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RESEARCH

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Comparison of different diet plans on patients with type 2 diabetes

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Abstract

Background Obesity and diabetes are interrelated growing problems worldwide. Life style modifications including nutritional intervention are considered the first line in management of diabetes.

Materials and methods Our study included 81 type 2 diabetic patients, all treated with Metformin 500 mg twice daily, with Body mass index (BMI) more than 25 kg/m^2. They were randomized to one of three dietary interventions; high protein diet (Zone diet), high fat diet (Modified Atkins) and conventional high carbohydrates diet with consideration of being on a caloric deficit diet of 500 kcal per day. Patients were assessed by: body mass index, waist circumference and bioelectrical impedance analysis (BIA) method for assessment of body fat and muscle mass (FM, MM) before and after 12 weeks of following a dietary plan. Laboratory tests included: Hemoglobin A1c, C-reactive protein levels, lipid profile and insulin resistance before and after 12 weeks of following a dietary plan.

Results Significant weight loss and reduction of BMI, reduction of waist circumference, significant fat mass reduction, significant muscle mass reduction, improvement of the insulin resistance, LDL and triglyceride reduction was achieved by the three dietary plans, with no significant difference between them. There was also significant improvement in HbA1c in all dietary plans; however Modified Atkins diet showed more significant improvement. Significant HDL improvement was seen with High carbohydrate diet and Modified Atkins diet, with more significant reduction with Modified Atkins diet, while Zone diet did not show significant improvement. CRP marker of inflammation showed significant improvement with High carbohydrate diet and Modified Atkins diet, while Zone diet did not show significant improvement.

Conclusion All three dietary plans show benefit and improve the anthropometric and metabolic outcomes of type 2 diabetic patients. Modified Atkins diet showed superior benefit as regards improvement of HbA1c, HDL and CRP in comparison to the other dietary plans.

Keywords Type II diabetes, Dietary plans, Obesity

Introduction

Obesity and diabetes are an interrelated growing problem worldwide [1]. Obesity is a well-known cause for development of insulin resistance, which can be a direct cause of type 2 diabetes [2]. Theories about development of insulin resistance include; Genetic predisposition, aging, sedentary lifestyle, central obesity, hyperinsulinemia, fatty liver, inflammation, lipotoxicity, endoplasmic reticulum stress, oxidative stress and mitochondrial dysfunction [3].

Life style modifications including nutritional intervention are considered the first line in management of diabetes [4]. Many studies conducted in the past 20 years have shown the benefits of the Mediterranean lifestyle for people with, or at risk of developing, type 2 diabetes mellitus. The philosophy of the Mediterranean diet consists of

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eating more legumes, vegetables, fruits, nuts, wholegrain foods, fish and olive oil. However, despite the large body of evidence, concerns exist amongst scientists regarding the reliability of the data related to this topic [5].

Lower carbohydrates, higher fat or higher protein dietary approaches have become more popular, with some studies promoting more reduction in body weight, insulin resistance, body inflammation and dyslipidemia [6].

Zone diet includes approximately 40% of the calories from low glycemic index carbohydrates, 30% of calories from proteins and 30% of calories from fats, which originated mainly from the theory of reduction of inflammation through manipulation of insulin/glucagon axis and eicosanoids [7].

Modified Atkins diet (MAD) stimulates the body to enter a metabolic state of ketosis. However, it is less worrisome and more appealing than the normal Ketogenic diet. It includes approximately 65% of the calories from fat sources, 10% from carbohydrates and 25% from proteins [8]. In comparison to traditional ketogenic diet; MAD fat to carbohydrate and protein ratio is 1:1 eg. 1 g of fat for every 1 g of combined carbohydrate + protein, meanwhile traditional ketogenic diet fat to carbohydrate ratio is 4:1.

Accordingly, we designed this study to compare traditional high carbohydrate diet to zone and modified Atkins diet and to observe their effect on weight loss, body composition, insulin resistance, inflammation, HbA1c and lipid profile in T2 diabetic patients.

Materials and methods

We conducted a prospective study in the Diabetes and Endocrinology Outpatient Clinic of Cairo University from November 2021 to August 2022 to compare the effect of different dietary plans on type 2 diabetic patients. The study is a randomized clinical trial, designed to compare traditional high carbohydrate diet to zone and modified Atkins diet and to observe their effect on weight loss, body composition, insulin resistance, inflammation, Hemoglobin A1c (HbA1c) and lipid profile. Participants were randomized in a nearly 1:1:1 ratio to the three dietary interventions. Randomization was performed by computer generated random numbers provided by independent biostatistician. Participants were not blinded (open label).

Eighty-one patients included 12 males and 69 females were recruited from the Diabetes and Endocrinology outpatient clinic of Kasr Alainy hospital. Any adult with type 2 diabetes with BMI > 25 kg/m^2, normal liver and kidney functions and age from 40 to 73 year was eligible for inclusion in the current study, while patients with Type 1 diabetes mellitus, BMI < 25 kg/m^2, chronic renal failure, liver cirrhosis, moderate or severe dyslipidemia, cancer or other chronic diseases or comorbidities were excluded.

