

Original Article

Sex-differences in dietary macronutrient intake and its association with metabolic syndrome components in adults with type 2 diabetes: a cross-sectional study

Daoud Daoudi^{1,2*} , Abderrahmane Moufid¹, Nouriya Elghoulam¹ , Aichetou Bouh^{1,3} ,
Aicha Madkour¹ , Hakim Belghiti⁴, Hassan Aguenau⁵ , Souad Benaich¹ , Slimane Mehdad¹ 

¹ Physiology and Physiopathology Research Team, Faculty of Sciences, Mohammed V University in Rabat, Rabat, Morocco

² Higher Institute of Nursing Professions and Health Technology of Fez, Annex Meknes, Meknes, Morocco.

³ National Institute of Oncology Sidi Mohammed Ben Abdellah, Faculty of Medicine and Pharmacy, Mohammed V University in Rabat, Rabat, Morocco

⁴ Clinical Nutrition Unit, Mohammed V Military Hospital of Instruction, Rabat, Morocco

⁵ Regional Designated Center of Nutrition AFRA/IAEA, International University of Rabat, Salé, Morocco

* Correspondence to: Daoud Daoudi, Physiology and Physiopathology Research Team, Faculty of Sciences, Mohammed V University in Rabat, Rabat, Morocco. E-mail address: daoud.daoudi@um5r.ac.ma

Received: 29 April 2026 / Accepted: 14 July 2026

Abstract

Metabolic syndrome (MetS) is highly prevalent in patients with type 2 diabetes (T2D) and increases cardiovascular risk. Sex-specific associations between macronutrient intake and MetS remain insufficiently explored. This study aimed to assess MetS prevalence and examine sex differences in associations between dietary macronutrient intake and MetS components. A cross-sectional study was conducted among 425 Moroccan adults with T2D. MetS was defined using harmonized IDF, AHA, and NHLBI criteria. Dietary intake was assessed using a 24-hour recall, and isoenergetic macronutrient substitution models were applied. The prevalence of MetS was 72.9%, higher in women than men (81.2% vs. 58.4%). Women showed higher BMI, waist circumference, and poorer metabolic profiles. In men, MetS was associated with central obesity, inadequate sleep, and family history of cardiometabolic disease. Replacing protein with fat was associated with lower odds of MetS (OR=0.58; 95% CI: 0.35–0.98), abdominal obesity (OR=0.60; 95% CI: 0.37–0.97), and hypertriglyceridemia (OR=0.57; 95% CI: 0.33–0.95). No significant associations were observed in women. MetS is highly prevalent among Moroccan adults with T2D, with clear sex differences. Macronutrient substitution was associated with favorable metabolic outcomes only in men, highlighting the importance of sex-specific nutritional strategies.

Keywords: metabolic diseases, type 2 diabetes mellitus, nutritional intake, isoenergetic substitution, cardiometabolic risk

Abbreviations: BMI – Body Mass Index; CVD – Cardiovascular Disease; FPG – Fasting Plasma Glucose; HDL-C – High-Density Lipoprotein Cholesterol; IDF – International Diabetes Federation; IPAQ-SF – International Physical Activity Questionnaire – Short Form; MetS – Metabolic Syndrome; OGTT – Oral Glucose Tolerance Test; SD – Standard Deviation; T2D – Type 2 Diabetes; WC – Waist Circumference



Introduction

Metabolic syndrome (MetS) is a cluster of cardio-metabolic abnormalities, including abdominal obesity, dyslipidemia, hypertension, and impaired glucose regulation, which markedly increase the risk of cardiovascular diseases (CVD) and type 2 diabetes (T2D) [1]. In individuals with T2D, the coexistence of multiple MetS components further amplifies the risk of cardiovascular complications and diabetes-related mortality [2]. Both global and regional data highlight a substantial burden of MetS among adults with T2D in both sexes, with similar frequencies observed in men and women, potentially reflecting biological, behavioral, and socio-cultural determinants [3].

Lifestyle modification, particularly dietary intervention, is central to the prevention and management of MetS, with combined approaches involving diet, physical activity, and weight control improving cardio-metabolic outcomes [4, 5]. In Morocco, rapid nutritional transition has led to shifts in dietary patterns and a rising burden of non-communicable diseases. Findings from Energy and Macronutrients Intake in Women at Reproductive Age in an Urban Setting of Morocco reveal low energy intake and nutrient imbalance, which are dependent on socioeconomic conditions [6]. Although diet plays a critical role, there is no agreement on the ideal proportion of macronutrients in Type 2 Diabetes Mellitus, underscoring the significance of context-based interventions [7]. Carbohydrate consumption, specifically, continues to be the main concern because of its influence on glucose control, lipid regulation, and visceral fatness [8, 9].

Moreover, the inconsistency in the findings related to macronutrient content and MetS persists. Under isoenergetic conditions, an increase in the consumption of one macronutrient implies a decrease in another; however, the interaction between these variables has received less consideration [10, 11]. In addition, inadequate control of total energy intake and inappropriate body mass index adjustment might result in biased results [12, 13].

The macronutrient substitution model represents an appropriate framework for assessing the effect of the substitution of one macronutrient by another under isoenergetic conditions. The application of this strategy in North African populations with T2D is scarce.

In this regard, this current study sought to assess the prevalence of MetS and its components as well as the relationship between macronutrient intake distribution and MetS variables based on gender in adult patients with type 2 diabetes mellitus in the Meknes area

of Morocco. We hypothesize that changes in macronutrient intake could have gender-based relationships with selected MetS parameters.

Material and methods

Study design and setting

The observational, descriptive, and analytic cross-sectional study was conducted between May 2024 and May 2025 at the Provincial Diabetes Center in Meknes, Morocco. Being one of the units within the Primary Health Care Network, this diabetes center offers specialized treatment to patients diagnosed with type 2 diabetes who have been referred from nearby primary health facilities, especially those with uncontrolled blood sugar levels.

Target population and sampling frame

The targeted population consisted of adults (≥ 18 years) suffering from type 2 diabetes under ongoing surveillance in the Network of Primary Health Care Facilities (RESSP) within Meknes. Based on information published by the Ministry of Health and Social Protection in its statistics [14], the total number of patients suffering from diabetes managed by the network is 33,485. With respect to the fact that 90–95% of all cases of diabetes suffer from type 2 diabetes [15], the source population could be estimated at 30,136 and 31,816 patients. For conservative estimation, a baseline figure of 30,136 patients was adopted as the sampling frame.

