The association between modified Nordic diet with sleep quality and circadian rhythm in overweight and obese woman: a cross-sectional study

Seyed Ahmad Mousavi1 · Atieh Mirzababaei2 · Farideh Shiraseb2 · Cain C. T. Clark3 · Khadijeh Mirzaei2

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Abstract
Objective Previous studies have shown an association between diet quality and sleep quality. The objective of this study was to investigate the association between modified Nordic diet with sleep quality and circadian rhythm in overweight and obese woman.

Methods We enrolled 399 overweight and obese women (body mass index (BMI): 25–40 kg/m²), aged 18–48 years, in this cross-sectional study. For each participant, anthropometric measurements, biochemical tests, and food intake were evaluated. Sleep quality and circadian rhythm was measured by Pittsburgh Sleep Quality Index (PSQI) and morning–evening questionnaire (MEQ) questionnaire. Modified Nordic diet score was measured using a validated 147-item food frequency questionnaire (FFQ).

Results Overall, 51.7% of the subjects were good sleepers (the Pittsburgh Sleep Quality Index (PSQI) < 5) while 48.3% were poor sleepers (PSQI ≥ 5). Moreover, participants were divided into five groups of MEQ, namely, completely morning 8 (2.4%), rarely morning 82 (24.8%), normal 196 (59.2%), rarely evening 43 (13%), and completely evening 2 (0.6%). After controlling for confounders, there was a significant association between poor sleep quality and the modified Nordic diet (OR = 0.80, %95 CI = 0.66–0.98, \(P = 0.01\)). Moreover, a significant positive association was observed between the completely morning and modified Nordic diet (OR = 1.80, %95 CI = 0.54–6.00, \(P = 0.03\)), in addition to a significant inverse association between the completely evening type and modified Nordic diet (OR = 0.16, %95 CI = 0.002–5.41, \(P = 0.02\)).

Conclusions The present study indicated that higher adherence to a modified Nordic diet reduces poor sleep quality. Also, the completely morning type was associated with higher adherence to a modified Nordic diet, and completely evening type was associated with lower adherence to a modified Nordic diet.

Levels of evidence Level IV, evidence obtained from multiple time series analysis.

Keywords Modified Nordic diet · Diet quality · Sleep quality · Circadian rhythm

Abbreviations
PSQI Pittsburgh Sleep Quality Index
MEQ Morning–evening questionnaire
FFQ Food frequency questionnaire
IPAQ International Physical Activity Questionnaire
WC Waist circumference
HC Hip circumference
EPA Eicosapentaenoic acid
DHA Docosahexaenoic acid
SCN Suprachiasmatic nuclei
NMDA \(\gamma\)-Methyl-\(\theta\)-aspartic acid
GABA \(\gamma\)-Aminobutyric acid
SOL Sleep onset latency
CCK Cholecystokinin

Khadijeh Mirzaei
mirzaei_kh@tums.ac.ir

1 Department of Nutrition Science, Science and Research Branch, Faculty of Medical Sciences and Technologies, Islamic Azad University, Tehran, Iran
2 Department of Community Nutrition, School of Nutritional Sciences and Dietetics, Tehran University of Medical Sciences (TUMS), P.O. Box: 14155-6117, Tehran, Iran
3 Centre for Intelligent Healthcare, Coventry University, Coventry CV1 5FB, UK
Introduction

All countries around the world have been and remain subject to the growing issue of obesity in recent decades, and it has turned into a major concern for the public health. It is remarkable that obesity has been quite aggressive in terms of its prevalence in the previous 2 decades [1]. Based on the report from National Health and Nutrition Examination and Survey done in the year 2017–2018, the obesity prevalence in adults was 42.4% in terms of age and no considerable difference between men and women was found, including all adults of any age [1]. An interrelated number of factors including genetic susceptibility, high-energy food consumption, and low physical activity have given rise to what can be called the global epidemic of obesity [2]. Moreover, obesity and impaired mental health are linked, resulting in anxiety, stress, depression, and low quality of sleep [3, 4]. It has been reported that duration of sleep has decreased from 9 to 7 h per day in the past 60 years [5], while insomnia is marked by 10–20% prevalence [6]. According to a number of reports, unfavorable sleep quality could be linked to greater obesity and it has turned quite widespread in the course of the last decade. In addition, sleep deprivation/insufficiency and lower diet quality are reportedly related to numerous chronic complications or diseases such as diabetes mellitus and metabolic syndrome [7–9]. Nordic diet represents a dietary pattern that emphasizes the consumption of traditional Nordic foods (the Scandinavian region) such as all grains, fruits (apples, pears, and berries), low-fat dairy products, fatty fish like salmon, cabbage, and root vegetables [10]. Researchers have shown that adherence to the Nordic diet may result in lower weight [11–14].