All patients received the same pharmacological treatment in the form of Metformin 500 mg twice daily after their main meals. All patients signed a written informed consent after detailed explanation of study procedure, expected risks, and anticipated benefits. The 81 patients included 12 males and 69 females, who were randomised to one of three dietary interventions (27 patients each) for 12 weeks;

- High protein diet (zone diet); which consists of 40% carbohydrates, 30% proteins and 30% fats.
- High fat diet, (modified Atkins); which consists of 65% fat, 25% proteins and 10% carbohydrates.
- Conventional high carbohydrates diet which consists of 45–60% carbohydrates, 10–35% proteins and 20–35%fats.

There was a consideration of being on caloric deficit diet of 500 kcal per day by using Mifflin-st jeor equation to calculate resting metabolic rate (RMR) which is then multiplied by a factor according to level of activity which can range from 1.38 in the most sedentary to 2.5 in very active individuals, thus calculating the total daily energy needs and then subtracting 500 to achieve a calorie deficit [9]. Patients were not advised to exercise or increase their physical activity.

Measurement of RMR was done using Mifflin-St Jeor Equation

$$\textbf{For men}: \mathrm{RMR} = (10\mathrm{XW}) + (6.25\mathrm{XH}) - (5\mathrm{XA}) + 5$$

$$\textbf{For women}: \mathrm{RMR} = (10\mathrm{XW}) + (6.25\mathrm{XH}) - (5\mathrm{XA}) - 161$$

Where: W is body weight in kg, H is body height in cm and A is age [8].

Patients had to attend an initial visit and then monthly visits to assess compliance to dietary plan with the final 4th visit after 12 weeks from the initial visit. On the 1st visit all patients were subjected to detailed history taking and clinical examination included height, weight and BMI, waist circumference (WC), fat mass (FM) and muscle mass (MM) by BIA and Calculated total daily energy expenditure. Fasting blood samples for Homeostasis model assessment of insulin resistance (HOMA-IR), HbA1c, Serum cholesterol, high density lipoprotein (HDL), low density lipoprotein (LDL), Triglycerides and C-reactive protein (CRP) were withdrawn. On the 2nd and 3rd visit, which were each 4 weeks apart, detailed clinical examination was done and the dietary plan of the

patients was checked for compliance and reviewed. Any concerns of the patients were addressed during the visit. On the 4th visit Patients came to follow-up anthropometric measurements and withdraw laboratory tests again to compare the outcome with the initially recorded data. All patients completed the 12 weeks and came to the 4th visit, with no withdrawal of any case from the study.

As regards the anthropometric measures height was measured using a validated stadiometer. The procedure was explained to the patients and they were told to stand barefoot with relaxed shoulders and with adherent scapulae, buttocks and heels to the wall and were positioned accurately below the stadiometer [10]. Multi-Frequency Bioelectrical Impedance (MF-BIA) is used to measure weight, fat mass and muscle mass [11]. The MF-BIA test starts with wiping hands and feet before the procedure followed by stepping onto the BIA and alignment of feet with the foot electrodes. The patient's weight will be automatically measured, which is followed by data entry (height, and age), and then grabbing the handles with both hands and placing thumbs on the oval electrodes. Keeping a steady posture during the device analysis with arms straight and keeping a 45-degree angle away from body [12].

As regards HbA1c, normal level is considered below 5.7% percent, prediabetes ranges from 5.7% to 6.4% and diabetes from 6.5% and above [13]. As regards fasting Lipids including Cholesterol, LDL, HDL and Triglycerides, the optimal level for each of the four standard tests in a lipid panel are as follows: Total cholesterol: Below 200 mg/dL, (HDL) cholesterol: Above 60 mg/dL, (LDL) cholesterol: Below 100 mg/dL (For people who have diabetes: Below 70 mg/dL), Triglycerides: Below 150 mg/dL [14].

CRP is an acute phase protein released in response to tissue-damaging processes such as infections, inflammation and malignant neoplasms. In most healthy adults CRP levels are below 0.3 mg/dL [15].

Ethical approval and consent to participate: study protocol and informed consent were submitted for Institutional Review Board and Ethical Committee at the internal medicine department of Cairo University and approval was granted on 10.4.2022 with the acceptance Code: MS-610 -2021.

Sample size

Randomized clinical trial aiming to assess the effect of different dietary intervention on body weight. Based on [16, 17] which reported large effect size. So, we will need to study 21 participant per group, it will be compensated by 15% due to the use of nonparametric tests so the final sample size will be 25 subject per group, (total sample size 75) to be able to reject the null hypothesis with probability (power) 0.80. The Type I error probability associated with test of this null hypothesis is 0.05. Sample size was calculated using G power program (version 3.1.9.2) [18].

