thus, more feasible strategies should be identified, considering that there is no single intervention or pattern of interventions suitable for all; weight reducing strategies should be tailored to the individual needs.

To date, studies demonstrating the benefits of weight reduction in people with type 2 diabetes are largely of short duration (up to 6 months); moreover, it is known the effort to keep over time the weight loss, particularly in the absence of the intensive support provided in a clinical trial. Usually, successful individuals can lose approximately 10% of baseline body weight with a hypocaloric regimen, though many regain one-third of this in the following year and all the weight loss within 5 years. Experience in the US National Weight Control Registry suggests that most people who successfully lose weight and maintain weight loss have experienced a triggering event such as an acute medical condition, so it is possible that a new diagnosis of type 2 diabetes could help to motivate an individual to lose weight (Wing and Phelan 2005).

Very low calorie diets, providing only 800 kcal/day, produce rapid weight loss but are not more effective of conventional diets in the long term; they should be reserved for people with severe obesity (BMI $\geq$35 kg/m^2) as part of a supervised weight management program. Nowadays, a 10 kg weight loss in the first 3–6 months, or 1–2 kg per month, has been proposed for people with diabetes. This weight loss can be attained with lifestyle programs that achieve a 500–750 kcal/day energy deficit or provide approximately 1200–1500 kcal/day for women and 1500–1800 kcal/day for men, adjusted for the individual's baseline body weight. In older people with diabetes, since body weight tends to increase with age, weight stabilization may be a more appropriate strategy.

Optimal Diet Composition

Nutrition therapy has an integral role in overall diabetes management and has the following goals:

– To control plasma glucose levels
– To prevent hypoglycemia, if the patient is treated with oral hypoglycemic drugs or with insulin
– To achieve and maintain a normal body weight
– To prevent or delay complications
– To control blood lipid levels and blood pressure
– To improve the quality of life

The current nutritional recommendations for people with diabetes emphasize the healthful eating patterns containing nutrient-dense, high-quality foods and a focus on specific nutrients. In this context, the Mediterranean diet (Estruch et al. 2013), dietary approaches to stop hypertension (DASH) (Cespedes et al. 2016; Ley et al. 2014), and plant-based diets (Rinaldi et al. 2016) are all examples of healthful eating patterns for people with diabetes, and the "Plate model" could be an example of the simple method applying these recommendations in daily life.

Current dietary recommendations for diabetic patients are particularly focused on optimizing the quantities and food sources of fat and carbohydrates within the same recommendations for healthy eating that applies to the general population. The composition of the diet recommended for people with diabetes is listed in Table 1 (American Diabetes Association 2017; Mann et al. 2004). These recommendations should take into account individual nutrition needs based on personal and cultural preferences, health literacy and numeracy, and access to healthful foods.

Fats

Total fat intake should be reduced to provide no more than 35% of energy. The type of fats consumed is more important than total amount of fat when looking at

Table 1 Medical Nutrition Therapy recommendations for people with diabetes from Scientific Associations of Diabetes specialists

Topic	Specific intake[a]	Recommendations[b]
Energy balance	–	• Modest weight loss achievable by the combination of reduction of calorie intake and lifestyle modification benefits overweight or obese adults with type 2 diabetes and those with prediabetes. Intervention programs to facilitate this process are recommended
Dietary carbohydrates **Added sugar** **Fiber**	45–60% of TE <10% of TE >20 g/ 1000 kcal	• Carbohydrate intake from whole grains, vegetables, fruits, legumes, and dairy products, with an emphasis on foods higher in fiber and lower in glycemic load, should be advised over other sources, especially those containing sugars. • People with diabetes and those at risk should avoid sugar-sweetened beverages in order to control weight and reduce their risk for CVD and fatty liver B and should minimize the consumption of foods with added sugar that have the capacity to displace healthier, more nutrient-dense food choices
Dietary fat **SAFA** **MUFA** **PUFA** **Cholesterol**	<35% of TE <10% of TE 10–20% of TE <10% of TE <300 mg/day	• Whereas data on the ideal total dietary fat content for people with diabetes are inconclusive, an eating plan emphasizing elements of a Mediterranean-style diet rich in monounsaturated fats may improve glucose metabolism and lower CVD risk and can be an effective alternative to a diet low in total fat but relatively high in carbohydrates. • Eating foods rich in long-chain v-3 fatty acids, such as fatty fish (EPA and DHA) and nuts and seeds (ALA) is recommended to prevent or treat CVD; however, evidence does not support a beneficial role for v-3 dietary supplements
Protein	10–20% of TE	• In individuals with type 2 diabetes, ingested protein appears to increase insulin response without increasing plasma glucose concentrations. Therefore, carbohydrate sources high in protein should not be used to treat or prevent hypoglycemia
Sodium	2300 mg/day	• As for the general population, people with diabetes should limit sodium consumption to 2300 mg/day, although further restriction may be indicated for those with both diabetes and hypertension

TE total energy, *SAFA* saturated fatty acids, *MUFA* monounsaturated fatty acids, *PUFA* polyunsaturated fatty acids

[a]Evidence-based nutritional approaches to the treatment and prevention of diabetes mellitus. Diabetes and Nutrition Study Group (DNSG), 2004

[b]American Diabetes Association. Standards of Medical Care in Diabetes 2017

metabolic goals and CVD risk (Office of Disease Prevention and Health Promotion 2015–2020; Estruch et al. 2013; Ros 2003; Forouhi et al. 2016; Wang et al. 2016). Therefore, the fat content of the diet should be manipulated to reduce intake of fats which promote alterations in plasma lipid profile. In particular, saturated and trans fatty acids (found in meat and dairy products, and in hard margarines, some salad dressing, and processed foods, respectively) should provide no more than 10% of total energy and dietary cholesterol should be limited to less than 300 mg/day (and less than 200 mg/day in people with alteration of lipid metabolism).