Inclusion and exclusion criteria

The following study is observational cross-sectional research conducted on adult patients with the age range ≥ 18 years old, suffering from a confirmed case of type 2 diabetes, under regular follow-up at the Meknes Diabetes Center and who gave written informed consent for participation. The subjects that were not eligible to participate included those with type 1 diabetes mellitus, other types of diabetes mellitus such as MODY and secondary cases, pregnant women, lactating women, and individuals affected by acute illnesses including tuberculosis and HIV infections.

Sample size and sampling strategy

The minimum sample size was calculated using the Cochran's formula for prevalence studies, assuming

an expected metabolic syndrome (MetS) prevalence of 78.4% [16]. The study employed a 95% confidence level ($Z=1.96$) with a 5% margin of error. Finite population correction was applied using the estimated T2D population in Meknes ($N=30,136$), yielding a minimum sample size of 262 participants diagnosed with T2D. To enhance statistical power and enable subgroup analyses, 425 patients with T2D were recruited using a consecutive non-probability sampling method during scheduled follow-up visits. Recruitment was stratified to approximate the local age–sex distribution. More details on sampling methods are provided elsewhere [17].

Data collection

Clinical and biochemical parameters

Clinical and biochemical data were extracted from participants' medical records, based on the average values recorded over the previous three months. Parameters included glycated hemoglobin (HbA1c), fasting plasma glucose (FPG), total cholesterol, triglycerides, high-density lipoprotein cholesterol (HDL-C) and low-density lipoprotein cholesterol (LDL-C). All data were verified by the study team to ensure accuracy and consistency.

Anthropometric measurements

Anthropometric measurements were done by healthcare professionals using standardized measuring devices. The weight of each participant was measured to an accuracy of 0.1 kg with the help of a calibrated digital scale. Height was measured to an accuracy of 0.1 cm with a stadiometer affixed to the wall. Waist circumference (WC) was measured by taking readings halfway between the lower edge of the rib cage and the iliac crest.

The body mass index (BMI) was determined from body weight/height² (kg/m²), according to WHO classifications. Central obesity was defined on the basis of the cut-off for WC of ≥ 80 cm for women and ≥ 94 cm for men.

Blood pressure measurement

Blood pressure (BP) was measured with an electronic sphygmomanometer according to international guidelines. The measurement was conducted following a minimum five-minute rest period while sitting. The participant sat comfortably with their back supported, both feet lying flat on the ground, and uncrossed legs. The BP cuff was positioned at the level of the heart,

covering the bare upper arm. Three measurements were performed, and the first reading was discarded to avoid stress-related bias. The average of the second and third readings was used for data analysis. High blood pressure, one of the diagnostic criteria of MetS, was considered present when the systolic BP ≥ 130 mmHg and/or the diastolic BP ≥ 85 mmHg, or the use of antihypertensive treatment.

Sociodemographic and lifestyle factors

Information on sociodemographic and behavioral factors were gathered using standardized questionnaires regarding age, gender, marital status, educational attainment, occupational status, use of tobacco and alcohol, and any medical and/or family histories. The participants' levels of physical activity were analyzed based on the International Physical Activity Questionnaire-Short Form (IPAQ-SF), an instrument aimed at measuring an individual's habitual physical activity in the past week, covering both walking, moderate, and vigorous physical activity and sedentary behavior. The respondents were divided into low, medium, and high physical activity levels based on the IPAQ scoring protocol. Sleep duration was self-reported and assessed based on the recommendations of the National Sleep Foundation, with any sleep less than 7 hours being considered inadequate [18].

Dietary assessment

The 24-hour dietary recall was used to determine dietary intake. Subjects provided information on all foods and drinks consumed over the past 24 hours. Portion size estimation was done by referring to the photo atlas for estimating portion sizes from the SU.VI. MAX study [19]. Food intake data was analyzed using the CIQUAL 2020 nutrient database from ANSES [20]. The overall daily energy intake, as well as nutrient consumption, was calculated by summing all foods and beverages reported by participants. The contribution of macronutrients was expressed as a percentage of total energy intake (%E), based on standard energy conversion values (9 kcal per gram for fats, and 4 kcal per gram for proteins and carbohydrates). Fiber intake was assessed and reported in grams per day.

Definition of metabolic syndrome

Metabolic syndrome (MetS) was defined according to the 2009 harmonized criteria established by the International Diabetes Federation (IDF), American Heart Association (AHA), and National Heart, Lung, and

Blood Institute (NHLBI) (Alberti *et al.*, 2009). In this study, MetS was diagnosed when participants exhibited at least three of the five metabolic abnormalities illustrated in Figure 1 [21].

Macronutrient substitution models

Associations between macronutrient intake and metabolic syndrome (MetS) were assessed using multivariate nutrient density substitution models [22, 23]:

- Each macronutrient was included as an independent variable, while one macronutrient was omitted to simulate isoenergetic substitution;
- Models were adjusted for total energy intake, remaining macronutrients, and potential confounders, including age, sex, residence, education, sleep duration, smoking, and physical activity;
- Lipid-related outcomes were additionally adjusted for lipid-lowering therapy, and blood pressure outcomes for antihypertensive medication.

This methodological approach allowed the estimation of the effect of increasing one macronutrient at the expense of another under isoenergetic conditions, while accounting for total energy intake and potential confounders.

Statistical analysis

All statistical analyses were performed using SPSS version 27.0.1.0. Continuous variables were first tested for normality using the Kolmogorov–Smirnov test. Based on their distribution, normally distributed data were presented as mean±standard deviation (SD) and compared using Student's *t*-test, whereas non-normally distributed variables were expressed as median [Q1–Q3] and analyzed using the Mann–Whitney *U* test. Categorical variables were summarized as frequencies and percentages with corresponding 95% confidence intervals (CI), and group comparisons were performed using the Chi-square test.

The missing data were addressed in terms of their percentage and pattern. Since missing values were present, imputation procedures were considered in order to prevent possible biases. When dealing with continuous variables, imputation via means was done whenever possible, whereas for imputing missing values in relationship to other variables, regression imputation was employed. In case of categorical variables, missing data were imputed using the modal class.