Statistical methods

We analyzed the data using statistical package for social sciences (SPSS) version 24 software for windows. Qualitative data was described in terms of frequencies and percentages. Quantitative data was described in terms of mean and standard deviations if normally distributed and median and interquartile ranges if non parametric. Kolmogrov-Semornov test was used to assess the normality of distribution of numerical variables. Chi square test was used to assess the association between categorical variables. Fissure exact test was used in case of violation of the assumptions. ANOVA was used to test the difference of numerical variables between more than 3 groups. Paired Sample T test was used to test the association between paired parametric numerical variables. *P* values less than 0.05 was considered statistically significant.

Results

A full set analysis was formed of 81 type 2 diabetic patients. Their mean age was 53.1 ± 7.3 years old. 85.2% of patients (69 patients) were females while 14.8% of patients (12 patients) were males. Their mean height was 166.56 ± 4.79 cm, mean weight was 92.61 ± 12.59 kg, mean BMI was 33.43 ± 4.94 kg/m^2 and average waist circumference was 125.9 ± 11.88 cm. Their mean FM was 45.56 ± 8.39 kg, while mean MM was 26.06 ± 3.99 kg.

Routine labs were performed for all included patients during their 1st visit and showed a mean HbA1c of 7.79 ± 1.18%. Their mean cholesterol levels were 181.4 ± 38.15 mg/dl, mean HDL serum levels were 40.13 ± 10.79 mg/dl, mean LDL serum levels were 110.6 ± 31.1 mg/dl and their mean triglyceride levels were 153.3 ± 65.5 mg/dl.

As regards their mean CRP levels, they were 10.44 ± 1.19 mg/l and their mean HOMA-IR was 6.57 ± 3.33.

All patients were randomized to participate in one of 3 groups: Group 1 (27 patients): Conventional high carbohydrates diet (HC group); Group 2 (27 patients): High protein diet (zone diet) (ZD group) and Group 3 (27 patients): High fat diet, (Modified Atkins) (HF group);

Concerning patients in the HC group, we found that

There was a significant decrease in patients' weight from 95.72 ± 13.11 kg to 91.67 ± 12.65 kg ($p < 0.001$). Also, there was a significant reduction in waist circumference from 130.33 ± 13.61 to 127.08 ± 13.18 cm ($P < 0.001$). Similarly, we found a significant decrease in the BMI

among patients in this group from 34.37 ± 5.49 kg/m^2 to 32.92 ± 5.28 kg/m^2 ($p < 0.001$), in addition to a significant decrease in FM and MM mean levels ($p < 0.001$ for both).

Moreover, HbA1c was significantly reduced from 7.57 ± 1.4 to 7.19 ± 1.34% ($p < 0.001$). We found a significant decrease in HOMA-IR mean, Cholesterol, LDL and triglycerides mean with $P < 0.001$ for all. In addition to this, there was a significant improvement in HDL mean levels among patients in this groups ($p = 0.008$). As regards CRP, there was a significant reduction among patients in this group from 10.9 ± 8.83 mg/l to 9.66 ± 7.58 mg/l ($p = 0.012$) (Table 1).

Concerning patients in the ZD group, we found that

There was a significant decrease in patients' weight from 87.17 ± 9.97 kg to 83.03 ± 9.55 kg ($p < 0.001$) and in waist circumference from 121.81 ± 9.63 to 118.57 ± 9.28 cm ($P < 0.001$). Similarly, we found a significant decrease in the BMI among patients in this group from 31.62 ± 3.38 kg/m^2 to 30.14 ± 3.28 kg/m^2 ($p < 0.001$). We also noticed a significant decrease in FM and MM mean levels ($p < 0.001$for both).

HbA1c was significantly reduced from 7.87 ± 1.11 to 7.48 ± 1.12% mg/dl among patients in this group ($p < 0.001$). Concerning insulin resistance, we found a significant decrease in HOMA-IR mean level ($p < 0.001$). In addition to that, the lipid profile showed significant reduction of Cholesterol, LDL and triglycerides ($p < 0.001$ for all). On the other hand, there was a slight improvement in HDL mean levels among patients in this group, however this was statistically insignificant ($p = 0.304$). We found a slight reduction in CRP levels from among patients in this group from 11.35 ± 3.46 mg/l to 8.86 ± 5.83 mg/l which was not statistically significant ($p = 0.057$) (Table 2).

Concerning patients in the MAD group, we found that

There was a significant decrease in patients' weight from 94.94 ± 13.04 kg to 90.55 ± 12.99 kg ($p < 0.001$). Also, a significant reduction in waist circumference from 125.56 ± 10.89 to 122.49 ± 10.62 cm ($P < 0.001$) was noticed. Similarly, we found a significant decrease in the BMI among patients in this group from 34.31 ± 5.33 kg/m^2 to 32.78 ± 5.27 kg/m^2 ($p < 0.001$). We also observed a significant decrease in FM and MM mean levels post treatment ($p < 0.001$, $p < 0.001$ respectively).

Also, HbA1c was significantly reduced from 7.92 ± 0.94 to 7.34 ± 0.82% among patients in this group ($p < 0.001$).

