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REVIEW ARTICLE

Effect of diet on type 2 diabetes mellitus: a review

Y. M. Khazrai[1]*
G. Defeudis[1]
P. Pozzilli[1,2]

[1]*Department of Endocrinology and Diabetes, University Campus Bio Medico, Via Alvaro del Portillo 21, Rome, Italy*

[2]*Centre of Diabetes, St. Bartholomew's and The London, School of Medicine, Queen Mary University, London, UK*

*Correspondence to:
Yeganeh Manon Khazrai, Department of Endocrinology and Diabetes, University Campus Bio Medico, Via Alvaro del Portillo 21, Rome, Italy.
E-mail: m.khazrai@unicampus.it

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Abstract

Type 2 diabetes mellitus is one of the fastest growing diseases; the number of people affected by diabetes will soon reach 552 million worldwide, with associated increases in complications and healthcare expenditure. Lifestyle and medical nutrition therapy are considered the keystones of type 2 diabetes prevention and treatment, but there is no definite consensus on how to treat this disease with these therapies.

The American Diabetes Association has made several recommendations regarding the medical nutrition therapy of diabetes; these emphasize the importance of minimizing macrovascular and microvascular complications in people with diabetes. Four types of diets were reviewed for their effects on diabetes: the Mediterranean diet, a low-carbohydrate/high-protein diet, a vegan diet and a vegetarian diet.

Each of the four types of diet has been shown to improve metabolic conditions, but the degree of improvement varies from patient to patient. Therefore, it is necessary to evaluate a patient's pathophysiological characteristics in order to determine the diet that will achieve metabolic improvement in each individual.

Many dietary regimens are available for patients with type 2 diabetes to choose from, according to personal taste and cultural tradition. It is important to provide a tailor-made diet wherever possible in order to maximize the efficacy of the diet on reducing diabetes symptoms and to encourage patient adherence. Additional randomized studies, both short term (to analyse physiological responses) and long term, could help reduce the multitude of diets currently recommended and focus on a shorter list of useful regimens.

Keywords type 2 diabetes; diets; weight loss; diabetes complication

Introduction

According to the World Health Organization, type 2 diabetes mellitus is caused by the body's ineffective use of insulin [1]. Type 2 diabetes accounts for 90% of all diabetes cases, and projections for the future look grim, as the number of people affected by diabetes is expected to rise to 552 million worldwide [2], with an accompanying increase in complications and healthcare expenditures. Although lifestyle modification and medical nutrition therapy are considered the keystones of type 2 diabetes prevention and treatment, there is no definite consensus on which dietary treatment is most appropriate to control hyperglycaemia and induce long-lasting weight loss [3]. The aim of this review

is to explore whether a 'diabetes diet' can be identified, which promotes controlled blood glucose levels and reduces the risk of diabetes complications.

Diabetes diets through the ages

Dietary treatment of diabetes has been prescribed since ancient times. The oldest evidence of dietary treatment of diabetes was recorded in the Ebers Papyrus in approximately 1550 BC (Table 1), where a diet rich in carbohydrates such as wheat, grains, grapes, honey and berries was recommended [4]. Many historians attribute the name 'diabetes' to Aretaus (AD 120–200); the word comes from the Greek verb 'diabaino', meaning 'to go' or 'to run through', after one of the symptoms of diabetes: polyuria [5]. Aretaus described the disease as 'the melting down of flesh and limbs into urine'. Galen (AD 128–200) believed diabetes to be a rare condition, as he saw only a few cases in his lifetime. However, he is reported to have devised a diet based on 'sun-dried membranes from young roosters' abdomen or drinks made of a mixture of mountain copper, dry acorn, flower of the wild pomegranate, oak gall, honey of roses and cold water' to treat the condition [6]. Although Hippocrates did not mention diabetes, he is the forerunner of healthy lifestyle intervention [7], and indeed phrases such as 'walking is man's best medicine' have made it through the ages. There are reports of diabetes being mentioned by two Indian doctors, Sushruta and Charuka (400 BC), who reported the presence of sugar in urine that strongly attracted ants. They also described two types of diabetes: '…the patient suffering from the former is thin, pale, eats less and drinks too much.... The patient with the latter is usually obese, eats a lot, is stout, is of sedentary habits and sleeps too much' [8,9]. The Persian physician Avicenna (AD 980–1037) further described diabetes and recommended a diet rich in lupin, fenugreek and zedoary [9], which was thought to reduce the urinary excretion of sugar. As diabetes was considered a kidney disease, much of its treatment aimed at reducing water losses. For example, Paracelsus (1493–1541) thought that diabetes was the result of salt deposition in the kidney. In the 17th century, Thomas Willis (1621–75) introduced the term 'mellitus', as he noticed that the urine of diabetic patients was sweet, but could not explain the reason for it: '…but why it should be so wonderfully sweet, like Sugar or Honey, is a knot not easy to untie' [10]. He recommended a diet containing milk and barley-water boiled with bread. In the 18th century, Mathew Dobson (1735–1784) confirmed the presence of sugar in urine and blood. John Rollo (1799) gave two of his patients affected by diabetes a 1500-calorie diet based on rancid meat and blood pudding that was low in carbohydrate and high in fat and protein, together with medication to reduce appetite; thus, he was the first to make the association between calorie restriction and a reduction in diabetes symptoms [11]. At the beginning of the 20th century, just before the discovery of insulin, Frederick Madison Allen (1879–1964) advocated a very low-calorie diet (a 'starvation diet'), which was high in protein and fat and low in carbohydrates. A similar diet was also recommended by Elliott Proctor Joslin (1869–1962). Additionally, Joslin observed that there was a type of diabetes that affected lean people