Recommendations for the dietary content of other fats reflect a balance between their favorable and adverse metabolic effects. Cis-monounsaturated fats (found in olive oil, peanut oil, sunflower oil, almonds, avocado) have a more favorable metabolic impact and may reduce insulin-resistance and plasma LDL-cholesterol concentrations as compared with saturated fat (Vessby et al. 2001). When they replace carbohydrate in a weight-maintaining diet, these fats are also associated with lower postprandial glycaemia and plasma triglyceride levels. They should nevertheless be limited because they are energy-dense and may cause weight gain, and in large amounts, increase insulin resistance.

Polyunsaturated fatty acids of n-3 series (found in fish and soybean oils) have favorable effects on plasma triglyceride levels and antithrombotic activity but may increase plasma LDL-cholesterol concentrations if consumed in large amounts, usually at pharmacological doses. Dietary n-6 polyunsaturated fatty acids are associated with reduced total and LDL-cholesterol compared with a diet high in saturated fat. Their hypocholesterolemic effect is slightly higher than that achieved with similar amounts of monounsaturated fat; in addition, they have also a small hypotriglyceridemic effect; however, they tend to decrease HDL cholesterol (Ooi et al. 2013).

Carbohydrates

Dietary carbohydrates represent the largest contributor to the energy intake in most countries and the main dietary component able to influence blood glucose levels, particularly in the postprandial state. Therefore, their intake is considered extremely important in the regulation of blood glucose levels in people with diabetes.

In the last few years, the debate on the pros and cons of carbohydrate-rich diets has been very hot on the basis of the possible unfavorable effects of dietary carbohydrates on glycemic control and plasma lipid levels, in particular on increase of plasma triglycerides and decrease of plasma HDL-cholesterol. Many of these controversies arise because it is not always recognized that carbohydrates are a heterogeneous class of nutrients with marked differences in their rate of digestion, absorption, and, therefore, on metabolic effects. So, in order to evaluate the variety of the blood glucose response in vivo after a meal containing carbohydrates, it is important to consider other important component, as the fiber content, the chemical composition of carbohydrates, and the physical structure of the foods present in the meal. To account for all these factors, Jenkins et al. (1981) introduced the concept of the glycemic index (GI), which attempts to quantify the potency of carbohydrate foods to raise blood glucose levels in vivo. Most trials that have compared the effects of low-GI and high-GI diets have shown that low-GI foods have more favorable effects on glycemic control (Riccardi et al. 2008). In nondiabetic populations, low-GI diets have been associated with lower plasma levels of insulin and lipids and improved glucose tolerance (Bell et al. 2015; Brand-Miller et al. 2009). In people with type 2 diabetes, a low-GI diet is associated with better glycemic control (as indicated by lower HbA1C or fructosamine levels) (Brand-Miller et al. 2003; Thomas and Elliott 2010). However, some studies have detected no difference between low- and high-GI foods on plasma lipids in people with diabetes.

A recent meta-analysis comparing the effects of low-GI diets with conventional or high-GI diets on glycemic control in patients with diabetes concluded that the low-GI diets improve the glycemic control reducing HbA1C by about 6% (for example, reducing an HbA1c of 8% to approximately 7.5%) (Wang et al. 2015). This effect is very important in people with diabetes because it is known that HbA1c is continuously related to the risk of diabetes complications, as demonstrated by the results of the United Kingdom Prospective Diabetes Study (UKPDS) in which the reduction of HbA1c by one percentage point was associated with a reduction of 21% in diabetes-related deaths and complications (UK Prospective Diabetes Study Group, 1998). Therefore, any reduction of glycated hemoglobin is welcome.

Based on this context, all nutritional recommendations available for people with diabetes consider the GI of foods the most important parameters for carbohydrates consumption. More in detail, European dietary recommendations state that "*Carbohydrate-containing foods which are high in dietary fibre or have a low glycaemic index are especially recommended*" (The Task Force on diabetes, pre-diabetes, and cardiovascular diseases 2013). The justification for this stance is that low-GI foods may help to improve glycemic control and lipid levels.

Also the American Diabetes Association and the UK recommendations recommend the utilization of the GI in the diet for people with diabetes (American Diabetes Association 2017; Dyson et al. 2011). However, according to ADA, it should always be taken into account that many healthy foods have a higher GI than foods with little nutritional value. For example, oatmeal has a higher GI than chocolate. Therefore, it is important to remember that the GI represents the type of carbohydrate in a food but says nothing about the amount of carbohydrate typically eaten. For this reason, the glycemic load (GL) has been proposed as a marker of the impact of a food on postprandial blood glucose since it takes into account both the amount of carbohydrate present in the portion of food eaten and the glycemic impact of that specific food as compared with a reference food like white bread.