Table 1 The difference between pre and post dietary plan anthropometric and laboratory findings among patients in HC group ($n = 27$)

Variable	Pre dietary plan ($N = 27$)	Post dietary plan ($N = 27$)	Mean difference 95% CI	*P* value
Weight (kg)	95.72 ± 13.11	91.67 ± 12.65	4.04 ± 0.94 3.67 – 4.42	< 0.001 P
Waist circumference (cm)	130.33 ± 13.61	127.08 ± 13.18	3.25 ± 0.99 2.86 – 3.64	< 0.001 P
BMI (kg/m^2)	34.37 ± 5.49	32.92 ± 5.28	1.45 ± 0.36 1.31 – 1.59	< 0.001 P
HbA1c (%)	7.57 ± 1.4	7.19 ± 1.34	0.39 ± 0.19 0.31 – 0.46	< 0.001 P
Cholesterol (mg/dL)	182.1 ± 39.81	178.68 ± 38.91	3.42 ± 2.41 2.47 – 4.38	< 0.001 P
HDL (mg/dL)	39.1 ± 11.49	39.4 ± 11.24	-0.27 ± 0.49 -0.47—-0.08	0.008 P
LDL (mg/dL)	110.04 ± 32.61	107.41 ± 31.83	2.63 ± 1.7 1.56 – 3.69	< 0.001 P
Triglycerides (mg/dL)	164.8 ± 82.12	156.64 ± 79.03	8.16 ± 4.75 6.28 – 10.04	< 0.001 P
CRP (mg/l)	10.9 ± 8.83	9.66 ± 7.58	1.29 ± 0.48 0.3 – 2.27	0.012 P
FM (kg)	47.59 ± 9.7	44.63 ± 9.32	2.96 ± 0.79 2.64 – 3.27	< 0.001 P
MM (kg)	26.97 ± 3.05	26.74 ± 3.06	0.23 ± 0.13 0.18 – 0.29	< 0.001 P
HOMA-IR	6.29 ± 4.65	5.9 ± 3.46	0.39 ± 0.27 0.29 – 0.5	< 0.001 P

BMI Body mass index, *HbA1c* Heamoglobin A1c, *HDL* High density lipoprotein, *LDL* Low density lipoprotein, *CRP* C reactive protein, *FM* Fat mass, *MM* Muscle mass, *HOMA-IR* Homeostasis model assessment of insulin resistance, *P* Paired sample T test

Table 2 The difference between pre and post dietary plan anthropometric and laboratory findings among patients in ZD group ($n=27$)

Variable	Pre dietary plan ($N=27$)	Post dietary plan ($N=27$)	Mean difference 95% CI	*P* value
Weight (kg)	87.17 ± 9.97	83.03 ± 9.55	4.14 ± 0.91 3.78 – 4.5	< 0.001 P
Waist circumference (cm)	121.81 ± 9.63	118.57 ± 9.28	3.24 ± 1.26 2.74 – 3.74	< 0.001 P
BMI (kg/m^2)	31.62 ± 3.38	30.14 ± 3.28	1.48 ± 0.28 1.37 – 1.59	< 0.001 P
HbA1c (%)	7.87 ± 1.11	7.48 ± 1.12	0.39 ± 0.17 0.33 – 0.46	< 0.001 P
Cholesterol (mg/dL)	185.27 ± 44.94	178.71 ± 43.98	6.56 ± 4.79 4.67 – 8.45	< 0.001 P
HDL (mg/dL)	39.1 ± 8.81	39.16 ± 8.84	-0.05 ± 0.28 -0.16 – 0.53	0.304 P
LDL (mg/dL)	116.98 ± 37.94	112.38 ± 36.47	4.6 ± 3.03 3.01 – 6.2	< 0.001 P
Triglycerides (mg/dL)	145.97 ± 51.86	135.89 ± 50.73	10.07 ± 5.93 7.72 – 12.42	< 0.001 P
CRP (mg/l)	11.35 ± 3.46	8.86 ± 5.83	2.49 ± 6.49 -0.08 – 5.06	0.057 P
FM (kg)	42.47 ± 7.75	39.45 ± 7.3	3.02 ± 0.82 2.69 – 3.34	< 0.001 P
MM (kg)	24.63 ± 3.1	24.36 ± 3.05	0.17 ± 0.09 0.14 – 0.21	< 0.001 P
HOMA-IR	6.87 ± 1.89	6.34 ± 1.54	0.53 ± 0.26 0.31 – 0.76	< 0.001 P

BMI Body mass index, *HbA1c* Heamoglobin A1c, *HDL* High density lipoprotein, *LDL* Low density lipoprotein, *CRP* C reactive protein, *FM* Fat mass, *MM* Muscle mass, *HOMA-IR* Homeostasis model assessment of insulin resistance, *P* Paired sample T test

Concerning insulin resistance, we found a significant decrease in HOMA-IR mean levels ($p<0.001$).