Table 1. Timeline of diets for treating diabetes mellitus

Historical period	Author/title	Type of diet
1550 BC	Ebers Papyrus	Rich in carbohydrates such as wheat, grains, grapes, honey and berries
AD 128–200	Galen	Sun-dried membranes from young roosters' abdomen or drinks made of a mixture of mountain copper, dry acorn, flower of the wild pomegranate, oak gall, honey of roses and cold water
980–1037	Avicenna	Rich in lupin, fenugreek and zedoary
1621–75	Thomas Willis	Milk and barley-water boiled with bread
1799	John Rollo	1500-calorie diet, low in carbohydrates and high in fat and protein, based on rancid meat and blood pudding
Beginning of the 20th century	Allen, Joslin	Very low-calorie diet, called the 'starvation diet', high in protein and fat and low in carbohydrates. Contained 70% fat, 10% carbohydrate, 20% protein
1940s	American Diabetes Association	Carbohydrate content of 40%
1950	American Diabetes Association	Normal quantity of calories, comprise 43% carbohydrate, 19% protein, 37% fat
1971	American Diabetes Association	45% or more carbohydrate
1979	American Diabetes Association	50–60% carbohydrate, 12–20% protein, 20–30% fat
1986	American Diabetes Association	55–60% carbohydrate, 0.8 g/kg protein, total fat <30%
1994	American Diabetes Association	10–20% protein, <10% from saturated fat
2008	American Diabetes Association	<130 g/day carbohydrate, 14 g fibre/1000 kcal, cholesterol <200 mg/day, 20% protein

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and was not related to age, in contrast to another type that correlated with obesity and age [12]. Both Allen's and Joslin's diets consisted of 70% fat, 10% carbohydrate and 20% protein [13]. These starvation diets were best endured by adults rather than by children, and were prescribed long after the discovery of insulin, as this was scarce and difficult to obtain at this time [13]. However, as time went on, it became evident that starvation diets were difficult to follow and caused problems such as a lack of energy and hypoglycaemia, as well as stunting the growth of children. With the introduction of insulin therapy, diets with higher carbohydrate content were proposed, and some doctors went as far as recommending 'free diets', with no carbohydrate restriction; however, as time went by, it was evident that although children did not die from starvation, they did continue to die from metabolic and cardiovascular complications [13]. In the 1940s, the American Diabetes Association (ADA) advised restricting carbohydrate content in the diet to 40% to improve glycemic control. Around the same time, in 1935, Himsworth identified two types of diabetes, thus opening the door to new types of diabetes treatment [14]. In the early 1970s, the ADA endorsed the use of individualized (but still prescriptive) diets, amending these recommendations in the 1980s to allow the inclusion of small amounts of sucrose and other refined sugars in the diet. In 2002, the ADA issued evidence-based recommendations, which have been revised and released yearly since then. Similar dietary guidelines have been supplied by other diabetes organizations, such as the Diabetes Nutrition Study Group of the European Association of the Study of Diabetes and Diabetes UK. All dietary guidelines recommend weight reduction and physical activity, as studies such as the Diabetes Prevention Program have shown that a healthy lifestyle reduces insulin resistance and glycaemia [15].