Nearly the entire living organisms enjoy transformed autoregulatory transcriptional-translational feedback loops that cause fluctuations over approximately 24 h. Such endogenous time-keeping mechanisms are named circadian clocks, whose major objective is to inject overt circadian rhythms to the organisms’ physiology to make sure that the major physiological functions and the outer environment remain synchronized. Any interference in circadian rhythms due to genetic or environmental factors will be quite ominous for metabolic health. In addition, it is widely known that host circadian rhythmicity and lipid metabolism cross-regulate and the circadian clock-lipid metabolism interplay plays a role in obesity progression [15]. Sleep difficulties and problems are widely deemed as the growing global epidemic [16, 17]. Indeed, different researchers have pointed to the relationship between sleep problems and obesity [18, 19] and found that the former serves as a definite factor in obesity progression, given that the changes yielding weight gain, shorter sleep duration, and lower sleep quality would cause behavioral, metabolic, and endocrine perturbations [20, 21]; in addition, any circadian rhythm interference corresponds to a significant obesity risk [15, 22]. Researchers have pointed out that Nordic-based diets may be linked to sleep quality positively [23, 24]. Nevertheless, one researcher has reported that the Nordic diet is not associated with sleep quality [25]. Therefore, this research paper investigated the link between the modified Nordic diet with sleep quality and circadian rhythm in overweight women.

Method

Study population

This cross-sectional study was conducted with 399 women, who were referred to health centers in Tehran, Iran, from 2017 to 2019. Inclusion criteria were; those aged 18–48 years, being overweight or obese (body mass index (BMI): 25–40 kg/m²), without any change in weight in the last year, the absence of any acute or chronic infection, no alcohol or drug or supplement abuse, no history of hypertension, and not being pregnant. The reason that BMI above 40 were excluded was due to the associated increase risk of morbidity [26].

Based on exclusion criteria, subjects that consumed less than 800 kcal and more than 4200 kcal were also excluded from the study. Written informed consent was obtained from all participants prior to taking part in the study. The study protocol was approved by the local ethical committee of Tehran University of Medical Sciences (Ethics number: IR.TUMS.MEDICINE.REC.1399.637).

Evaluation of food intake

To assess the dietary intake of participants, a semi-quantitative food frequency questionnaire (FFQ) with 147 Iranian food items, containing a list of foods with standard serving sizes was used. The FFQ assesses the usual food intake over the previous year. The high reliability and validity of the FFQ has been confirmed previously [27]. All FFQ and demographic questionnaires were completed by trained nutritionists. The energy of food consumed was evaluated using Nutritionist 4 software. The Nordic diet is a dietary pattern referring to consumption of traditional foods from the Nordic countries (the Scandinavian region), including whole grains, fruits (such as apples, pears, and berries), low-fat dairy products, fatty fish, such as salmon, cabbage, and root vegetables. The modified Nordic diet score was based on: [1] rye and wholegrain breads with a median of 90, [2] oatmeal (chickpea, lentil, bean, oat, frumenty, soybean, split pea, vicia faba, and mung bean) with a median of
20, [3] cabbages and vegetables (cucumber, lettuce, celery, tomato, zucchini, raw and boiled spinach, bell pepper, and leafy vegetables) with a median of 132, [4] apples, pears and high antioxidant fruits (apple, apple juice, peach, strawberry, nectarine, pear, persimmon, apricot, dry apricot, mulberries, dry mulberries, plum, and dry plum) with a median of 97, [5] root vegetables (potato, raw and boiled carrot, garlic, onion, and turnip) with a median of 41 and [6] fish (fish conserved in salt and oil and other fish) with a median of 2. We calculated the median consumption of these food groups according to the FFQ. Consumption above and below median intake were given 1 and 0 points, respectively. The score of each group was summed and was classified: 0–1 point for low adherence, 2–3 points for medium adherence, and 4–6 points for high adherence [10].