Logistic regression was employed for analyzing binary outcome variables (MetS and its individual components), which are presented through odds ratios (OR) along with 95% CI. Generalized linear modeling was conducted for continuous outcome variables (SBP, DBP, HDL-C, triglycerides, and waist circumference), which are presented through regression coefficients (B) along with 95% Wald CI. Statistical significance was defined as a *p*-value<0.05.

MetS prevalence was calculated using pooled sex data, while sex-stratified analyses were performed separately.

Results

This cross-sectional study included 425 adults diagnosed with type 2 diabetes from Meknes, Morocco. The overall prevalence of metabolic syndrome (MetS) was 72.9%, with a markedly higher prevalence among women than men (81.2% vs. 58.4%) (Table 1).

Among women, significant differences according to MetS status were observed for age and educational level (*p*=0.008 and *p*<0.001, respectively). Women with MetS exhibited significantly higher anthropometric measures, including waist circumference (99 [95–104] vs. 79 [78–80] cm, *p*<0.001) and body mass index (BMI) (31.9 [31.0–33.9] vs. 24.9 [23.6–27.0] kg/m², *p*<0.001). Low physical activity was markedly more prevalent among women with MetS compared to those without MetS (89.6% vs. 10.4%, *p*=0.002). Furthermore, a positive family history of hypertension and cardiovascular disease was significantly more frequent in women with MetS (90.1% vs. 9.9%, *p*<0.001 and 87.1% vs. 12.9%, *p*=0.009, respectively). In contrast, no significant difference was observed in family history of diabetes between the groups (*p*=0.650).

Among men, age did not differ significantly according to MetS status (median 59 [50–64] vs. 60 [49–65] years, *p*=0.780). However, men with MetS presented significantly higher waist circumference (100 [97–106] vs. 90 [83–92] cm, *p*<0.001) and BMI (31.5 [31.0–32.3] vs. 25.5 [24.1–26.7] kg/m², *p*<0.001) compared with their non-MetS counterparts. In contrast to women, Sleep duration was significantly linked to MetS among men, with an increased occurrence of MetS observed in those reporting inadequate sleep (69.6% vs. 30.4%, *p*=0.004). Low physical activity was also significantly more common in men with MetS (71.6% vs. 28.4%, *p*=0.004). Additionally, men with MetS were more likely to report a positive family history of hypertension, cardiovascular

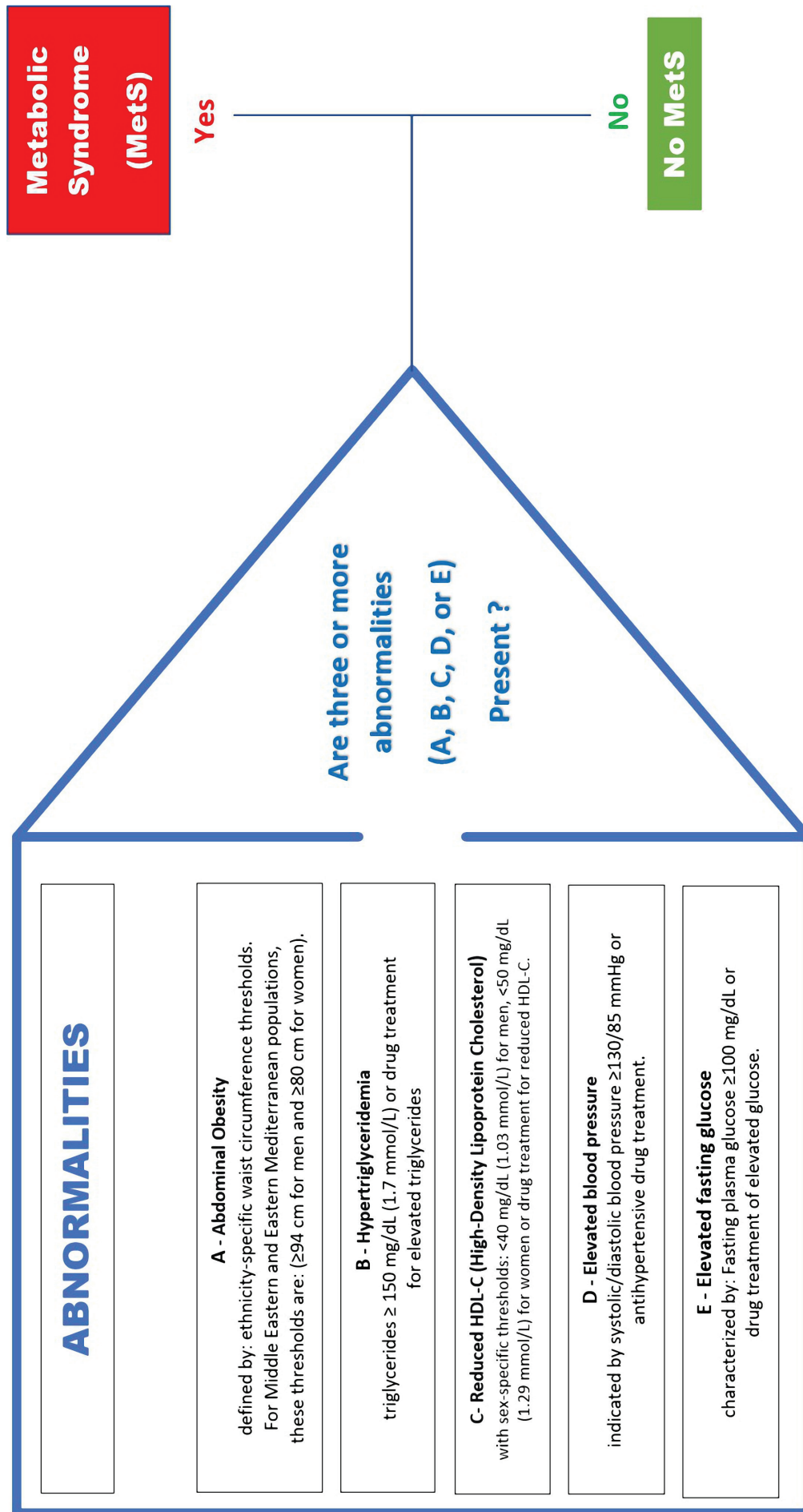


Figure 1: Flowchart illustrating the diagnosis of Metabolic Syndrome (MetS) based on the 2009 Joint Interim Statement (IDF/AHA/NHLBI), requiring the presence of three or more cardiometabolic abnormalities.