The glycemic load (GL) is calculated by multiplying the GI of a food by the amount of carbohydrate in grams per serving and dividing the total by 100.

There are other important reasons for encouraging consumption of low-GI foods. In general, foods with a low glycemic index tend to be high in fiber and micronutrients – for example, legumes, oats, pasta, and some raw fruits have low GI values (Atkinson et al. 2008).

Dietary Fibers

Intake of dietary fiber is associated with lower all-cause mortality in people with diabetes. There is a large body of evidence that a diet moderately rich in carbohydrates and fibers, and, consequently, with a low glycemic index and mainly based on consumption of legumes, vegetables, fruits, and whole grain cereals improves blood glucose control and reduces plasma cholesterol levels in diabetic patients as compared with a low carbohydrate-low fiber diet. In particular, this type of diet keeps low plasma insulin and triglyceride concentrations despite its higher carbohydrate intake and induces also a significant reduction in postprandial blood glucose and triglyceride rich lipoprotein levels which play a relevant role in modulating the cardiovascular risk in patients with type 2 diabetes (De Natale et al. 2009). The net LDL-cholesterol reduction due to the doubling of fiber intake can be more than 10%. The beneficial effects of high-fiber diets on LDL-cholesterol have been confirmed by a meta-analysis comparing the effects of low-GI vs. high-GI diets. The significant decrease in LDL-cholesterol observed with the low-GI diets was related to their fiber content and, in fact, it was not any more evident when studies with high-fiber diets were excluded from the analysis (Goff et al. 2013).

Dietary fiber seems able to counteract the rising effect of carbohydrates on fasting triglycerides. In the last years, much attention has been paid to postprandial lipemia as a cardiovascular risk factor and, indeed, large epidemiological studies suggest that postprandial triglycerides are a stronger cardiovascular risk factor than fasting triglyceride levels (Bansal et al. 2007). Different dietary components modulate the postprandial triglyceride response. Recently, much attention has been devoted to the effects of dietary fiber on postprandial triglycerides. In people with type 2 diabetes, a fiber-rich diet reduces the postprandial triglyceride response, mainly due to the reduction of lipoproteins carrying exogenous lipids. On the same line, a diet based on wholegrain cereals, as compared to a diet with refined cereals, reduces postprandial triglyceride levels by 40% in people with the metabolic syndrome (Giacco et al. 2014). In this study, the decrease in postprandial triglycerides was significantly and inversely correlated with the intake of cereal fiber, supporting the role of cereal fiber in the modulation of the postprandial metabolism.

The effects of dietary fiber on HDL-cholesterol are negligible. Together with the reduction of LDL-cholesterol, a small decrease in HDL-cholesterol has been reported with high-fiber diets in some studies; however, on the overall, the magnitude of this effect is much less relevant than that obtained on LDL-cholesterol. Although solubility of fiber was thought to determine physiological effect, more recent studies suggest that other properties of fiber, such as fermentability and viscosity may be more important (Slavin 2013). As a matter of fact, dietary fibers improve glucose and lipid metabolism slowing food digestion and nutrient absorption and producing in the colon short-chain fatty acids that, in turn, modulate liver glucose production and lipid synthesis. Therefore, people with diabetes should not be excluded from the public health campaign that encourages eating five portions of fruit and vegetables a day and promotes wholegrain cereal foods as a substitute for the refined ones. In addition, for diabetic patients it may be helpful, among the high fiber foods, to tilt the balance of consumption in favor of those with a low GI.

Sugar

In the past, people with diabetes were recommended to completely avoid sugar. In fact, it was believed that eating sugar would raise blood glucose. Conversely, available scientific evidence from clinical studies shows that dietary sucrose influences blood glucose levels not more than an equivalent caloric amounts of starch. It is important to underline that the excess of energy intake from nutritive sweeteners or foods and beverages containing high amounts of nutritive sweeteners should be avoided, since they provide “empty” calories and can lead to weight gain (Evert et al. 2013).

Fructose is a common naturally occurring monosaccharide found in fruits, in some vegetables, and honey and is also widely used as sweetener of drink or added in processed foods in substitution of sucrose. Fructose consumed as “free fructose” (i.e., naturally occurring in foods such as fruit) may result in better glycemic control compared with isocaloric intake of sucrose or starch, and free fructose is not likely to have detrimental effects on triglycerides as long as its intake is kept low (less than 5% energy).

People with diabetes should limit or avoid intake of sugar-sweetened beverages (SSBs) (from any caloric sweetener, including high-fructose corn syrup and sucrose) to reduce the risk of weight gain and worsening the cardiometabolic profile.