Diabetes medical nutrition therapy according to the American Diabetes Association

The ADA publications 'Nutrition Recommendations and Interventions for Diabetes' in 2008 [16] and 'Standards of Medical Care in Diabetes' in 2013 [17,18] emphasized that the initial evaluation of people newly diagnosed with diabetes is limited to the analysis of their eating patterns, nutritional status and weight history. On this particular point, there are several recommendations for medical nutrition therapy. In general, individuals who have diabetes or prediabetes (i.e. patients with impaired fasting glucose, impaired glucose tolerance or glycosylated haemoglobin [HbA_{1C}] level of 5.7–6.4%) should be made aware of beneficial nutrition interventions, along with their healthcare providers. Patients should receive individualized medical nutrition therapy as needed to achieve treatment goals. Therefore, medical nutrition therapy plays a role at three levels: in primary prevention, interventions are aimed at delaying or arresting the development of diabetes; in secondary and tertiary prevention, medical nutrition therapy is used to try and prevent or control the complications of diabetes, respectively.

In patients with diabetes, medical nutrition therapy should help a patient to achieve and maintain normal blood glucose levels and a lipid/lipoprotein profile, as well as blood pressure levels in the normal range or as close to normal as is safely possible. A patient's personal food preferences should be taken into account when formulating a medical nutrition therapy, in order to maintain the pleasure of eating, thus creating a tailor-made diet.

Weight loss is recommended for all overweight or obese individuals who have, or are at risk of developing, diabetes. In fact, modest weight loss has been shown to improve insulin resistance, so either a low-carbohydrate, low-fat calorie-restricted diet or a Mediterranean diet may be effective in the short term (up to two years), coupled with the monitoring of lipid profiles and renal function.

For carbohydrates in particular, the ADA encourages a reduction so as to achieve a lowering of postprandial glucose. The quantity of carbohydrate ingested is usually the biggest determinant of postprandial response, but the type of carbohydrate also affects this response, as specified by the type of food ingested (type of starch, ripeness of food, degree of processing, and style of preparation) [16]. Increased fibre intake appears to be beneficial for people with diabetes, with dietary intake goals of 14 g/1,000 kcal being recommended [19]. Sugar alcohols and non-nutritive sweeteners, when consumed within the daily intake range, can be considered safe for inclusion in a medical nutrition therapy diet [16].

Recommendations on fat consumption state that saturated fat should make up less than 7% of the total calories in the diet and intake of trans-fatty acids should be reduced. There is also a recommendation to consume less than 200 mg/day of cholesterol and to have two or more servings of fish (with the exception of commercially fried fish fillets) [20,21] per week to increase n-3 polyunsaturated fatty acid intake; consumption of n-3 fatty acids from fish or from food supplements has been shown to reduce adverse coronary heart disease outcomes [22].

The ADA recommends that people with diabetes should consume protein amounting to no more than 15–20% of the energy intake to maintain normal renal function. The recommended daily allowance is 0.8 g good quality protein, defined as having high protein digestibility corrected amino acid scoring pattern scores, and providing all nine essential amino acids, per kilogram body

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weight per day (on average, 10% of total calories) [23]. Limiting protein intake for patients with diabetes to no more than 20% of energy intake could be an important way of controlling renal function. Furthermore, dietary protein can improve insulin response without increasing plasma glucose concentrations [24,25].

Routine dietary supplementation with antioxidants, such as vitamins C and E, and carotene, is not advised because long-term safety knowledge is currently lacking.

The ADA also provides some recommendations on lifestyle and physical activity. Physical activity is strongly encouraged for patients with type 2 diabetes because many patients are overweight, are insulin resistant and have dyslipidemia and hypertension, all of which can be improved with exercise. Trying to reduce saturated fatty acids and cholesterol by improving exercise training and reducing energy intake could be helpful.