**Assessment of sleep quality**

The Pittsburgh Sleep Quality Index (PSQI) was applied to subjectively measure the sleep quality of participants. It evaluates usual sleep habits during the past month, and total scores could range from 0 to 21, with a global sum of “5” or greater indicates poor sleep quality [28]. In Iran, sleep status has been investigated by the validated Pittsburgh questionnaire [29].

**Assessment of circadian rhythm**

The morning–evening questionnaire (MEQ) was utilized to assess circadian rhythm. The sum provides a score ranging from 16 to 86; scores of 41 and below indicate "evening types", scores of 59 and above indicate "morning types", scores between 42 and 58 indicate "intermediate types. A previous study investigated the content and convergent validity of the Persian Morningness–Eveningness Personality Questionnaire in employees and approved its’ validity and reliability [30].

**Assessment of other variables**

Demographic questionnaire including job status, educational level, marital status, and economic status was completed by trained nutritionists.

**Assessment of physical activity**

Physical activity levels were assessed using a seven-item International Physical Activity Questionnaire (IPAQ) and the results were reported as metabolic equivalent hours per week (MET·h week−1) [31].

**Assessment of anthropometric measurement**

The weight of the individuals was measured with the use of a digital scale (Seca, Hamburg, Germany), in light clothing and unshod, with a precision of 0.1 kg. The height of participants was evaluated using a Seca stadiometer, with a precision of 0.1 cm. BMI was calculated as weight (kg)/height² (m). Waist (WC) and hip circumference (HC) were measured in the smallest girth and the largest girth, respectively, to the nearest 0.1 cm.

**Statistical analysis**

A normal distribution of data was established using the Kolmogorov–Smirnov test. We divided the modified Nordic diet score into tertiles and general characteristics across tertiles of the modified Nordic diet score were reported as mean ± standard deviations (SD) for continuous variables, while categorical variables were expressed as numbers and percentages. One-way analysis of variance (ANOVA) and chi-squared test were used for quantitative and qualitative variables, respectively. Post hoc multiple comparison analysis using Bonferroni-corrected t tests was used to investigate significant differences mean between groups: analysis of covariance (ANCOVA) was used to identify dietary intake differences between tertiles of the modified Nordic diet score and all values were adjusted for energy intake, BMI, age, physical activity. Moreover, we used multinomial logistic regressions to calculate odds ratio (OR) and 95% CI for circadian rhythm and sleep quality across tertiles of modified Nordic diet score in crude and multivariable-adjusted models (adjusted for BMI, age, physical activity, energy intake, economic status, marital status, occupation, education, housing status, supplement consumption). All statistical analyses were done using the Statistical Package for Social Sciences (version 22; SPSS Inc.). P < 0.05 was considered to be statistically significant and P = 0.06 was considered represent marginal significance.

**Results**

**Study population characteristic**

A total of 399 women, aged 18–48 years, participated in this study. The quantitative and qualitative characteristics of the study subjects were presented across the tertiles modified Nordic diet shown in Table 1. The age and BMI of participants was 36.61 ± 9.11 year and 31.25 ± 4.30 kg/m², respectively. Moreover, participants were divided into five groups of MEQ, namely, completely morning 8 (2.4%), rarely morning 82 (24.8%), normal 196 (59.2%), rarely evening 43 (13%), completely evening 2 (0.6%), respectively. Sleep
Table 1  General characteristic variables across modified Nordic diet in overweight and obese women (n = 399)