Table 1: Sociodemographic and clinical characteristics of participants by sex and metabolic syndrome (MetS) status.

Variable	Total (n=425)	Women with MetS (n=220, 81.2%)	Women without MetS (n=51, 18.8%)	P-value	Men with MetS (n=90, 58.4%)	Men without MetS (n=64, 41.6%)	P-value
Age (years)	55 [46–64]	55 [48–62]	45 [40–61]	0.008*	59 [50–64]	60 [49–65]	0.780
Place of residence							
Urban	267 (62.8%)	145 (81.9%)	32 (18.1%)		62 (68.9%)	28 (31.1%)	
Rural	158 (37.2%)	75 (79.8%)	19 (20.2%)	0.659	28 (43.8%)	36 (56.2%)	0.002*
Education level							
None	209 (49.2%)	129 (86.0%)	21 (14.0%)		40 (67.8%)	19 (32.2%)	
Primary	121 (28.5%)	59 (85.5%)	10 (14.5%)		30 (57.7%)	22 (42.3%)	
Middle school	55 (12.9%)	20 (71.4%)	8 (28.6%)	<0.001*	16 (59.3%)	11 (40.7%)	0.004*
High school	21 (4.9%)	8 (53.3%)	7 (46.7%)		1 (16.7%)	5 (83.3%)	
University	19 (4.5%)	4 (44.4%)	5 (55.6%)		3 (30.0%)	7 (70.0%)	
Sleep duration							
Adequate	202 (47.5%)	98 (77.2%)	29 (22.8%)		35 (46.7%)	40 (53.3%)	0.004*
Inadequate	223 (52.5%)	122 (84.7%)	22 (15.3%)	0.110	55 (69.6%)	24 (30.4%)	
Waist circumference (cm)	97 [88.5–102]	99 [95–104]	79 [78–80]	<0.001*	100 [97–106]	90 [83–92]	<0.001*
BMI (kg/m²)	31.2 [26.1–32.69]	31.9 [31.0–33.9]	24.9 [23.6–27.0]	<0.001*	31.5 [31.0–32.3]	25.5 [24.1–26.7]	<0.001*
Physical activity level							
Low	208 (48.9%)	120 (89.6%)	14 (10.4%)		53 (71.6%)	21 (28.4%)	
Moderate	163 (38.4%)	77 (72.0%)	30 (28.0%)	0.002*	24 (42.9%)	32 (57.1%)	0.004*
High	54 (12.7%)	23 (76.7%)	7 (23.3%)		13 (54.2%)	11 (45.8%)	

Table 1: Continued.

Variable	Total (n=425)	Women with MetS (n=220, 81.2%)	Women without MetS (n=51, 18.8%)	P-value	Men with MetS (n=90, 58.4%)	Men without MetS (n=64, 41.6%)	P-value
Family history of hypertension	210 (49.4%)	128 (90.1%)	14 (9.9%)	<0.001*	46 (67.6%)	22 (32.4%)	0.030*
Family history of cardiovascular diseases	221 (52%)	122 (87.1%)	18 (12.9%)	0.009*	59 (72.8%)	22 (27.2%)	<0.001*
Family history of diabetes	317 (74.6%)	162 (81.8%)	36 (18.2%)	0.650	75 (63.0%)	44 (37.0%)	0.030*
Triglycerides (mmol/L)	1.88 [1.20–2.05]	2.21 [2.03–2.37]	1.25 [1.12–1.35]	<0.001*	2.18 [2.11–2.38]	1.24 [1.13–1.39]	<0.001*
HDL-C (mmol/L)	1.03 [0.78–1.55]	1.01 [0.96–1.05]	1.93 [1.84–2.02]	<0.001*	0.98 [0.94–1.02]	1.74 [1.63–1.84]	<0.001*
Systolic BP (mmHg)	140 [130–150]	150 [145–161]	120 [115–127]	<0.001*	150 [140–150]	120 [110–126]	<0.001*
Diastolic BP (mmHg)	80 [70–90]	85 [80–95]	74 [70–87]	<0.001*	85 [80–94]	72 [70–83]	<0.001*
Fasting glucose (mmol/L)	10.43 [8.33–12.77]	10.4 [8.3–12.9]	9.0 [7.4–12.8]	<0.001*	10.7 [8.5–13.1]	9.4 [8.4–12.0]	<0.001*

Note: MetS – metabolic syndrome; TG – triglycerides; HDL-C – high-density lipoprotein cholesterol; BP – blood pressure; BMI – body mass index. Values are presented as median [interquartile range, IQR] for continuous variables and frequency (percentage) for categorical variables. Percentages are column-based. P-values were obtained using the Mann-Whitney U test for continuous variables and the Chi-square test (or Fisher's exact test when expected cell counts were <5) for categorical variables. For variables with more than two categories (education level and physical activity), P-values refer to the global Chi-square test across all categories. Normality of continuous variables was assessed using the Shapiro-Wilk test. Statistical significance was defined as $P < 0.05$ (two-sided).

disease, and diabetes (67.6% vs. 32.4%, $p=0.030$; 72.8% vs. 27.2%, $p<0.001$; and 63.0% vs. 37.0%, $p=0.030$, respectively).

The biochemical variables were worse in individuals with MetS than those without it for both women and men. Triglycerides, HDL cholesterol, blood pressure, and glucose concentrations were significantly higher in subjects with MetS than in those without MetS ($p<0.001$) (Table 1).

Regarding dietary intake (Table 2), women with MetS reported a slightly lower total energy intake compared with women without MetS (2057 ± 228 vs. 2127 ± 234 kcal/day, $p=0.050$), alongside a significantly higher proportion of energy derived from fat (22.8% vs. 18.5%, $p=0.007$). Fiber intake did not differ significantly between groups. Among men, total energy intake was significantly higher in those with MetS compared with non-MetS participants (2123 ± 221 vs. 2021 ± 210 kcal/day, $p=0.004$), while macronutrient distribution and fiber intake were comparable between groups.

Macronutrient substitution analyses revealed sex-specific associations with MetS and its components (Table 3). In women, none of the substitution models showed statistically significant associations. In men, replacing protein with fat was associated with a reduced likelihood of MetS (OR=0.58; 95% CI: 0.35–0.98), abdominal obesity (OR=0.60; 95% CI: 0.37–0.97), and hypertriglyceridemia (OR=0.57; 95% CI: 0.33–0.95).