As for the lipid profile, we found that there was a significant reduction in post treatment levels of Cholesterol, LDL and triglycerides ($p<0.001$, $P=0.002$, $P<0.001$ respectively). On the other hand, there was a significant improvement in HDL mean levels among patients in this groups ($p=0.003$). We also found a significant reduction in CRP levels among patients in this group from 9.04 ± 7.57 mg/l to 7.85 ± 5.41 mg/l ($p=0.027$) (Table 3).

Difference between the three dietary plans

We compared between all 3 study groups concerning their anthropometric and laboratory findings and found that:

Weight, BMI and Waist circumference reductions among the three dietary groups were statistically insignificant ($p=0.363$, 0.698 and 0.765 respectively). MM reduction showed less reduction with Zone diet, however the difference was statistically insignificant ($P=0.737$ and 0.263 respectively).

HbA1c showed most reduction in MAD group ($p=0.002$). Similarly, Triglycerides showed more reduction in MAD group, the differences were statistically insignificant ($P=0.274$). In addition to that, HDL improved in MAD group ($p=0.023$).

On the other hand, Cholesterol showed most reduction in ZD group with a statistical significance of ($p=0.026$). Similarly, LDL showed more reduction in ZD group, however the difference was statistically insignificant ($P=0.172$).

CRP reduction between dietary groups was statistically insignificant ($P=0.471$) and HOMA-IR showed more reduction in MAD group, but the difference was statistically insignificant ($P=0.232$) (Table 4).

Discussion

T2DM is a serious public health concern with a considerable impact on human life and health expenditures [13].

Recently, concerns have been raised that more than one-third of the diabetes related deaths occur in people under the age of 60 due to the increased consumption of unhealthy diets and sedentary lifestyles, resulting in elevated BMI and fasting plasma glucose [19].

Type 2 diabetes patients are associated with several common metabolic abnormalities including insulin resistance, hyperglycemia, dyslipidemia and inflammation [20]. Obesity is a major risk factor for development

Table 3 The difference between pre and post dietary plan anthropometric and laboratory findings among patients in MAD group ($n=27$)

Variable	Pre dietary plan ($N=27$)	Post dietary plan ($N=27$)	Mean difference 95% CI	*P* value
Weight (kg)	94.94 ± 13.04	90.55 ± 12.99	4.39 ± 0.95 4.02 – 4.77	< 0.001 P
Waist circumference (cm)	125.56 ± 10.89	122.49 ± 10.62	3.06 ± 0.92 2.69 – 3.42	< 0.001 P
BMI (kg/m^2)	34.31 ± 5.33	32.78 ± 5.27	1.52 ± 0.29 1.41 – 1.64	< 0.001 P
HbA1c (%)	7.92 ± 0.94	7.34 ± 0.82	0.58 ± 0.26 0.48 – 0.68	< 0.001 P
Cholesterol (mg/dL)	176.82 ± 28.91	172.52 ± 27.2	4.3 ± 3.15 2.26 – 6.34	< 0.001 P
HDL (mg/dL)	42.19 ± 11.92	42.66 ± 11.49	-0.46 ± 0.73 -0.75—-0.17	0.003 P
LDL (mg/dL)	104.77 ± 19.87	101.63 ± 18.08	3.14 ± 2.86 1.21 – 5.06	0.002 P
Triglycerides (mg/dL)	149.26 ± 59.78	138.81 ± 57.19	10.45 ± 5.91 8.1 – 12.79	< 0.001 P
CRP (mg/l)	9.04 ± 7.57	7.85 ± 5.41	1.19 ± 0.65 0.15 – 2.25	0.027 P
FM (kg)	46.62 ± 6.87	43.49 ± 6.82	3.12 ± 0.77 2.82 – 3.43	< 0.001 P
MM (kg)	26.58 ± 5.2	26.36 ± 5.15	0.22 ± 0.18 0.15 – 0.29	< 0.001 P
HOMA-IR	6.56 ± 3.01	5.88 ± 3.76	0.67 ± 0.33 0.35 – 1.01	< 0.001 P

BMI Body mass index, *HbA1c* Heamoglobin A1c, *HDL* High density lipoprotein, *LDL* Low density lipoprotein, *CRP* C reactive protein, *FM* Fat mass, *MM* Muscle mass, *HOMA-IR* Homeostasis model assessment of insulin resistance, *P* Paired sample T test

of type 2 diabetes together with complex genetic and environmental factors [21].

The metabolic consequences of insulin resistance can result in hyperglycemia, hypertension, dyslipidemia, visceral adiposity, hyperuricemia, elevated inflammatory markers, endothelial dysfunction, and a prothrombic state. Progression of insulin resistance can lead to metabolic syndrome, nonalcoholic fatty liver disease, and type 2 diabetes mellitus [22].

Lifestyle modification is the primary focus for the treatment of insulin resistance. Nutritional intervention with caloric deficit dietary plan and reduction of carbohydrates that stimulate excessive insulin demand are considered the cornerstone of treatment. Furthermore, physical activity helps to increase energy expenditure and improve muscle insulin sensitivity [22].