| Variables | Modified Nordic diet tertiles | p value* | p value** |
|-----------|------------------------------|----------|----------|
|           | T1 (n = 72) ± SD             | T2 (n = 156) ± SD | T3 (n = 171) ± SD |
|           | Mean ± SD                    |           |          |
| Age (year) | 36.76 ± 10.11                | 36.28 ± 9.06 | 36.97 ± 8.75 | 0.78 | 0.40 |
| Weight (kg) | 81.72 ± 13.57               | 80.47 ± 11.53 | 81.82 ± 12.78 | 0.58 | 0.16 |
| Height (cm) | 161.42 ± 6.43               | 161.42 ± 5.76 | 160.95 ± 5.75 | 0.73 | 0.14 |
| IPAQ (METs h/week) | 890.56 ± 842.83b | 1345.89 ± 2566.82b | 1208.47 ± 1978.65 | 0.49 | 0.03 |
| Anthropometric indices | | | |
| BMI (kg/m²) | 31.45 ± 4.67               | 30.83 ± 3.70 | 31.55 ± 4.63 | 0.28 | 0.52 |
| HC (cm) | 112.11 ± 8.59               | 112.66 ± 8.85 | 115.49 ± 10.37 | 0.12 | 0.64 |
| WHR | 0.83 ± 0.06               | 0.83 ± 0.12 | 0.83 ± 0.15 | 0.96 | 0.58 |
| WC (cm) | 98.18 ± 10.18               | 96.81 ± 12.67 | 18.73 ± 1.69 | 0.87 | 0.59 |
| Blood Parameters | | | |
| FBS (mg/dl) | 87.10 ± 7.60               | 87.49 ± 10.45 | 87.52 ± 9.65 | 0.97 | 0.26 |
| Cholesterol (mg/dl) | 192.38 ± 35.56            | 185.27 ± 34.69 | 183.29 ± 36.69 | 0.38 | 0.78 |
| TG (mg/dl) | 123.76 ± 85.23               | 129.10 ± 69.17 | 116.25 ± 63.97 | 0.40 | 0.31 |
| HDL (mg/dl) | 47.94 ± 14.13a             | 45.70 ± 9.79 | 46.95 ± 10.38a | 0.06 | 0.04 |
| LDL (mg/dl) | 97.17 ± 24.70               | 96.38 ± 22.37 | 94.21 ± 25.15 | 0.71 | 0.94 |
| AST (µKat/L) | 18.12 ± 6.16              | 17.94 ± 7.18 | 18.14 ± 8.64 | 0.98 | 0.9 |
| ALT (µKat/L) | 18.66 ± 9.88              | 19.39 ± 12.77 | 19.78 ± 15.68 | 0.9 | 0.96 |
| Qualitative variables | | | |
| Marital status | | | |
| Single | 21 (19.4) | 46 (42.6) | 41 (38) | 0.66 | 0.59 |
| Married | 51 (17.8) | 112 (39.2) | 123 (43) | |
| Education status | | | |
| Illiterate | 0 (0) | 3 (75) | 1 (25) | 0.54 | 0.77 |
| Diploma | 11 (22.4) | 20 (40.8) | 18 (36.7) | |
| Bachelor and higher | 61 (17.9) | 136 (39.6) | 145 (42.5) | |
| Job-status | | | |
| Unemployed | 40 (18.1) | 89 (40.3) | 92 (41.6) | 0.95 | 0.68 |
| Employed | 26 (18.1) | 56 (38.9) | 62 (43.1) | |
| Home Ownership | | | |
| Yes | 25 (17.7) | 52 (36.9) | 64 (45.4) | 0.60 | 0.60 |
| No | 42 (18.9) | 91 (41) | 89 (40.1) | |
| Economic status | | | |
| Poor | 9 (22.5) | 18 (45) | 13 (32.5) | 0.04 | 0.05 |
| Moderate | 35 (21) | 76 (45.5) | 56 (35.5) | |
| Good | 27 (15.5) | 62 (35.6) | 85 (48.9) | |
| Supplement consumption | | | |
| Yes | 27 (17) | 66 (41.5) | 66 (41.5) | 0.93 | 0.82 |
| No | 33 (18.4) | 74 (41.3) | 72 (40.2) | |

IPAQ international physical activity questionnaire; BMI body mass index; WHR waist to hip ratio; WC: waist circumference; HP hip circumference; FBS: fasting blood sugar; TG triglyceride; HDL high-density lipoprotein; LDL low-density lipoprotein; AST aspartate aminotransferase; ALT Alanine aminotransferase; hs_CRP high sensitivity C-reactive protein

* p values resulted from ANOVA analysis. p value < 0.05 is significant

** p values presented resulted from ANCOVA analysis and were adjusted for age, BMI, energy, and physical activity

a Association between low tertile and high tertile of modified Nordic diet adherence, resulted by Bonferroni analysis

b Association between low tertile and medium tertile of modified Nordic diet adherence, resulted by Bonferroni analysis
quality was classified into two groups: good sleep quality 166 (51.7%), and poor sleep 155 (48.3%). The economic status of the study population in upper tertile was better than lower tertile, also in the upper tertile, more people were married vs. lower tertiles.