A meta-analysis of controlled intervention studies with a duration of less than 12 weeks in people with diabetes compared the impact of fructose with that of other sources of carbohydrate on glycemic control (Cozma et al. 2012). The results showed that an isocaloric exchange of fructose for other carbohydrates did not significantly affect fasting glucose or insulin and reduced glycated blood proteins. However, strong evidence exists that consuming high levels of fructose-containing beverages may have particularly adverse effects on selective deposition of visceral fat, lipid metabolism, blood pressure, and insulin sensitivity (Evert et al. 2013). Thus, recommendations for diabetic people about sugar intake should on the one hand consider the unfeasibility of too stringent limitations of added sugar, particularly for children but, on the other hand, should take into account potential metabolic consequences of excessive consumption of sweetened foods and, even more, beverages, particularly soft drinks, that could lead to further deterioration of insulin resistance and obesity.

Protein

Protein intake in economically developed countries is high and exceeds metabolic needs; in the United States, for example, it is estimated that protein accounts for 10–20% of the energy intake. Current recommended limits are based on a pragmatic interpretation of the available evidence and awareness that attempts to restrict protein intake below 0.6 g/kg/day may precipitate nutritional deficiency.

Protein does not affect the rate at which glucose is absorbed from a meal or postprandial blood glucose levels. In people with type 1 diabetes and incipient nephropathy, high protein intake may increase the progression of renal disease; however, little is known about the effects of high protein consumption in people with type 2 diabetes. Protein increases satiety; diets that are high in protein but low in carbohydrate do achieve weight loss but not more so than other types of calorie restriction diets. Furthermore, such diets tend to be high in fat and this may induce plasma LDL-cholesterol increases. There is no evidence that high protein diets are beneficial in people with type 2 diabetes.

There is no strong evidence to suggest higher benefits from plant protein as compared to animal protein; however, considering that foods as meat, processed meat, milk products, eggs, although rich in essential aminoacids are also rich in saturated fats, it is appropriate to limit animal protein intake (National Kidney Foundation 2012).

Diet and Cardiovascular Morbidity/Mortality

The inverse association between the adherence to a healthy diet (Mediterranean diet, DASH diet, Prudent diet) and cardiovascular disease has been found in many large prospective studies in nondiabetic populations (Sofi et al. 2010; Salehi-Abargouei et al. 2013; Hu et al. 2000) and some data are available also for diabetic patients.

More in detail, a greater adherence to a healthy diet, characterized by high consumption of whole-grains, vegetables, fruit, nuts, and fish compared to meat, poultry, and eggs, is associated with a reduction by 20% of recurrent cardiovascular events in a large cohort of patients with previous CVD and/or diabetes. These data indicate that a healthy diet may be important not only in primary prevention but also in secondary prevention or in high CV-risk individuals, such as diabetic patients. Moreover, the beneficial effects are in addition to those obtained with the pharmacological therapy generally used in secondary prevention (Dehghan et al. 2012).

The association between diet and mortality in type 1 diabetic subjects has been investigated in the EURODIAB study that is the first European prospective study on this issue; the results have shown that, in a cohort of almost 2000 subjects, a 5 g-increase of fiber intake, especially soluble fiber, within the range commonly consumed in patients with type 1 diabetes (11.3–28.3 g/day) is associated with lower CVD mortality (−16%) and all-cause mortality (−28%) (Schoenaker et al. 2012) confirming the importance of dietary fibers in diabetes management also for what concerns type 1 diabetes.

The casual relationship between diet and cardiovascular risk in type 2 diabetic patients has been evaluated in the Look AHEAD trial (The Look AHEAD Research Group 2013). This study has shown that an intensive lifestyle modification program focused on weight reduction is able to improve all cardiovascular risk factors, as reported above, whereas does not reduce the occurrence of cardiovascular events and mortality compared to the usual care group in the long term. Completely different are the results obtained in the PREDIMED study (Estruch et al. 2013) which was not focused on reducing excessive body weight but aimed exclusively at achieving dietary modifications resembling the traditional Mediterranean diet. In fact, in this study a Mediterranean diets supplemented with either extra-virgin olive oil or nuts was able to reduce significantly (almost 30%) the incidence of major CV events compared to the control diet in high-risk individuals, including subjects with T2D ($n = 3614$, almost 50% of the total population).

Although the early termination of the trial may lead to an overestimation of treatment effects (Bassler et al. 2010), the results suggest that changes in diet composition, even small, may be really effective, possibly more than weight reduction, in reducing CVD in type 2 diabetic subjects.

Diet and Type 2 Diabetes Prevention

Diet represents the cornerstone of diabetes treatment since it can induce significant improvements of blood glucose control and other metabolic cardiovascular risk factors (Franz et al. 2010; Lindström et al. 2006) and might potentially reduce the risk of long-term complications (Laakso 1999). A healthy diet, as part of an appropriate lifestyle, is also able to prevent type 2 diabetes. Studies using lifestyle interventions in people with impaired glucose tolerance have shown a reduction in diabetes incidence (Eriksson and Lindgärde 1991; Pan et al. 1997; Tuomilehto et al. 2001; Knowler et al. 2002; Ramachandran et al. 2006; Kosaka et al. 2005). Lifestyle intervention in these studies lasting for 3–6 years emphasized body weight control (weight reduction >5–10% of initial body weight), physical activity, and dietary modifications such as a fat intake <30% of daily energy intake, saturated fat <10% of daily energy intake, and a fiber intake >15 g/1000 kcal. In particular, both the Finnish Diabetes Prevention Study (Tuomilehto et al. 2001) and the US Diabetes Prevention Program (Knowler et al. 2002) showed a 58% relative risk reduction in the progression from impaired glucose tolerance to type 2 diabetes, during a mean intervention period of about 3 years.