Analyses of continuous metabolic syndrome components (Table 4) further supported sex-specific patterns. In women, replacing fat or protein with carbohydrates was associated with modest reductions in diastolic blood pressure; however, these associations did not reach statistical significance. In men, no significant associations were observed between macronutrient substitutions and systolic or diastolic blood pressure, HDL cholesterol, triglyceride levels, or waist circumference.

Discussion

The cross-sectional study conducted among adults with type 2 diabetes in Meknes, Morocco, revealed that there is an extremely high prevalence rate of metabolic syndrome (72.9%). Gender differences were clearly evident, with women having a greater prevalence rate of MetS than men (81.2% for women vs. 58.4% for men). This result is consistent with the results obtained in other studies carried out in North Africa and other developing nations. Some of the possible causes of this

disparity in gender include menopausal effects, aging effects on fat accumulation, and low physical activity levels among women [3, 24, 25].

The anthropometric factors were found to be important predictors of MetS for both genders, emphasizing the importance of abdominal obesity and overweight in the pathogenesis of MetS. The positive relationship between the measures of body size and MetS seen in this study is consistent with the vast literature demonstrating the significance of visceral fat as a major contributor to the increased risk of cardio-metabolic disorders by means of inflammation, dyslipidemia, and altered glucose metabolism [25, 26]. The combination of sedentariness with high adiposity levels, especially among females, underscores the additive impact of these factors [26, 27].

In men, MetS showed a more significant link to familial cardiometabolic risk, which included a history of high blood pressure, heart disease, and diabetes within the family. This could imply that heredity might be a stronger determinant in this population, especially in combination with lifestyle and environmental factors, like diet and sleep. This has been observed elsewhere, too, where a genetic disposition seems to exacerbate the impact of calorie consumption on metabolism [28–30].

Those who had MetS were found to have a generally unfavourable metabolic state, which was manifested in the form of dyslipidaemia, hypertension, and impaired glucose homeostasis. Instead of being individually associated with metabolic derangements, these changes were indicative of a group of related metabolic disorders, which collectively contribute to raising an individual's risk of developing cardiovascular disease in patients with type 2 diabetes mellitus. There is ample evidence that demonstrates the strong association between such clusters of risk factors and high morbidity and mortality from cardiovascular diseases in diabetes populations [31–33].

Sex-specific dietary analyses revealed significant differences between the two groups. While among women, MetS was related to higher percentage of dietary fat calories despite reduced total energy intake, it is possible that this reflects a combination of poor qualitative dietary factors and insufficient physical activity, leading to greater fat deposition and metabolic derangements. Such diet patterns have previously been observed in populations undergoing the nutritional transition and adopting diets more abundant in fat content and high-energy foods [34]. In turn, among men with MetS, higher total energy intake was

Table 2: Daily energy and macronutrient intake by sex and metabolic syndrome (MetS) status.

Variable	Total		Women		Men				
	With MetS (n=310, 72.9%)	Without MetS (n=115, 27.1%)	P-value	With MetS (n=220, 81.2%)	Without MetS (n=51, 18.8%)	P-value	With MetS (n=90, 58.4%)	Without MetS (n=64, 41.6%)	P-value
Energy intake (kcal/d) Mean±SD	2076±227	2068±226	0.739	2057±228	2127±234	0.050	2123±221	2021±210	0.004 *
Carbohydrates (%E) Median [IQR]	42.7 [35.1–51.2]	44.9 [37.9–50.3]	0.473	43.4 [35.2–51.0]	45.4 [34.7–50.1]	0.551	41.6 [35–51.3]	43.1 [38.3–50.3]	0.531
Protein (%E) Median [IQR]	15.7 [12.1–19.5]	15.8 [12.4–18.7]	0.859	15.3 [12.5–19.7]	14.7 [11.9–17.6]	0.137	14.9 [11–19.8]	16.5 [12.5–21.0]	0.113
Fat (%E) Median [IQR]	23.7 [16.9–32.9]	20.8 [15.77–26.5]	0.021*	22.8 [17.2–29.7]	18.5 [13.2–26.8]	0.007*	24.8 [16.6–34.4]	21.3 [17.6–27.8]	0.286
Dietary fiber (g/day) Median [IQR]	27.7 [20.6–34.7]	27.8 [20.5–33.8]	0.830	27.4 [20.6–35.1]	27.8 [21.1–35.4]	0.981	28.3 [22–34]	28.0 [22–34.5]	0.741

Note: MetS – metabolic syndrome; %E – percentage of total energy intake. Continuous variables are presented as mean±standard deviation (SD) for normally distributed variables and median [interquartile range, IQR] for non-normally distributed variables. P-values were calculated using the independent samples t-test for normally distributed variables and the Mann–Whitney U test for non-normally distributed variables. Macronutrient intake is expressed as percentage of total energy intake (%E). Normality was assessed using the Shapiro–Wilk test. Statistical significance was defined as $P < 0.05$ (two-sided).

Table 3: Adjusted odds ratios (AOR) for metabolic syndrome and its components per 5% isoenergetic substitution of dietary macronutrients, stratified by sex.

Macronutrient (substitution)	Sex	MetS AOR (95% CI)	Raised BP AOR (95% CI)	Low HDL-C AOR (95% CI)	Raised TG AOR (95% CI)	Abdominal obesity AOR (95% CI)
CHO (fat)	Women	0.88 (0.75–1.04)	0.89 (0.75–1.05)	0.97 (0.86–1.10)	1.01 (0.89–1.14)	0.95 (0.79–1.14)
	Men	1.02 (0.84–1.24)	1.15 (0.90–1.45)	1.13 (0.92–1.40)	0.92 (0.76–1.11)	0.97 (0.79–1.18)
CHO (protein)	Women	0.89 (0.77–1.04)	0.81 (0.74–1.06)	0.94 (0.82–1.07)	0.98 (0.86–1.12)	0.93 (0.76–1.12)
	Men	0.98 (0.80–1.20)	1.14 (0.90–1.45)	1.15 (0.92–1.44)	0.95 (0.79–1.15)	1.01 (0.83–1.22)
Protein (fat)	Women	0.91 (0.60–1.37)	0.88 (0.56–1.38)	1.12 (0.80–1.55)	1.09 (0.79–1.15)	1.09 (0.66–1.81)
	Men	0.58 (0.35–0.98) *	1.07 (0.58–1.97)	0.86 (0.54–1.37)	0.60 (0.37–0.97) *	0.57 (0.33–0.95) *

Note: AOR – Adjusted odds ratios (AORs) represent the effect of a 5% increase in energy intake from the independent macronutrient, with a simultaneous isoenergetic decrease in the excluded macronutrient. Models were adjusted for age, place of residence, education level, sleep duration, smoking status, physical activity level, and total energy intake. MetS – metabolic syndrome; BP – blood pressure; HDL-C – high-density lipoprotein cholesterol; TG – triglycerides; CHO – carbohydrate. * – Statistical significance was defined as $P < 0.05$ (two-sided). No correction for multiple comparisons was applied; therefore, results should be interpreted with caution.