Obese older adults have been shown to benefit from specific dietary intervention: a goal of gaining or losing >10 lb or 10% of body weight in <6 months should be addressed when considering medical nutrition therapy [24,26,27]. Moderate energy restriction (with a daily multivitamin supplement if appropriate) and an increase in physical activity could decrease body mass and central adiposity and improve insulin sensitivity. Caution should be taken in patients receiving insulin or insulin secretagogues as they are at elevated risk of hypoglycaemic episodes.

For tertiary prevention, the ADA recommends that a reduction in dietary protein intake to 0.8–1.0 g per kilogram body weight per day in individuals in the early stages of chronic kidney disease and to 0.8 g per kilogram body weight per day in patients in the later stages of chronic kidney disease, may improve measures of renal function in patients with microvascular complications. A reduction in dietary protein may also have positive effects on cardiovascular risk factors [16]. Patients at risk for cardiovascular disease are advised to consume diets high in fruits, vegetables, whole grains and nuts, which may reduce their risk further [16]. In patients with symptomatic heart failure, a dietary sodium intake of <2000 mg per day is strongly recommended, to reduce the symptoms of this condition [16].

Types of diets

The Mediterranean diet

The Mediterranean diet was designated an Intangible Cultural Heritage of Humanity by UNESCO in 2010 and reflects dietary habits in the Mediterranean region. The Mediterranean diet is rich in whole grains, legumes, vegetables, fruits and monounsaturated fatty acids (such as those found in olive oil), with limited amounts of poultry, fish, dairy, red wine and (even more rarely) red meat [28]. The beneficial effects of this diet were acknowledged by Keys *et al*. in the 1960s, when he demonstrated a positive correlation between consumption of a Mediterranean diet and the prevention of heart disease [29]. Further studies have brought to light positive effects of the diet on weight control and type 2 diabetes [30,31].

Shai *et al*. (Table 2) conducted a 2-year randomized controlled dietary intervention, the Dietary Intervention Randomized Controlled Trial (DIRECT), to compare three types of diets: low fat, low carbohydrate and Mediterranean. The study population, consisting of 322 adults with a mean body mass index of 31 kg/m^2 and either type 2 diabetes or coronary heart disease, was randomly assigned to one of the three diet groups [32]. Both the Mediterranean and low-carbohydrate diets proved to be more effective than the low-fat diet for weight loss, with the Mediterranean diet causing a significant decrease in C-reactive protein ($p < 0.05$) and fasting plasma glucose levels, and insulin resistance ($p < 0.001$) at 24 months. The authors observed that the Mediterranean diet was more effective in terms of weight loss and leptin levels in women than in men and thus recommended further investigation of these issues. The study findings were limited, however, by the fact that more men (86%) were enrolled than women.

Studies have also shown positive effects of the Mediterranean diet on glycemic control [32–35]. Recently, a review and meta-analysis by Ajala *et al*. [3] of studies on various diets such as low-carbohydrate, Mediterranean, high-protein and low glycemic index diets found that the Mediterranean diet was the only one to significantly reduce weight as well as being the most effective in lowering glycemic levels and triglycerides in the blood. The beneficial effects of the Mediterranean diet were also evidenced in a review by Esposito *et al*. [33], where it was shown that patients who followed this type of diet had better glycemic control and less insulin resistance than patients in the control group. Positive effects on cardiovascular disease have been ascribed to its high content in monounsaturated fatty acids compared with saturated fatty acids [34].

A study by Elhayany *et al*. [35] evaluated the effects of three different diets on the reduction of fasting plasma glucose, HbA_{1c} and triglycerides. A total of 259 patients with type 2 diabetes and a mean body mass index of 31 kg/m^2 were randomly assigned to either a low-carbohydrate content Mediterranean (LCM) diet or a traditional Mediterranean (TM) diet or the 2003 ADA diet for a year.

After 12 months, there was a weight loss of 7.7 kg for ADA diet, 7.4 kg for TM diet and 10.1 kg for LCM diet.