Many studies conducted in the past 20 years have shown the benefits of the Mediterranean lifestyle for people with, or at risk of developing, type 2 diabetes mellitus. The philosophy of the Mediterranean diet consists of eating more legumes, vegetables, fruits, nuts, wholegrain foods, fish and olive oil. However, despite the large body of evidence, concerns exist amongst scientists regarding the reliability of the data related to this topic [5].

Therefore, this study is made to compare two popular diets, zone diet (High protein diet) and modified Atkins (High fat diet) to traditional high carbohydrate, in adults with type 2 diabetes regarding their effect on BMI, WC, FM and MM (using BIA method), insulin resistance (using HOMA-IR), inflammation (using CRP levels) and lipid profile.

In our study there was significant reduction of weight and BMI among three dietary groups with no significant difference between dietary groups; High carbohydrate diet group: 4.04 ± 0.94 kg, Zone diet group: 4.14 ± 0.91 kg and Modified Atkins diet group: 4.39 ± 0.95 kg. This stands in agreement with McAuley et al. who reported in their study with 96 insulin-resistant women (BMI > 27 kg/m2); significant weight loss with Modified Atkins diet group and zone diet group in comparison to high carbohydrate diet [23].

We found significant WC reduction across all dietary groups with no statistical significance difference between the three dietary groups; (High carbohydrate diet group: 3.25 ± 0.99 cm, Zone diet group: 3.24 ± 1.26 cm and Modified Atkins diet group: 3.06 ± 0.92 cm). Kerksick et al. reported in their study which included 161 sedentary, obese women; significant waist circumference

Table 4 The difference between study groups concerning their anthropometric and laboratory changes post dietary plans

Variable	HC group (*N* = 27)	ZD group (*N* = 27)	MAD group (*N* = 27)	*P* value
Weight (kg)	-4.04 ± 0.94	-4.14 ± 0.91	-4.40 ± 0.95	0.363 A
BMI (kg/m^2)	-1.45 ± 0.36	-1.48 ± 0.28	-1.52 ± 0.30	0.698 A
Waist circumference (cm)	-3.25 ± 0.99	-3.24 ± 1.26	-3.06 ± 0.92	0.765 A
HbA1c (%)	-0.39 ± 0.20	-0.40 ± 0.17	-0.58 ± 0.26	0.002 A 0.999* 0.004** 0.007***
Cholesterol (mg/dL)	-3.42 ± 2.41	-6.56 ± 4.79	-4.30 ± 5.16	0.026 A 0.027* 0.999** 0.127***
HDL (mg/dL)	0.27 ± 0.49	0.06 ± 0.28	0.46 ± 0.73	0.023 A 0.425* 0.561** 0.018***
LDL (mg/dL)	-2.63 ± 2.70	-4.60 ± 4.03	-3.14 ± 4.86	0.172 A
Triglycerides (mg/dL)	-8.16 ± 4.75	-10.07 ± 5.93	-10.45 ± 5.91	0.274 A
CRP (mg/l)	-1.29 ± 2.48	-2.49 ± 6.50	-1.20 ± 2.65	0.471 A
FM (kg)	-2.96 ± 0.79	-3.02 ± 0.82	-3.12 ± 0.77	0.737 A
MM (kg)	-0.23 ± 0.13	-0.17 ± 0.09	-0.22 ± 0.18	0.263 A
HOMA-IR	-0.39 ± 0.27	-0.53 ± 0.56	-0.67 ± 0.83	0.232 A

Negative values indicate reduction

BMI Body mass index, *HbA1c* Heamoglobin A1c, *HDL* High density lipoprotein, *LDL* Low density lipoprotein, *CRP* C reactive protein, *FM* Fat mass, *MM* Muscle mass, *HOMA-IR* Homeostasis model assessment of insulin resistance, *A* ANOVA test

* Group 1 vs Group 2

** Group 1 vs Group 3

*** Group 2 vs Group3

reduction with no significance between dietary groups after 14 weeks with very low carbohydrate high protein diet, low carbohydrate low protein diet and high carbohydrate low protein diet groups [24]. However, McAuley et al. reported in their study that included 96 insulin-resistant women (BMI > 27 kg/m^2); more WC reduction with Modified Atkins diet and Zone diet [23].

As for body composition all dietary groups showed significant reduction in fat mass; High carbohydrate diet group: 2.96 ± 0.79 kg, Zone diet group: 3.02 ± 0.82 kg and Modified Atkins diet group: 3.12 ± 0.77 kg, with no significant reduction between the three dietary groups. De Souza et al. reported in their study that included 424 adults (BMI 25-40 kg/m^2); different macronutrients were not associated with significant difference in fat mass reduction [25]. On the other hand, Pasiakos et al. reported in their study that included 39 individuals (BMI 22 to 29 kg/m^2) on energy deficit diet who consume two and three times the RDA of protein intake lost more fat mass than individuals on energy deficit who consume RDA of protein intake (0.8 g protein per kg body weight) [26].