Table 4: Multivariable-adjusted associations between isoenergetic macronutrient substitution and metabolic syndrome components, stratified by sex.

Macronutrient (substitution)	Sex	SBP B (95% CI)	DBP B (95% CI)	HDL-C B (95% CI)	TG B (95% CI)	WC B (95% CI)
CHO (fat)	Women	0.03 (-0.05, 0.11)	-0.04 (-0.09, 0.01)	0.00 (0.00, 0.01)	0.00 (-0.02, 0.03)	0.30 (-0.30, 0.89)
	Men	-0.04 (-0.17, 0.08)	0.01 (-0.07, 0.10)	-0.01 (-0.02, 0.01)	0.00 (-0.04, 0.03)	0.10 (-0.60, 0.79)
CHO (protein)	Women	0.03 (-0.05, 0.10)	-0.03 (-0.09, 0.02)	0.00 (-0.02, 0.01)	0.01 (-0.01, 0.03)	0.38 (-0.19, 0.96)
	Men	-0.04 (-0.17, 0.09)	0.02 (-0.06, 0.10)	-0.01 (-0.02, 0.01)	-0.01 (-0.05, 0.03)	0.13 (-0.53, 0.79)
Protein (fat)	Women	0.17 (-0.62, 0.96)	0.07 (-0.06, 0.20)	-0.02 (-0.05, 0.00)	0.05 (-0.01, 0.11)	0.94 (-0.45, 2.32)
	Men	0.24 (-0.89, 1.38)	0.12 (-0.51, 0.29)	0.01 (-0.02, 0.04)	-0.03 (-0.11, 0.05)	0.90 (-0.48, 2.30)

Note: SBP – systolic blood pressure; DBP – diastolic blood pressure; HDL-C – high-density lipoprotein cholesterol; TG – triglycerides; WC – waist circumference; CHO – carbohydrate. Regression coefficients (B) represent the change in the outcome variable per 5% increase in energy intake from the independent macronutrient, with a simultaneous isoenergetic decrease in the excluded macronutrient. Linear regression models were adjusted for age, place of residence, education level, sleep duration, smoking status, and physical activity level. Models for lipid outcomes (HDL-C and TG) were additionally adjusted for lipid-lowering medication use, and models for blood pressure outcomes (SBP and DBP) were adjusted for antihypertensive medication use. Units: SBP and DBP in mmHg; HDL-C and TG in mmol/L; WC in cm.

demonstrated without significant changes in macronutrient content, which indicates that total excess calorie intake could be a driving factor in development of metabolic abnormalities in this group [35].

Macronutrient substitution models further emphasized differential effects based on gender. No significant associations were found among women, but men who substituted dietary fats for protein had reduced odds for MetS and abdominal obesity. These results indicate that men and women may have differential physiological mechanisms regarding macronutrient replacement, which may be explained by their differences in hormonal environment, body composition, insulin resistance, and lipoprotein metabolism. Similar trends have been documented previously regarding the relationship between cardiometabolic risks and macronutrient consumption based on sex [36–38].

Collectively, these findings highlight the need to consider gender-based approaches to managing metabolic syndrome in Moroccan patients with type 2 diabetes mellitus. Management must include physical activity promotion and culturally tailored dietary advice, balancing energy expenditure and quality of macronutrients. The discrepancies between our findings and those of others can be attributed to differences in cultural beliefs, diet, genetics, and the country's nutritional transition towards more energy-dense diets, which contribute to metabolic disorders in the region [3, 39]. Understanding such contextual variables is crucial for designing evidence-based and sustainable programs to prevent metabolic syndrome and their associated complications.

There are various strengths to this study, which include its relatively large sample size of adult type 2 diabetics as well as the use of energy adjusted macronutrient substitution models. The latter makes for a more refined assessment of the possible influence of food composition on components of metabolic syndrome. The sex-stratified nature of the analysis also adds to the biological significance of the results obtained, as it emphasizes the importance of gender difference in such cases, despite being inadequately studied otherwise.

Nevertheless, some weaknesses have to be mentioned as well. First off, the cross-sectional nature of the study makes it impossible to derive causal relations from the results. In addition, diet composition was self-reported, meaning that there was always a chance of recall bias and inaccurate measurements. Moreover, such factors as diet quality, psychosocial stress, and medication adherence were not controlled for, thereby posing a risk of residual confounding.

Conclusion

This study emphasizes the relatively high prevalence of metabolic syndrome in adults with type 2 diabetes mellitus among the Moroccan population, with an increased incidence rate among females. The sex differences among various social-demographic, anthropometric, biochemical, lifestyle, and nutritional aspects have been demonstrated, indicating the heterogeneous and multifactorial background of MetS. Abdominal obesity, abnormal lipid profile, high blood pressure, and hyperglycemia were regarded as key factors related to insufficient physical activities and energy imbalance.

In addition, the substitution analysis between macronutrients confirmed the existence of unique gender-related links and proved that qualitative changes in dietary habits may affect the cardiometabolic health of patients differently. This information may be valuable for the development of sex-specific treatment strategies aiming at reducing abdominal obesity, increasing physical activities, and improving macronutrient content.

Conflict of interest

The authors declare no conflict of interest.

Ethics approval

The approval for this study was obtained from the Regional Directorate of Health and Social Protection of the Fez-Meknes region (approval ID: 2774/2024).

Consent to participate

Written informed consent was obtained from all participants after they were fully informed about the study objectives. Confidentiality was strictly maintained through anonymization and secure data storage. Participants were informed of their right to withdraw from the study at any time without any consequences to their care.