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Table 2. Summary of trials on dietary control of type 2 diabetes mellitus

Reference	Participants	Number of participants	Intervention	Duration	Relevant variables	Significant outcome measures
			Low carbohydrate compared with other diets			
Westman *et al.*, 2008 [63]	Obese adults with type 2 diabetes	97 (50 completed trial)	Low-carbohydrate diet: 13% carbohydrates, 28% protein, 59% fat, versus control diet (low GI): 44% carbohydrates, 20% protein, 36% fat	6 months	Body weight, HbA_{1c}, fasting plasma glucose, lipids	Higher weight loss (24.2 kg) and high-density lipoprotein cholesterol (+0.14 mmol/L), lower HbA1c (by 21%)
Elhayany *et al.*, 2010a [35]	Overweight adults with type 2 diabetes	174 (124 completed trial)	Low-carbohydrate diet (Mediterranean) : 35% low glycemic index carbohydrates, 45% fat rich in monounsaturated fatty acids,15–20% protein, versus traditional Mediterranean diet: 50–55% low glycemic index carbohydrates, 30% fat rich in monounsaturated fatty acids, 15–20% protein	1 year	Body weight, HbA_{1c}, lipids	Weight loss of 7.4 kg for TM and 10.1 kg for LCM diets. Cholesterol increased (0.1 mmol/L ± 0.02) only on the LCM ($p < 0.002$). The reduction in serum Tg was greater in the LCM (−1.3 mmol/L) and TM (−1.5 mmol/L) than in the ADA (−0.7 mmol/L), $p = 0.001$
			Vegan and vegetarian compared with other diets			
Barnard *et al.*, 2009 [65]	Overweight adults with type 2 diabetes	99	Vegan diet: 10% fat, 15% protein, 75% carbohydrates, versus control diet (American Diabetes Association): 15–20% protein, 60–70% carbohydrates and monounsaturated fatty acids	74 weeks	Body weight, lipids, HbA_{1c}	Lower total cholesterol (20.53 compared with 20.18 mmol/L), low density lipoprotein cholesterol (20.35 compared with 20.09 mmol/L), and HbA_{1c} (20.4% compared with 0.01%)
			Mediterranean compared with other diets			
Esposito *et al.*, 2009 [46]	Overweight adults with newly diagnosed type 2 diabetes cross-sectional study	215	Mediterranean diet: 50% of energy from carbohydrates, rich in vegetables and whole grains, and low in red meat	4 years (results at 1 year used for meta-analysis)	Time to introduction of antidiabetic medication, body weight, fasting plasma glucose, HbA_{1c}, lipids	Fewer patients needed antidiabetic medication at 4 years (44% compared with 70%)
Elhayany *et al.*, 2010b [35]	Overweight adults with type 2 diabetes	174 (118 completed trial)	Mediterranean diet: 50–55% Low glycemic index carbohydrates, 30% fat rich in monounsaturated fatty acids, 15–20% protein, versus Control diet (American Diabetes Association): 15–20%	1 year	Weight, fasting plasma glucose, HbA_{1c}, lipids	Weight loss of 7.7 kg for ADA, 7.4 kg for TM. Lower triglycerides (20.58 mmol/L) Reduction in HbA1c was significantly greater in the LCM diet than in the ADA diet (−2.0 and −1.6%, respectively, $p < 0.022$). The reduction in serum Tg was

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			protein, 7% saturated fat, 60–70% carbohydrates			greater in the LCM (−1.3 mmol/L) and TM (−1.5 mmol/L) than in the ADA (−0.7 mmol/L), $p = 0.001$.
			High protein compared with other diets			
Larsen *et al.*, 2011 [58]	Overweight/ obese adults with type 2 diabetes	108 (99 completed trial)	High-protein diet: 26.5% protein, 45% carbohydrates, 31% fat, versus control diet (high in carbohydrates): 19% protein, 48% carbohydrates, 32% fat	1 year	Weight, lipids, HbA_{1c}	No evidence of superior benefit in either diet.
			Low fat, high protein compared with low-fat, high-carbohydrate diets			
Krebs *et al.*, 2012 [59]	Overweight/obese adults with type 2 diabetes	419 (294 completed trial)	High-protein diet: 30% protein, 40% carbohydrate, 30% fat High-carbohydrate diet: 15% protein, 55% carbohydrate, 30% fat	2 years	Body weight, waist circumference, HbA1c, lipids, blood pressure, renal function	No significant difference in any measured variables
			Low-fat, low-carbohydrate and Mediterranean diets			
Shai *et al.*, 2008 [32]	Obese patients affected either with type 2 diabetes or coronary heart disease	322	Low-fat, restricted calorie diet: 1500 kcal per day for women and 1800 kcal per day for men, 30% fat, 10% saturated fat, Mediterranean diet: 1500 kcal per day for women and 1800 kcal per day for men, <35% fat. Low-carbohydrate diet: non-restricted calorie, protein and fat, 20 g of carbohydrates per day for 2 months, with a gradual increase to a maximum of 120 g per day.	24 months	HbA1c, insulin resistance, body weight	Both Mediterranean and low-carbohydrate diets proved to be more effective for weight loss

LCM, low-carbohydrate content Mediterranean; TM, traditional Mediterranean; ADA, American Diabetes Association.