**Study population characteristic among tertiles of modified Nordic diet score**

After controlling for potential confounders (age, physical activity (PA), total energy intake, and BMI) with ANCOVA, a significant mean difference was observed among tertiles of the modified Nordic score in terms of physical activity ($P = 0.03$), such that there was a difference was between T1 and T2 following Bonferroni post hoc analysis where physical activity was greater in T2 than T1, while for HDL ($P = 0.04$), there was a mean difference was between T1 and T3 such that HDL mean was greater in T3 than T1. There was a marginally significant difference for the economic status variable ($P = 0.05$).

**Dietary intake of study subject across tertiles of modified Nordic diet score**

The modified Nordic diet components, macronutrient, and micronutrient across tertiles of modified Nordic diet score are presented in Table 2. After adjustment with potential confounders (total energy intake, physical activity, BMI, and age) participants with high modified Nordic diet adherence (T3) consumed a significantly higher amount of protein, Eicosapentanoic acid (EPA), Docosahexaenoic acid (DHA), Potassium, Magnesium, Zinc, Iron, vitamin B6, vitamin C, Caffeine ($P < 0.001$), fat ($P = 0.002$), calcium ($P = 0.003$) than low-modified Nordic diet adherence (T1), while carbohydrate was marginally significant ($P = 0.05$). As expected, across tertiles, significantly higher consumption of fish, root vegetable, cabbages, whole grain, oatmeal, rye bread, apple pear, vegetables ($P < 0.001$), red meat ($P = 0.01$), legumes ($P < 0.001$), fruits, and Sugar-sweetened beverages ($P = 0.09$) were evident in the highest levels of adherence to the modified Nordic diet.

**Circadian rhythm and sleep quality across tertiles of modified Nordic diet score**

The relationship between circadian rhythm and sleep quality with modified Nordic diet in crude and adjusted models is shown in Table 3. Model 1 was adjusted for energy intake, BMI, age, physical activity. Model 2 was further adjusted for economic status, job status, marital status, education. Model 3 was adjusted for homeownership, supplement consumption, caffeine consumption. After adjusting for homeownership, supplement consumption, and caffeine, a marginally significant difference was observed between the T1 and T3, according to Bonferroni post hoc testing, in terms of sleep quality in model 3 ($P = 0.05$), such that sleep quality was greater in T1 than T3. Moreover, no significant difference was observed between tertiles in model 1 and model 2 in sleep quality or any models for circadian rhythm.

**The association between sleep quality and circadian rhythm with modified Nordic diet score**

The association between sleep quality and circadian rhythm with modified Nordic diet was shown in the crude and adjusted regression models in Table 4. A significant inverse association was observed between the poor sleep quality and modified Nordic diet in the crude model (OR = 0.81, %95 CI = 0.68–0.98, $P = 0.02$), and this remained significant after controlling for confounders (economic status energy intake, BMI, age, physical activity) in the adjusted model (OR = 0.80, %95 CI = 0.66–0.98, $P = 0.01$). A significant positive association was observed between the completely morning type and modified Nordic diet in the adjusted model (OR = 1.80, %95 CI = 0.54–6.00, $P = 0.03$), and a significant inverse association was observed between completely evening type and modified Nordic diet in the adjusted model (OR = 0.16, %95 CI = 0.002–5.41, $P = 0.02$).

**Discussion**

This paper aims to investigate the relationship of the modified Nordic diet with sleep quality and circadian rhythm in woman suffering obesity. It is hypothesized that greater compliance with the modified Nordic diet score, representing a healthy dietary pattern, corresponds to high sleeping quality. The results of this study provide a new and distinct understanding of the relationship and possible pathways between sleep and diet. Accordingly, the outcomes illustrated an inverse relationship between compliance with the modified Nordic diet and poor sleep quality status. Besides, a considerable meaningful relationship between the completely morning and modified Nordic diet was observed. A considerable inverse relation between completely evening type and modified Nordic diet was observed.