References

1. Timalisina S, Pandit P. Prevalence of Metabolic Syndrome and Its Components in Patients with Type 2 Diabetes Mellitus: A

- Cross-Sectional Study at a Tertiary Care Teaching Hospital. Journal of Chitwan Medical College. 2019 Jun 21;9(2):24–9. Located at: Nepal
2. Gimeno Orna JA, Lou Arnal LM, Molinero Herguedas E, Boned Julián B, Portilla Córdoba DP. Metabolic Syndrome as a Cardiovascular Risk Factor in Patients With Type 2 Diabetes. Revista Española de Cardiología (English Edition). 2004 Jun 1;57(6):507–13. doi:10.1016/S1885-5857(06)60626-9
3. Ogbera AO. Prevalence and gender distribution of the metabolic syndrome. Diabetology & Metabolic Syndrome. 2010 Jan 12;2(1):1. doi:10.1186/1758-5996-2-1
4. Caceaune E, Licăroiu D, Brădescu O, Caceaune N, Ionescu-Tîrgoviște C. METABOLIC DISORDERS AND CARDIOVASCULAR RISK ENHANCED BY NONALCOHOLIC FATTY LIVER DISEASE IN PATIENTS WITH METABOLIC SYNDROM. Romanian Journal of Diabetes Nutrition and Metabolic Diseases. 2012 May 31;19(2):151–60.
5. Park S, Lee J, Seok JW, Park CG, Jun J. Comprehensive lifestyle modification interventions for metabolic syndrome: A systematic review and meta-analysis. Journal of Nursing Scholarship. 2024;56(2):249–59. doi:10.1111/jnu.12946
6. Barich F, Laamiri FZ, Mehdad S, Benaich S, Rami A, Idrissi M, et al. Energy and Macronutrients Intakes among Childbearing Age Women Living in the Urban Area of Morocco: A Cross-Sectional Study. J Nutr Metab. 2020;2020:2685809. doi:10.1155/2020/2685809 PubMed PMID: 33005453; PubMed Central PMCID: PMC7508217.
7. Evert AB, Boucher JL, Cypress M, Dunbar SA, Franz MJ, Mayer-Davis EJ, et al. Nutrition therapy recommendations for the management of adults with diabetes. Diabetes Care. 2014 Jan;37 Suppl 1:S120–143. doi:10.2337/dc14-S120 PubMed PMID: 24357208.
8. Omura Y, Murakami K, Matoba K, Nishimura R, Sasaki S. Effects of individualized dietary advice compared with conventional dietary advice for adults with type 2 diabetes: A randomized controlled trial. Nutrition, Metabolism and Cardiovascular Diseases. 2022 Apr 1;32(4):1035–44. doi:10.1016/j.numecd.2021.11.006 PubMed PMID: 35115208.
9. WU Y, EHLERT BW, PERELMAN D, PARK H, METWALLY AA, LU Y, et al. 1596-P: Personalized Glycemic Response to Carbohydrates and Associated Physiological Signatures in Multiomics. Diabetes. 2024 Jun 14;73(Supplement_1):1596-P. doi:10.2337/db24-1596-P
10. Harrison T, Lane KE, Boddy LM, Amirabdollahian F, Davies IG. Macronutrient intake and prevalence of markers of metabolic syndrome in white UK adult males in the National Diet and Nutrition Survey Rolling Programme 2008–2014. Proceedings of the Nutrition Society. 2017 Jan;76(OCE4):E198. doi:10.1017/S0029665117003603
11. Wali JA, Solon-Biet SM, Freire T, Brandon AE. Macronutrient Determinants of Obesity, Insulin Resistance and Metabolic Health. Biology. 2021 Apr;10(4):336. doi:10.3390/biology10040336
12. McKeown NM, Meigs JB, Liu S, Saltzman E, Wilson PWF, Jacques PF. Carbohydrate nutrition, insulin resistance, and the prevalence of the metabolic syndrome in the Framingham Offspring Cohort. Diabetes Care. 2004 Feb;27(2):538–46. doi:10.2337/diacare.27.2.538 PubMed PMID: 14747241.
13. Freire RD, Cardoso MA, Gimeno SGA, Ferreira SRG, Japanese-Brazilian Diabetes Study Group. Dietary fat is associated with metabolic syndrome in Japanese Brazilians. Diabetes Care. 2005 Jul;28(7):1779–85. doi:10.2337/diacare.28.7.1779 PubMed PMID: 15983334.
14. MSPS/DPRF. Santé en chiffre 2023 [Internet]. 2024 [cited 2025 Jul 23]. Available from: <https://www.sante.gov.ma/Documents/2025/01/Sante%20en%20chiffre%202023%20VF.pdf>
15. MSPS. Protocole thérapeutique : le diabète [Internet]. Edition 2023; 2023 [cited 2025 Jul 23]. Available from: [https://www.sante.gov.ma/Documents/2024/11/PT%20Diabete%20\(3\).pdf](https://www.sante.gov.ma/Documents/2024/11/PT%20Diabete%20(3).pdf)
16. Essafi MA, Bouabdellaoui L, Aynaou H, Salhi H, El Ouahabi H. Metabolic Syndrome in Patients With Diabetes Mellitus. Cureus. 2022 Apr 25. doi:10.7759/cureus.24469
17. Daoudi D, Elghoulam N, Mahri NE, Bouh A, Aboussaleh Y, Zinedine A, et al. Prevalence and correlates of metabolic syndrome in type 2 diabetes patients: A cross sectional study at the provincial diabetes center in Meknes, Morocco. Clinical Epidemiology and Global Health. 2026 Mar 1;38. doi:10.1016/j.cegh.2026.102320
18. Hirshkowitz M, Whiton K, Albert SM, Alessi C, Bruni O, DonCarlos L, et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. Sleep Health. 2015 Mar;1(1):40–3. doi:10.1016/j.sleh.2014.12.010 PubMed PMID: 29073412.
19. Hercberg S, Deheeger M, Preziosi P. Portions alimentaires: manuel-photos pour l'estimation des quantités. SU. VI. MAX-Candia; 1994.
20. French Agency for Food, Environmental and Occupational Health & Safety. Ciqua [Internet]. 2020 [cited 2026 Mar 30]. Available from: <https://ciqua.anses.fr/>
21. Alberti KGMM, Eckel RH, Grundy SM, Zimmet PZ, Cleeman JI, Donato KA, et al. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. Circulation. 2009 Oct 20;120(16):1640–5. doi:10.1161/CIRCULATIONAHA.109.192644 PubMed PMID: 19805654.
22. Skilton MR, Laville M, Cust AE, Moulin P, Bonnet F. The association between dietary macronutrient intake and the prevalence of the metabolic syndrome. British Journal of Nutrition. 2008 Aug;100(2):400–7. doi:10.1017/S0007114507898655
23. Sekgala MD, Opperman M, Mpahleni B, Mchiza ZJR. Association between Macronutrient and Fatty Acid Consumption and Metabolic Syndrome: A South African Taxi Driver Survey. International Journal of Environmental Research and Public Health. 2022 Jan;19(23):15452. doi:10.3390/ijerph192315452
24. Mouzouni FZ, Mehdad S, Mounach S, Iraqi H, Benkirane H, Benaich S, et al. Diabetes prevalence is associated with obesity, hypertension, dyslipidemia, and sociodemographic factors in adults living in Casablanca-Settat and Rabat-Sale-Kenitra regions, Morocco. Int J Diabetes Dev Ctries. 2022 Jul 1;42(3):565–72. doi:10.1007/s13410-021-01006-7
25. Daoudi D, Moufid A, Elghoulam N, Bouh A, El Kari K, Rabi B, et al. Exploring the relationships of Metabolic Syndrome with sociodemographic factors, weight status, dietary and lifestyle behaviors in Moroccan adults. Clinical Epidemiology and Global Health. 2025 Jul 1;34:102058. doi:10.1016/j.cegh.2025.102058
26. Toppo A, Varma S, Sahu L. Comparative Evaluation of Metabolic Syndrome in Premenopausal and Postmenopausal Women. IOSR JDMS. 2017 Aug;16(06):01–9. doi:10.9790/0853-1606140109