Significant reduction in muscle mass was observed with all dietary groups, but Zone diet showed the least reduction; High carbohydrate diet group: 0.23 ± 0.13 kg, Zone diet group: 0.17 ± 0.09 kg and Modified Atkins diet group: 0.22 ± 0.18 kg, however there is no significant reduction between dietary groups. Backx et al. reported in their study that included 61 overweight and obese men and women (63 ± 5 years) who were randomly assigned to either a high protein diet (1.7 g/ kg per day) or normal protein diet (0.9 g/ kg per day) during a 12-weeks 25% energy intake restriction; a lean body mass decline by 1.8 ± 2.2 and 2.1 ± 1.4 kg, respectively, with no significant differences between groups ($P = 0.213$) [27].

Interestingly significant improvement in insulin resistance resembled by HOMA-IR occurred with all dietary groups, but Modified Atkins diet showed more improvement of insulin resistance 0.67 ± 0.33; High carbohydrate diet group: 0.39 ± 0.27, Zone diet group: 0.53 ± 0.26, with no significant reduction between dietary groups. Willems et al. reported in their meta-analysis study that included 725 and 732 adults (BMI > 30 kg/m^2) participants that followed either low fat hypo-caloric diet or low carbohydrate hypo-caloric diet respectively; more HOMA-IR reduction is seen with low carbohydrate diets than low fat diets at 6 months [28]. Also, Charlot et al. reported in their meta-analysis study; 4 out of 5 studies

show significant reduction in HOMA-IR by ketogenic diet [29]. This also stands in agreement with Clamp et al. who reported in their study including overweight/obese women (20–45 years) that weight reduction itself was a strong predictor of improved insulin resistance [30].

In our study significant HbA1c reduction seen among three dietary groups; High carbohydrate diet group: 0.39 ± 0.19%, Zone diet group: 0.39 ± 0.17% and Modified Atkins diet group: 0.58 ± 0.26%, however Modified Atkins diet showed more significant reduction. Stulnig et al. prove that a protein-enriched and low-glycemic-index diet supplemented with long-chain omega-3 PUFAs in a real-life clinical setting improved glycemic control, waist circumference, and silent inflammation in overweight or obese patients with type 2 diabetes [31]. Shantha et al. reported in their study that included 72 individuals with mean baseline body mass index of 35.1 kg/m^2, mean age of 52.6 years, and mean starting HbA1c% was 8.6; for every 10% weight loss, the predicted reduction in HbA1c% was 0.81 among patients with type 2 diabetes (32 Moreover, Ahmed et al. reported in their study that included 49 patients with type 2 diabetes who followed low carbohydrate high fat diet for ≥ 3 months, and compared glycemic outcomes with age-matched and body mass index (BMI)-matched controls who received usual care (n = 75); the low carbohydrate high fat group showed a significantly greater reduction in HbA1c [33].

Dyson et al. proved that low carbohydrate diets failed to show superiority over higher carbohydrate intakes for any of the measures evaluated including weight loss, glycemic control, lipid concentrations, blood pressure, and compliance with treatment [34]. While on the other end, Kumar et al. suggests that low carbohydrate (< 130 g/day of carbohydrate) and very low carbohydrate, ketogenic diets (typically < 50 g/day of (VLCKD) can be effective tools for managing diabetes given their beneficial effects on weight loss, glycemic control and also result in favorable lipid profile changes. However, these beneficial effects can be limited by poor dietary adherence [35].

We found in our study significant reduction in LDL in High carbohydrate diet group: 2.63 ± 1.7 mg/dL, Zone diet group: 4.6 ± 3.03 mg/dL and Modified Atkins diet group: 3.14 ± 2.86 mg/dL and Triglycerides reduction with all dietary groups; High carbohydrate diet group: 8.16 ± 4.75 mg/dL, Zone diet group: 10.07 ± 5.93 mg/dL and Modified Atkins diet group: 10.45 ± 5.91 mg/dL, meanwhile HDL showed significant improvement only with High carbohydrates diet; -0.27 ± 0.49 mg/dL and Modified Atkins diet; -0.46 ± 0.73 mg/dL. Brown et al. reported in their study that included 604 patients with mean BMI of 35.1, and mean age was 47.7 years, 45 patients (11.2%) were diabetic and followed an individualized caloric deficit diet for 15 weeks; < 5% weight loss led to reduction in only triglycerides, while reduction 5–10% of body weight led to reduction of triglycerides, total cholesterol, and LDL cholesterol, while > 10% weight reduction led to reduction of triglycerides, total cholesterol, and LDL cholesterol with undesirable changes in HDL [36].