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The reduction in HbA1c was significantly greater in the LCM diet than in the ADA diet (−2.0% and −1.6%, respectively, $p < 0.022$). HDL cholesterol increased (0.1 mmol/L ± 0.02) only on the LCM ($p < 0.002$). The reduction in serum Tg was greater in the LCM (−1.3 mmol/L) and TM (−1.5 mmol/L) than in the ADA (−0.7 mmol/L), $p = 0.001$ (Table 2).

The beneficial effects of the Mediterranean diet on diabetes and obesity have been shown in several reviews [29–36]. The protective effects of its main components (e.g. olive oil) on cardiovascular disease have long been documented and were recently reaffirmed by Estruch *et al*. [37]. Olive oil and other ingredients of the Mediterranean diet, such as red wine, fruits and vegetables, have anti-inflammatory properties due to the presence of phenolic compounds [38]. Moreover, both olive oil (rich in monounsaturated fatty acids) and oily fish such as sardines (rich in n-3 fatty acids) increase adiponectin levels, which correlate with insulin sensitivity [39–41].

Another important component of the Mediterranean diet is dietary fibre, which helps increase satiety levels and thus reduce calorie intake [31,42,43], as well as having other positive effects such as improving postprandial glycaemia and lowering HbA_{1c}, which would not be expected in a diet so rich in carbohydrate [44–49]. All the nutritional characteristics mentioned above, as well as its palatability, make the Mediterranean dietary pattern a good choice for patients with type 2 diabetes, as long as it is accompanied by physical activity in order to keep control of its high energy content [50].

Low-carbohydrate, high-protein diets

The rationale for low-carbohydrate diets in patients with type 2 diabetes is that blood glucose increases as a result of carbohydrate ingestion; thus, a low-carbohydrate diet lowers glycemic and insulin levels, causing an increase in circulating fatty acids that can be used as energy by the body, with the production of ketone bodies. This turns into rapid weight loss and increased satiety [51]. Critics of this type of diet argue that less carbohydrate usually results in an increase in the proportion of saturated fatty acids in the diet, with associated negative effects on cardiovascular disease [52]. However, researchers such as Westman and Vernon [53] have suggested that low-carbohydrate diets lower glycaemia, reducing the need for medication that, in turn, decreases the risk of hypoglycaemia (correlated with a high risk of morbidity and mortality), which favours weight loss.

An important issue is to standardize what is defined as a low-carbohydrate diet [54–56]. Accurso *et al*. [55], for example, accepted the ADA's definition that a low-carbohydrate diet contains less than 130 g carbohydrate per day (i.e. 26% of 2000 kcal diet as carbohydrate); they consider a diet with 45–26% of total energy as carbohydrate to be a moderate carbohydrate diet. A diet containing 30 g carbohydrate daily is considered a very low-carbohydrate ketogenic diet. According to Wheeler *et al*. [56], 30–40% of calories as carbohydrate are indicative of a moderate-to-low carbohydrate diet, whereas a very low-carbohydrate diet contains 21–70 g of carbohydrate per day.

Studies on the efficacy of low-carbohydrate diets in subjects with type 2 diabetes have mainly been short term and with small population sizes, although benefits have been reported, especially on weight loss [57]. However, Larsen *et al*. recently studied two groups of adults with type 2 diabetes for 1 year. One group of 53 individuals was randomized to a diet high in protein (30% of total energy intake) and low glycemic index carbohydrate (40% of total energy), whereas a group of 46 individuals were assigned to a diet with 15% energy intake from protein and 55% energy from low glycemic index carbohydrate (Table 2). At the end of the intervention period, there were no significant differences between the two groups in terms of weight loss, serum triacylglycerol, total cholesterol and high-density lipoprotein cholesterol levels, blood pressure and renal function [58].