27. Kc K, Katwal S, Yadav GK, Adhikari A, Thapa RK, Jha SK, et al. Family history of hypertension and its relation to other variables in hypertensive patients: a cross-sectional study from a tertiary care hospital. *IJS Global Health*. 2023 Sep;6(5):e0235. doi:10.1097/GH9.0000000000000235
28. Rojek A, Chrostowska M, Dudziak M, Narkiewicz K. Wpływ rodzinnego obciążenia nadciśnieniem tętniczym na rozwój otyłości brzusznej i zmiany w układzie sercowo-naczyniowym — wyniki 10-letniej prospektywnej obserwacji młodych zdrowych mężczyzn. 2011.
29. Chen YY, Fang WH, Wang CC, Kao TW, Chang YW, Yang HF, et al. Association of Percentage Body Fat and Metabolic Health in Offspring of Patients with Cardiovascular Diseases. *Sci Rep*. 2018 Sep 14;8(1):13831. doi:10.1038/s41598-018-32230-7
30. Ahmed W, Dixit P, Halli S. Additive interaction of family medical history of cardiovascular diseases with hypertension and diabetes on the diagnosis of cardiovascular diseases among older adults in India. *Front Cardiovasc Med*. 2024 Dec 5;11. doi:10.3389/fcvm.2024.1386378
31. Chelamkuri G, Venkateshwarlu. A Study of Biochemical Profile in Metabolic Syndrome. *Indian journal of applied research* [Internet]. 2015 [cited 2025 Aug 24];5(10). Available from: [https://www.worldwidejournals.com/indian-journal-of-applied-research-\(IJAR\)/fileview/October_2015_1492520011__197.pdf](https://www.worldwidejournals.com/indian-journal-of-applied-research-(IJAR)/fileview/October_2015_1492520011__197.pdf)
32. Chen WH, Hu Y, Zhao Y, Li ZY, Chen YT, Huang RC. The triglyceride-glucose index is a predictor for cardiovascular events and all-cause mortality in young and middle-aged patients with metabolic syndrome. *Eur Heart J*. 2024 Oct 28;45(Supplement_1):ehae666.2906. doi:10.1093/eurheartj/ehae666.2906
33. Trivedi AP, Patel MN, Panchal KR, Patel DS. Comparative Biochemical Analysis of Non-Diabetic Individuals with and without Metabolic Syndrome: A Cross-Sectional Study. *South Eastern European Journal of Public Health*. 2024 Nov 23;1177–81. doi:10.70135/seejph.vi.2369
34. FAO, WHO. Fats and fatty acids in human nutrition. Report of an expert consultation. *FAO Food Nutr Pap*. 2010;91:1–166. PubMed PMID: 21812367.
35. Veluvali A, Snyder M. Dietary fiber deficiency in individuals with metabolic syndrome: a review. *Current Opinion in Clinical Nutrition & Metabolic Care*. 2023 Nov;26(6):564. doi:10.1097/MCO.0000000000000971
36. Jolly SE, Eilat-Adar S, Wang H, Mete M, Fabsitz RR, Devereux RB, et al. Sex-specific associations of nutrition with hypertension and systolic blood pressure in Alaska Natives findings from the GOCADAN study. *International Journal of Circumpolar Health*. 2011 Feb 18;70(3):254–65. doi:10.3402/ijch.v70i3.17828 PubMed PMID: 21631966.
37. Ma Y, Su C, Wang H, Wang Z, Liang H, Zhang B. Relationship between carbohydrate intake and risk factors for cardiovascular disease in Chinese adults: data from the China Health and Nutrition Survey (CHNS). *Asia Pac J Clin Nutr*. 2019;28(3):520–32. doi:10.6133/apjcn.201909_28(3).0011 PubMed PMID: 31464398.
38. Mohammadifard N, Mansourian M, Firouzi S, Taheri M, Haghighatdoost F. Longitudinal association of dietary carbohydrate and the risk cardiovascular disease: a dose-response meta-analysis. *Crit Rev Food Sci Nutr*. 2022;62(23):6277–92. doi:10.1080/10408398.2021.1900057 PubMed PMID: 33739217.
39. Lepping K, Adams-Campbell LL, Hicks J, Mills M, Dash C. Dietary fiber intake and metabolic syndrome in postmenopausal African American women with obesity. *PLOS ONE*. 2022 Sep 2;17(9):e0273911. doi:10.1371/journal.pone.0273911