Beside these studies focused on the effects of lifestyle modifications and dietary changes on the risk to develop type 2 diabetes, several observational studies have shown an association between consumption of specific food groups or healthy dietary patterns and the risk of type 2 diabetes (Table 2). The EPIC-Potsdam study, in line with previous studies, has confirmed that higher intakes of whole-grain bread, fruits, raw vegetables, and coffee are inversely associated with type 2 diabetes risk in a large cohort of healthy subjects, during an average follow-up of 8 years (vonRuesten et al. 2013). These foods are good sources of dietary fiber and antioxidant, vitamins and minerals that could contribute to their protective role against type 2 diabetes. In support of their role in diabetes prevention is also the evidence that fiber rich foods have a lower impact on blood glucose levels after a meal. Indeed all pharmacological (Chiasson et al. 2002) and nonpharmacological interventions tested so far in people with pre-diabetes, able to reduce glycemia after meals with whatever mechanism, have proven effective in the prevention of type 2 diabetes.

Conversely, high intakes of red meat, butter, sauces and fat dairy are associated with an increased risk of type 2 diabetes (vonRuesten et al. 2013). Fish consumption in some studies has been found to be associated with a lower risk of diabetes (Nkondjock and Receveur 2003; Adler et al. 1994). Whether the protective effect of fish is due to its n-3 fatty acid content or to other components, such as protein, is a matter of debate. The mechanisms by which fat consumption could influence the development of diabetes is strictly linked to insulin sensitivity. In fact, dietary fat can influence insulin sensitivity independently of any change in body weight; this influence will obviously affect also the development of the Metabolic Syndrome which is strongly associated with impaired insulin sensitivity. Animal studies have clearly shown that a high-fat diet, particularly if high in saturated fat, decreases insulin sensitivity. Several cross-sectional studies have examined dietary fat in

Table 2 Foods, nutrients and dietary patterns associated with risk of developing type 2 diabetes

	Increased risk	Degree of evidence	Decreased risk	Degree of evidence
Foods	Soft drinks	++	Whole grains	++
	Red meat and processed meat	++	Tea and coffee	++
	Oil and hydrogenated margarines	+	Milk and dairy products low in fat	++
	Eggs	+	Fruits, vegetables, legumes	++
	High alcohol consumption	++	Moderate alcohol consumption	+
			Nuts	+
Nutrients	Saturated fatty acids	+	Fibers	++
	Trans fatty acids	+	Unsaturated fatty acids	++
			Antioxidants	+
			Magnesium	+
Dietary patterns	High glycemic load	++	Mediterranean diet	+++
	Western diet	++		

Degree of evidence from prospective epidemiological studies = +++ High;++ Moderate; + Reasonable

relation to fasting and post-load plasma insulin concentrations, which are both markers of insulin resistance. The consistent finding is a positive association between saturated fat intake and hyperinsulinemia, independently of body fat. These data have been partly confirmed in human intervention studies using more accurate techniques to evaluate insulin resistance. Why dietary fat quality can influence insulin sensitivity is not completely understood; however, the effects of dietary fatty acids on insulin sensitivity are thought to be mediated, at least partially, by the fatty acid composition of cell membranes (Riccardi et al. 2004). A specific fatty acid profile in cell membranes could influence insulin action through several potential mechanisms, including altered insulin receptor binding or affinity, and by influencing ion permeability and cell signaling. Insulin resistant states are associated with a plasma fatty acid pattern characterized by an increased proportion of palmitic acid and a low proportion of linoleic acid, with a distribution of other fatty acids that indicates an increased activity of D9- and D6-desaturases. These changes are possibly related, to a large extent, to the type of fat in the diet and are consistent with a diet where animal (saturated) fat consumption is increased and vegetable (unsaturated) fat consumption is reduced. The deteriorating effect of saturated fat on insulin sensitivity is supported by controlled intervention studies in which the comparison was performed between saturated fat and either monounsaturated or polyunsaturated fat (Vessby et al. 2001).

Looking at the association between dietary pattern and risk of type 2 diabetes, data from epidemiological study have shown that an higher adherence to a Mediterranean dietary pattern is associated with a significant reduction by 12% of type 2 diabetes risk compared with individuals with lower adherence to Mediterranean diet in a large cohort of healthy subjects from Mediterranean and non-Mediterranean countries (InterAct Consortium et al. 2011).

The role of dietary patterns and, in particular, of the Mediterranean diet in reducing type 2 diabetes risk has been clearly reinforced by the results of the PREDIMED study (Salas-Salvadó et al. 2011). After a median follow-up of 4 years, a multivariable adjusted hazard ratio for the incidence of type 2 diabetes was almost 50% lower in the participants assigned to the MedD as compared to the control diet. In addition, increased adherence to MedD was inversely associated with the development of diabetes. It has to be underlined that in this study the reduction of type 2 diabetes was observed in absence of any significant changes in body weight or physical activity, suggesting that the mechanisms involved in diabetes risk reduction in this study are independent from body weight loss and could be related to an improvement in insulin sensitivity and/or a reduction of oxidative stress and inflammation.