Former cross-sectional researches have predominantly obtained findings pertaining to the relationship between diets with sleep quality and circadian rhythm. One of the relevant studies has illustrated that a short sleep duration as well as poor sleep quality are linked to minor compliance with Mediterranean and Nordic diets [25].

Circadian rhythm can be modulated by Melatonin so as to ameliorate sleep disorders [32–34]; indeed, it is posited that melatonin is able to diminish the circadian signal from the Supra-Chiasmatic Nuclei (SCN), thus increasing heat.
Table 2  Dietary intake of study subject across tertiles of modified Nordic diet score (n = 399)

| Variables               | Modified Nordic diet component | T1 (n=72) ± SD | T2 (n=156) ± SD | T3 (n=171) ± SD | p value |
|-------------------------|--------------------------------|---------------|---------------|---------------|---------|
| Fish (g/day)            | Crude                          | 5.89 ± 10.36  | 9.13 ± 8.31   | 15.15 ± 14.51 | < 0.001 |
|                         | Adjusted                       | 5.59 ± 2.07   | 9.18 ± 1.26   | 16.38 ± 1.20  | < 0.001 |
| Rootvegetable (g/day)   | Crude                          | 45.21 ± 22.20 | 66.78 ± 40.66 | 118.46 ± 58.89| < 0.001 |
|                         | Adjusted                       | 57.90 ± 8.70  | 71.80 ± 5.30  | 117.4 ± 5.08  | < 0.001 |
| Apple pear (g/day)     | Crude                          | 63.30 ± 44.32 | 111.09 ± 84.17| 179.31 ± 117.23| < 0.001 |
|                         | Adjusted                       | 74.20 ± 16.8  | 119.06 ± 10.27| 186.85 ± 9.78 | < 0.001 |
| Cabbage (g/day)         | Crude                          | 147.83 ± 97.48| 251.56 ± 205.44| 412.25 ± 199.80| < 0.001 |
|                         | Adjusted                       | 38.62 ± 31.71 | 240.48 ± 19.3 | 409.67 ± 18.38| < 0.001 |
| Rye bread (g/day)      | Crude                          | 28.62 ± 15.61 | 45.15 ± 34.36 | 77.09 ± 53.50 | < 0.001 |
|                         | Adjusted                       | 30.86 ± 7.23  | 43.65 ± 4.40  | 77.58 ± 4.19  | < 0.001 |
| Other food groups       | Whole grains (g/day)            |               |               |               |         |
|                         | Crude                          | 4.20 ± 4.64   | 4.68 ± 7.20   | 11.46 ± 12.88 | < 0.001 |
|                         | Adjusted                       | 4.23 ± 1.72   | 4.63 ± 1.04   | 11.45 ± 1.00  | < 0.001 |
| Dairy (g/day)           | Crude                          | 280.02 ± 195.72| 347.59 ± 212.28| 464.67 ± 268.79| 0.12    |
|                         | Adjusted                       | 339.53 ± 38.79| 368.45 ± 23.60| 427.31 ± 22.62| 0.10    |
| Red meat (g/day)       | Crude                          | 14.56 ± 11.06 | 17.53 ± 14.95 | 27.64 ± 21.61 | < 0.001 |
|                         | Adjusted                       | 17.30 ± 2.62  | 17.57 ± 1.60  | 24.03 ± 1.53  | 0.01    |
| Legumes (g/day)        | Crude                          | 28.59 ± 16.33 | 41.05 ± 27.64 | 72.28 ± 48.75 | < 0.001 |
|                         | Adjusted                       | 27.67 ± 6.51  | 40.12 ± 3.96  | 72.72 ± 3.80  | < 0.001 |
| Vegetables (g/day)     | Crude                          | 213.57 ± 96.52| 343.22 ± 215.41| 598.26 ± 245.16| < 0.001 |
|                         | Adjusted                       | 225.43 ± 36.54| 344.29 ± 22.23| 592.68 ± 21.31| < 0.001 |
| Nuts (g/day)           | Crude                          | 10.11 ± 17.73 | 11.93 ± 14.84 | 18.16 ± 16.02 | 0.001   |
|                         | Adjusted                       | 9.07 ± 3.38   | 12.99 ± 2.40  | 17.41 ± 3.29  | 0.75    |
| Fruits (g/day)         | Crude                          | 333.05 ± 248.08| 452.40 ± 286.93| 672.01 ± 352.02| < 0.001 |
|                         | Adjusted                       | 400.43 ± 47.29| 457.52 ± 28.77| 613.08 ± 27.58| < 0.001 |
| Sugar-sweetened beverages (g/d) | Crude                          | 24.35 ± 8.32  | 30.94 ± 8.26  | 20.05 ± 48.80 | 0.40    |
|                         | Adjusted                       | 30.85 ± 9.16  | 31.69 ± 5.57  | 14.80 ± 5.34  | 0.09    |
| Macronutrients         | Energy (kcal/day)              | 2474.35 ± 88.99| 2559.77 ± 80.31| 2701.13 ± 74.49| 0.14    |
|                         | Protein (g/day)                | 77.53 ± 2.75  | 83.92 ± 1.68  | 95.63 ± 1.59  | < 0.001 |
|                         | Carbohydrate (g/day)           | 360.42 ± 8.07 | 360.27 ± 4.94 | 376.63 ± 4.68 | 0.05    |
|                         | Fat (g/day)                    | 99.15 ± 3.48  | 98.36 ± 2.13  | 88.11 ± 2.02  | 0.002   |
Table 2 (continued)