Similarly, Krebs *et al*. [59] compared a low-fat, high-protein diet (total energy comprised 30% from protein, 40% from carbohydrate and 30% from fat) to a low-fat, high-carbohydrate diet (total energy comprised 15% from protein, 55% from carbohydrate and 30% from fat) (Table 2). A total of 419 adults with type 2 diabetes were blindly randomized to either diet. After 1 year, 70% of the initial participants had completed the study, but there were no significant differences between the two groups in terms of weight loss (average of 2–3 kg), waist circumference reduction (average of 2–3 cm), HbA_{1c}, renal function and cholesterol. A meta-analysis of randomized controlled trials published in 2012 [60] concluded that there was no great difference in terms of weight loss between a low-carbohydrate diet high in protein and an isocaloric diet with moderate protein.

The benefits of ketogenic diets on glycemic control were recently reviewed by Paoli *et al*. [61]. A majority of studies claimed an improvement in glycemic control and a reduction in medication with this diet [62,63]. However, studies on ketogenic diets are few, and this area requires further investigation.

Vegetarian and vegan diets

Vegetarian and vegan diets appear to improve weight loss and metabolic control in patients with type 2 diabetes.

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This is ascribed to a higher consumption of low glycemic index food rich in fibre; the typically lower saturated fatty acid content of these diets is associated with improvements in plasma lipids [64]. This has been demonstrated by Barnard *et al*. [65] in a study in which 99 patients with type 2 diabetes were randomized to either a low-fat vegan diet (15% energy from protein [i.e. legumes], 75% energy from low glycemic index carbohydrate such as vegetables and legumes, 10% energy from fat) or to a conventional ADA diabetes diet (15–20% energy from protein, 60–70% energy from monounsaturated fatty acids and carbohydrate, and <7% energy from saturated fatty acids.). After 74 weeks, individuals on both diets had lost weight, with no significant differences between the two groups. However, the vegan diet group experienced greater improvements in glycaemia and plasma lipids than those in the conventional diet group. A larger multicenter study has recently confirmed these data following 18 weeks of dietary intervention in employees of a major US company, located throughout the US [66].

According to Trapp and Barnard [67], vegetarian and vegan diets should be considered for the treatment of patients with type 2 diabetes, whereas Orlich *et al*. [68] found reduced mortality from a vegetarian diet in male participants of a prospective cohort study involving 96 469 Seventh-day Adventist men and women recruited between 2002 and 2007. The benefits of vegetarian and vegan diets for healthy nutrition and the treatment of chronic diseases have also been confirmed by the ADA [69].

Conclusion

Different types of diets have been shown to be associated with improvements in metabolic conditions, and as Ajala *et al*. [3] concluded in their review, patients with type 2 diabetes can choose from many beneficial dietary regimens according to their personal tastes and cultural traditions. Obesity is considered a major risk factor for type 2 diabetes and cardiovascular disease, and many studies suggest that weight management is the most important therapeutic tool for patients with type 2 diabetes, although complete remission of the disease is not possible following weight loss [70,71]. However, the relationship between obesity and type 2 diabetes is controversial, and in 2011, an international working group of experts in the pathophysiology, genetics, clinical trials and clinical care of patients with obesity and type 2 diabetes participated in a conference held by the Endocrine Society, the ADA and the European Association for the Study of Diabetes. Researchers agreed that the relationship between obesity and type 2 diabetes needs more in-depth analysis, as some questions remain unanswered, such as why not all obese patients develop diabetes and what is the pathogenic mechanism linking the two conditions [72]. Moreover, the Look AHEAD (Action for Health in Diabetes) clinical trial was recently stopped before completion by the funding body (US National Institutes of Health) as it failed to show that intensive lifestyle intervention was useful in reducing cardiovascular events in patients with type 2 diabetes, although the study group (lifestyle intervention) lost more weight and exercised more than the control group (health practitioner advice only) [73]. There is a need to improve the quality of randomized studies in the short term, to include assessment of the psychological aspects involved in whether a patient can reach their targets or not, and increase the number of long-term studies (between 1 and 5 years) to accurately assess the benefits of various diets on the symptoms of type 2 diabetes.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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