In addition to the effect of diet composition, new data from the Diabetes Prevention Study (DPS) have further outlined the importance of more global lifestyle modifications on the reduction of type 2 diabetes; in fact, the benefits of moderate weight reduction, together with an increase of physical activity and changes in diet composition, are preserved in the long term, even many years after the conclusion of the intervention (Lindström et al. 2013).

Although lifestyle interventions are not easily applicable in real-life, the European Diabetes Prevention Study (EDIPS) has recently shown that the Finnish DPS protocol can be applicable with success in other European countries reducing by 57% the cumulative type 2 diabetes incidence during a mean follow-up of 3.1 years (Penn et al. 2013).

References

Adler AI, Boyko EJ, Schraer CD, et al. Lower prevalence of impaired glucose tolerance and diabetes associated with daily seal oil or salmon consumption among Alaska natives. Diabetes Care. 1994;17:1498–501.

American Diabetes Association. Standards of medical care in diabetes – 2017. Diabetes Care. 2017;40(Suppl 1):S1–S135.

Atkinson FS, Foster-Powell K, Brand-Miller JC. International tables of glycemic index and glycemic load values: 2008. Diabetes Care. 2008;31(12):2281–3.

Bansal S, Buring JE, Rifai N, et al. Fasting compared with nonfasting triglycerides and risk of cardiovascular events in women. JAMA. 2007;298(3):309–16.

Bassler D, Briel M, Montori VM, et al. Stopping randomized trials early for benefit and estimation of treatment effects: systematic review and meta-regression analysis. JAMA. 2010;303:1180–7.

Bell KJ, Bao J, Petocz P, Colagiuri S, Brand-Miller JC. Validation of the food insulin index in lean, young, healthy individuals, and type 2 diabetes in the context of mixed meals: an acute randomized crossover trial. Am J Clin Nutr. 2015;102(4):801–6.

Brand-Miller J, Hayne S, Petocz P, Colagiuri S. Low-glycemic index diets in the management of diabetes: a meta-analysis of randomized controlled trials. Diabetes Care. 2003;26(8):2261–7.

Brand-Miller JC, Stockmann K, Atkinson F, Petocz P, Denyer G. Glycemic index, postprandial glycemia, and the shape of the curve in healthy subjects: analysis of a database of more than 1,000 foods. Am J Clin Nutr. 2009;89(1):97–105.

Cespedes EM, Hu FB, Tinker L, et al. Multiple healthful dietary patterns and type 2 diabetes in the women's health initiative. Am J Epidemiol. 2016;183:622–33.

Chiasson JL, Josse RG, Gomis R, Hanefeld M, Karasik A, Laakso M, STOP-NIDDM Trail Research Group. Acarbose for prevention of type 2 diabetes mellitus: the STOP-NIDDM randomised trial. Lancet. 2002;359(9323):2072–7.

Coppell KJ, Kataoka M, Williams SM, et al. Nutritional intervention in patients with type 2 diabetes who are hyperglycaemic despite optimised drug treatment–lifestyle over and above drugs in diabetes (LOADD) study: randomised controlled trial. BMJ. 2010;341:c3337.

Cozma AI, Sievenpiper JL, de Souza RJ, et al. Effect of fructose on glycemic control in diabetes: a systematic review and meta-analysis of controlled feeding trials. Diabetes Care. 2012;35:1611–20.

De Natale C, Annuzzi G, Bozzetto L, Mazzarella R, Costabile G, Ciano O, Riccardi G, Rivellese AA. Effects of a plant-based high-carbohydrate/high-fiber diet versus high-monounsaturated fat/low-carbohydrate diet on postprandial lipids in type 2 diabetic patients. Diabetes Care. 2009;32(12):2168–73.

Dehghan M, Mente A, Teo KK, et al. Relationship between healthy diet and risk of cardiovascular disease among patients on drug therapies for secondary prevention: a prospective cohort study of 31 546 high-risk individuals from 40 countries. Circulation. 2012;126:2705–12.

Dyson PA, Kelly T, Deakin T, Duncan A, Frost G, Harrison Z, Khatri D, Kunka D, McArdle P, Mellor D, Oliver L, Worth J, Diabetes UK Nutrition Working Group. Diabetes UK evidence-based nutrition guidelines for the prevention and management of diabetes. Diabet Med. 2011; 28(11):1282–8.

Eriksson KF, Lindgärde F. Prevention of type 2 (non-insulin-dependent) diabetes mellitus by diet and physical exercise. The 6-year Malmö feasibility study. Diabetologia. 1991;34(12):891–8.

Estruch R, Ros E, Salas-Salvadó J, PREDIMED Study Investigators, et al. Primary prevention of cardiovascular disease with a Mediterranean diet. N Engl J Med. 2013;368:1279–90.

Evert AB, Boucher JL, et al. Nutrition therapy recommendations for the Management of adults with diabetes: position statement by the ADA. Diabetes Care. 2013;36:3821–42.

Flegal KM, Carroll MD, Ogden CL, Johnson CL. Prevalence and trends in obesity among US adults, 1999–2000. JAMA. 2002;288(14):1723–7.