| Variables                          | Modified Nordic diet components | T1(n = 72) ± SD                         | T2(n = 156) ± SD                        | T3(n = 171) ± SD                        | p value |
|-----------------------------------|---------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|---------|
| Micronutrients                    |                                 |                                        |                                        |                                        |         |
| EPA (mg/day)                      | 0.01 ± 0.006                    | 0.024 ± 0.004                          | 0.05 ± 0.004                           | < 0.001                                |         |
| DHA (mg/day)                      | 0.04 ± 0.02                     | 0.081 ± 0.012                          | 0.16 ± 0.011                           | < 0.001                                |         |
| Minerals                          |                                 |                                        |                                        |                                        |         |
| Potassium (mg/day)                | 3348.43 ± 149.65                | 3909 ± 161                             | 4920.33 ± 86.72                        | < 0.001                                |         |
| Mg (mg/day)                       | 382.75 ± 13.35                  | 435.01 ± 8.16                          | 498.59 ± 17.73                         | < 0.001                                |         |
| Zinc (mg/day)                     | 11.52 ± 0.36                    | 12.36 ± 0.22                           | 13.55 ± 0.20                           | < 0.001                                |         |
| Calcium (mg/day)                  | 1047.34 ± 50.84                 | 1103.09 ± 31.10                        | 1227.64 ± 29.46                        | 0.003                                   |         |
| Iron (mg/day)                     | 17.26 ± 0.47                    | 17.83 ± 0.28                           | 19.44 ± 0.27                           | < 0.001                                |         |
| Vitamins                          |                                 |                                        |                                        |                                        |         |
| B1 (mg/day)                       | 2.098 ± 0.06                    | 2.06 ± 0.03                            | 2.05 ± 0.035                           | 0.84                                   |         |
| B6 (mg/day)                       | 1.82 ± 0.68                     | 1.99 ± 0.04                            | 2.41 ± 0.039                           | < 0.001                                |         |
| B12 (mcg/d)                       | 4.32 ± 0.36                     | 4.29 ± 0.23                            | 4.45 ± 0.21                           | 0.87                                   |         |
| C (mg/day)                        | 152.15 ± 15.15                  | 159.42 ± 9.27                          | 224.24 ± 8.78                          | < 0.001                                |         |
| E (mg/day)                        | 17.58 ± 1.50                    | 18.93 ± 0.92                           | 16.25 ± 0.87                           | 0.12                                   |         |
| D (mcg/d)                         | 1.69 ± 0.26                     | 1.83 ± 0.16                            | 2.21 ± 0.15                           | 0.15                                   |         |
| Others                            |                                 |                                        |                                        |                                        |         |
| Caffeine (mg/day)                 | 135.88 ± 25.88                  | 162.69 ± 15.83                         | 141.31 ± 15.00                         | 0.51                                   |         |

p value < 0.05 is significant

DHA docosahexaenoic acid, EPA eicosatetraenoic acid
* p values resulted from ANOVA analysis
** p values resulted from ANCOVA analysis and were adjusted for energy intake, physical activity, BMI, age

a From this row, all variables were adjusted for energy intake, physical activity, BMI, age