In our study, Zone diet showed most reduction in LDL, however no significant difference in reduction of LDL was seen between dietary groups. Farnsworth et al. reported in their study that included 57 overweight patients with a parallel design included either a high-protein diet of meat, poultry, and dairy foods (high protein diet: 27% of energy as protein, 44% as carbohydrate, and 29% as fat) or a standard-protein diet (standard-protein diet: 16% of energy as protein, 57% as carbohydrate, and 27% as fat) during 12 weeks of energy restriction (6–6.3 MJ/d) and 4 weeks of energy balance (approximately 8.2 MJ/d); High protein diet did not offer any additional LDL reduction [37]. LDL was primary affected by weight loss. On the other hand, McAuley et al. reported in their study that included 96 insulin-resistant women (BMI > 27 kg/m^2); LDL cholesterol was significantly reduced in the high-protein group compared to Modified Atkins diet and High carbohydrate diet [23].

We found that, triglycerides reduction was seen with Modified Atkins diet, however no significant difference in triglycerides reduction is seen between dietary groups. McAuley et al. reported in their study that included 96 insulin-resistant women (BMI > 27 kg/m^2); Zone diet and Modified Atkins diet showed more significant reduction in triglycerides than high carbohydrate diet [20]. Moreover, Zomer et al. reported in their systemic review and meta-analysis; 5–10% weight loss led to a 16 mg/dl reduction in triglycerides [38].

We noticed statistically significant HDL improvement seen with both high carbohydrate diet and Modified Atkins diet, HDL was more significantly improved in Modified Atkins diet group than high carbohydrate diet. However, Zomer et al. reported in their systemic review and meta-analysis; 5–10% weight loss resulted in a non-significant increase in HDL increase [38].

In our study there was significant reduction of CRP with high carbohydrate diet; 1.29 ± 0.48 mg/l and Modified Atkins diet; 1.19 ± 0.65 mg/l, with no significant difference between both dietary groups. Forsythe et al. reported in their study that included 40 overweight men and women aged 18–55 year with a BMI (25 kg/m2) who participated in a 12 week randomized, controlled, dietary intervention trial comparing a very low caloric ketogenic diet to a low fat diet; both diets led to a similar significant reduction in the acute phase reactant C-reactive protein (-23%) [39]. Also, Selvin et al. reported in their meta-analysis; 1 kg weight loss will produce a – 0.13 mg/l

reduction in CRP through diet and lifestyle modifications [40]. However, McAuley et al. reported in their study that included 96 insulin-resistant women (BMI > 27 kg/m^2); no significant difference in CRP levels reduction between Zone diet, Modified Atkins diet and High carbohydrate diet [23].

The main strength of the current study is the novelty of comparing the different dietary plans clinical and laboratory outcomes on type 2 diabetic patients. We faced few limitations in terms of relatively small sample size compared to abovementioned studies, being a single institutional study, which limit the generalizability of the study results. Further studies are still required to evaluate the long-term role the different dietary plans on diabetes and its complications.

Conclusion

Our conclusion is: All three dietary plans show benefit and improve the anthropometric and metabolic outcomes of type 2 diabetic patients. However, Modified Atkins diet showed superior benefit as regards improvement of HbA1c, HDL and CRP in comparison to the other dietary plans.

Abbreviations:

ADA	American Diabetes Association
AI	Adequate Intake
ASM	Appendicular skeletal muscle mass
BIA	Bioelectrical impedance analysis
BMI	Body mass index
BW	Body weight
CHO	Carbohydrate
CRP	C—reactive protein
CVD	Cardiovascular disease
FEL	Food Exchange List
FFAs	Free fatty acids
FFM	Fat free mass
FM	Fat mass
HbA1C	Hemoglobin A1C
HC	High carbohydrate
HDL	High-density lipoprotein
HDL-C	High-density lipoprotein cholesterol
HOMA-IR	Homeostasis model assessment of insulin resistance
HR	Hip ratio
IDF	.International Diabetes Federation
IDL	Intermediate-density lipoprotein
IR	Insulin resistance
KD	Ketogenic diet
LDL	Low-density lipoprotein
LDL-C	Low-density lipoprotein cholesterol
MAD	Modified Atkins diet
MF-BIA	Multiple-frequency BIA
MM	Muscle Mass
RDA	Recommended daily allowance
RTSM	Relative total skeletal muscle mass
SPSS	Statistical package for social sciences
T2DM	Type 2 diabetes mellitus
TGs	Triglycerides
VF	Visceral fat
WC	Waist circumference
WHO	World health organization
WHR	Waist- hip ratio
ZD	Zone diet

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Authors' contribution
SF and GA analyzed and interpreted the patient's data. MN collected the data. MN wrote the statistics of the manuscript. SF was a major contributor in writing the manuscript. AE and SA suggested the objective of the work, supervised the work and revised the results and manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
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Declarations

Ethics approval and consent to participate
Study protocol and informed consent were submitted for Institutional Review Board and Ethical Committee at the internal medicine department of Cairo University and approval was granted on 10.4.2022 with the acceptance Code: MS-610 -2021.

Consent for publication
Oral and written informed consents were obtained from the patients or from the eligible relatives.

Competing interests
The authors declare that they have no competing interests.

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