Forouhi NG, Imamura F, Sharp SJ, et al. Association of plasma phospholipid n-3 and n-6 polyunsaturated fatty acids with type 2 diabetes: the EPIC-InterAct Case-Cohort Study. PLoS Med. 2016;13:e1002094.

Franz MJ, Powers MA, Leontos C, et al. The evidence for medical nutrition therapy for type 1 and type 2 diabetes in adults. J Am Diet Assoc. 2010;110:1852–89.

Giacco R, Costabile G, Della Pepa G, et al. A whole-grain cereal-based diet lowers postprandial plasma insulin and triglyceride levels in individuals with metabolic syndrome. Nutr Metab Cardiovasc Dis. 2014;24(8):837–44.

Goff LM, Cowland DE, Hooper L, Frost GS. Low glycaemic index diets and blood lipids: a systematic review and meta-analysis of randomised controlled trials. Nutr Metab Cardiovasc Dis. 2013;23(1):1–10.

Goldstein DJ. Beneficial health effects of modest weight loss. Int J Obes Relat Metab Disord. 1992;16:397–415.

Hu FB, Rimm EB, Stampfer MJ, et al. Prospective study of major dietary patterns and risk of coronary heart disease in men. Am J Clin Nutr. 2000;72:912–21.

InterAct Consortium, Romaguera D, Guevara M, et al. Mediterranean diet and type 2 diabetes risk in the European Prospective Investigation into Cancer and Nutrition (EPIC) study: the InterAct project. Diabetes Care. 2011;34:1913–8.

Jenkins DJ, Wolever TM, Taylor RH, et al. Glycemic index of foods: a physiological basis for carbohydrate exchange. Am J Clin Nutr. 1981;34:362–6.

Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, Nathan DM, Diabetes Prevention Program Research Group. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med. 2002;346(6):393–403.

Kosaka K, Noda M, Kuzuya T. Prevention of type 2 diabetes by lifestyle intervention: a Japanese trial in IGT males. Diabetes Res Clin Pract. 2005;67(2):152–62.

Laakso M. Hyperglycemia and cardiovascular disease in type 2 diabetes. Diabetes. 1999;48:937–42.

Ley SH, Hamdy O, Mohan V, Hu FB. Prevention and management of type 2 diabetes: dietary components and nutritional strategies. Lancet. 2014;383:1999–2007.

Lindström J, Peltonen M, Eriksson JG, et al. High-fibre, low-fat diet predicts long-term weight loss and decreased type 2 diabetes risk: the Finnish Diabetes Prevention Study. Diabetologia. 2006;49:912–20.

Lindström J, Peltonen M, Eriksson JG, et al. Improved lifestyle and decreased diabetes risk over 13 years: long-term follow-up of the randomised Finnish Diabetes Prevention Study (DPS). Diabetologia. 2013;56:284–93.

Look AHEAD Research Group. Eight-year weight losses with an intensive lifestyle intervention: the Look AHEAD study. Obesity (Silver Spring). 2014;22:5–13.

Look AHEAD Research Group. Long-term effects of a lifestyle intervention on weight and cardiovascular risk factors in individuals with type 2 diabetes mellitus: four-year results of the Look AHEAD trial. Arch Intern Med. 2010;170:1566–75.

Mann JI, De Leeuw I, Hermansen K, Diabetes and Nutrition Study Group (DNSG), et al. Evidence-based nutritional approaches to the treatment and prevention of diabetes mellitus. Nutr Metab Cardiovasc Dis. 2004;14:373–94.

National Kidney Foundation. KDOQI clinical practice guidelines for diabetes and chronic kidney disease. Am J Kidney Dis. 2012;49(Suppl 2):S1–S179.

Nkondjock A, Receveur O. Fish-seafood consumption, obesity, and risk of type 2 diabetes: an ecological study. Diabetes Metab. 2003;29:635–42.

Office of Disease Prevention and Health Promotion, U.S. Department of Health and Human Services. Dietary Guidelines for Americans: 2015–2020. 8th ed. Available from https://health.gov/dietaryguidelines/2015/guidelines/.

Ooi EM, Ng TW, Watts GF, Barrett PH. Dietary fatty acids and lipoprotein metabolism: new insights and updates. Curr Opin Lipidol. 2013;24(3):192–7.

Pan XR, Li GW, Hu YH, Wang JX, Yang WY, An ZX, Hu ZX, Lin J, Xiao JZ, Cao HB, Liu PA, Jiang XG, Jiang YY, Wang JP, Zheng H, Zhang H, Bennett PH, Howard BV. Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance. The Da Qing IGT and Diabetes Study. Diabetes Care. 1997;20(4):537–44.

Pastors JG, Warshaw H, Daly A, Franz M, Kulkarni K. The evidence for the effectiveness of medical nutrition therapy in diabetes management. Diabetes Care. 2002;25:608–13.

Penn L, White M, Lindström J, et al. Importance of weight loss maintenance and risk prediction in the prevention of type 2 diabetes: analysis of European Diabetes Prevention Study RCT. PLoS One. 2013;8:e57143.

Ramachandran A, Snehalatha C, Mary S, Mukesh B, Bhaskar AD, Vijay V, Indian Diabetes Prevention Programme (IDPP). The Indian Diabetes Prevention Programme shows that lifestyle modification and metformin prevent type 2 diabetes in Asian Indian subjects with impaired glucose tolerance (IDPP-1). Diabetologia. 2006;49(2):289–97.

Riccardi G, Giacco R, Rivellese AA. Dietary fat, insulin sensitivity and the metabolic syndrome. Clin Nutr. 2004;23(4):447–56. Review.

Riccardi G, Rivellese AA, Giacco R. Role of glycemic index and glycemic load in the healthy state, in prediabetes, and in diabetes. Am J Clin Nutr. 2008;87(1):269S–74S.

Rinaldi S, Campbell EE, Fournier J, O'Connor C, Madill J. A comprehensive review of the literature supporting recommendations from the Canadian Diabetes Association for the use of a plant-based diet for management of type 2 diabetes. Can J Diabetes. 2016;40:471–7.

Ros E. Dietary cis-monounsaturated fatty acids and metabolic control in type 2 diabetes. Am J Clin Nutr. 2003;78(Suppl):617S–25S.
Salas-Salvadó J, Bulló M, Babio N, et al. Reduction in the incidence of type 2 diabetes with the Mediterranean diet: results of the PREDIMED-Reus nutrition intervention randomized trial. Diabetes Care. 2011;34:14–9.
Salehi-Abargouei A, Maghsoudi Z, Shirani F, Azadbakht L. Effects of dietary approaches to stop hypertension (DASH)-style diet on fatal or nonfatal cardiovascular diseases–incidence: a systematic review and meta-analysis on observational prospective studies. Nutrition. 2013;29:611–8.
Schoenaker DA, Toeller M, Chaturvedi N, et al. Dietary saturated fat and fibre and risk of cardiovascular disease and all-cause mortality among type 1 diabetic patients: the EURODIAB Prospective Complications Study. Diabetologia. 2012;55:2132–41.
Slavin J. Fiber and prebiotics: mechanisms and health benefits. Nutrients. 2013;5(4):1417–35. https://doi.org/10.3390/nu5041417. Review.
Sofi F, Abbate R, Gensini GF, Casini A. Accruing evidence on benefits of adherence to the Mediterranean diet on health: an updated systematic review and meta-analysis. Am J Clin Nutr. 2010;92:1189–96.
The Look AHEAD Research Group. Cardiovascular effects of intensive lifestyle intervention in type 2 diabetes. N Engl J Med. 2013;369(2):145–54.
The Task Force on diabetes, pre-diabetes, and cardiovascular diseases. ESC guidelines on diabetes, pre-diabetes, and cardiovascular diseases developed in collaboration with the EASD. Eur Heart J. 2013;34:3035.
Thomas DE, Elliott EJ. The use of low-glycaemic index diets in diabetes control. Br J Nutr. 2010;104(6):797–802.
Tuomilehto J, Lindström J, Eriksson JG, Valle TT, Hämäläinen H, Ilanne-Parikka P, Keinänen-Kiukaanniemi S, Laakso M, Louheranta A, Rastas M, Salminen V, Uusitupa M, Finnish Diabetes Prevention Study Group. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. N Engl J Med. 2001;344(18):1343–50.
UK Prospective Diabetes Study (UKPDS) Group. Effect of intensive blood-glucose control with metformin on complications in overweight patients with type 2 diabetes (UKPDS 34). Lancet. 1998;352(9131):854–65.
UK Prospective Diabetes Study 7. UK Prospective Diabetes Study 7: response of fasting plasma glucose to diet therapy in newly presenting type II diabetic patients, UKPDS Group. Metabolism. 1990;39:905–12.
Vessby B, Uusitupa M, Hermansen K, Riccardi G, Rivellese AA, Tapsell LC, Nälsén C, Berglund L, Louheranta A, Rasmussen BM, Calvert GD, Maffetone A, Pedersen E, Gustafsson IB, Storlien LH, KANWU Study. Diabetologia. 2001;44(3):312–9.
vonRuesten A, Feller S, Bergmann MM, Boeing H. Diet and risk of chronic diseases: results from the first 8 years of follow-up in the EPIC-Potsdam study. Eur J Clin Nutr. 2013;67:412–9.
Wang Q, Xia W, Zhao Z, Zhang H. Effects comparison between low glycemic index diets and high glycemic index diets on HbA1c and fructosamine for patients with diabetes: a systematic review and meta-analysis. Prim Care Diabetes. 2015;9(5):362–9. https://doi.org/10.1016/j.pcd.2014.10.008. Epub 2014 Dec 16.
Wang DD, Li Y, Chiuve SE, et al. Association of specific dietary fats with total and causespecific mortality. JAMA Intern Med. 2016;176:1134–45.
Williamson DF, Thompson TJ, Thun M, Flanders D, Pamuk E, Byers T. Intentional weight loss and mortality among overweight individuals with diabetes. Diabetes Care. 2000;23(10):1499–504.
Wing RR, Phelan S. Long-term weight loss maintenance. Am J Clin Nutr. 2005;82(Suppl 1):222S–5S.
Wing RR, Bolin P, Brancati FL, et al. Look AHEAD Research Group. Cardiovascular effects of intensive lifestyle intervention in type 2 diabetes. N Engl J Med. 2013;369:145–54.