Table 3 Circadian rhythm and sleep quality across tertiles of modified Nordic diet score (n = 399)

| Variables                      | Model      | Circadian rhythm and sleep quality of participant |
|-------------------------------|------------|-----------------------------------------------|
|                               | T1(n = 72) ± SD | T2(n = 156) ± SD | T3(n = 171) ± SD | p value** ± SD |
| PSQI score                    | Crude      | 5.89 ± 3.98 | 6.14 ± 3.55 | 6.00 ± 3.40 | 0.90 |
|                               | Model1     | 5.98 ± 0.71 | 5.81 ± 0.41 | 5.37 ± 0.39 | 0.65 |
|                               | Model2     | 5.81 ± 0.72 | 5.84 ± 0.42 | 5.50 ± 0.39 | 0.82 |
|                               | Model3     | 8.49 ± 1.41a | 5.61 ± 0.66 | 5.64 ± 0.57a | 0.05 |
| MEQ score                     | Crude      | 53.45 ± 9.38 | 52.19 ± 10.93 | 52.81 ± 8.78 | 0.71 |
|                               | Model1     | 52.03 ± 1.76 | 52.58 ± 1.06 | 53.67 ± 1.04 | 0.65 |
|                               | Model2     | 52.13 ± 1.76 | 52.23 ± 1.08 | 53.61 ± 1.05 | 0.61 |
|                               | Model3     | 49.00 ± 3.34 | 53.60 ± 1.55 | 53.38 ± 1.35 | 0.47 |

PSQI Pittsburgh sleep questionnaire index, MEQ morningness eveningness questionnaire

Model 1 was adjusted for energy intake, BMI, age, physical activity
Model 2 was adjusted for economic status, job status, marital status, education
Model 3 was adjusted for homeownership, supplement consumption, caffeine consumption

p value < 0.05 consider significant

** p values presented resulted from ANOVA and ANCOVA analysis
a Association between low tertile and high tertile of modified Nordic diet adherence, resulted by Bonferroni analysis
loss that causes drowsiness through the preoptic area of the anterior hypothalamus [35]. As demonstrated, the concentration of melatonin in human serum might increase considerably after melatonin-containing food consumption, such as fruits and vegetables [36]. In animal foods, melatonin concentration was determined to be greater in fish than in meat [37]. Other researches have shown that calcium, magnesium, and potassium represent neuromodulators in the sleep/wake cycle and are instrumental to melatonin production through tryptophan hydroxylase activation [38, 39]. Different micronutrients contribute to sleep and circadian regulation, especially the ones that favor melatonin synthesis (folate, vitamin B6, and zinc) [40]; indeed, adults with short sleep have been reported to have insufficient intake of copper, folate, iron, magnesium, riboflavin, zinc, and vitamins A, C, and K [41]. One of the cell-autonomous time-keeping components is intracellular magnesium concentration that helps find key clock properties in human cell lines and unicellular alga [42]. Moreover, magnesium is essentially conducive to ion transport and electrical conductivity, facilitating \(N\)-methyl-\(d\)-Aspartic Acid (NMDA) receptor function, a significant regulator for sleep [43]. Magnesium can contribute to the synthesis of melatonin as a cofactor in serotonin \(N\) acetyltransferase (arylalkylamine-\(N\)-acetyltransferase; AANAT). In addition, it makes the serotonin-to-\(N\)-acetylserotonin conversion easier, which is the rate-limiting step in melatonin synthesis [44]. Another research associated low calcium intake with insomnia, and low carbohydrate intake was linked considerably to insomnia. In addition, the link between low potassium intake and greater daytime sleepiness was considered and low calcium and vitamin C intake considerably corresponded to greater non-restorative sleep [45]. Less sleep constraints related to elevated calcium could result from calcium effects on reducing blood pressure [46]. The melatonin role in circadian rhythms is often investigated using two animal models namely melatonin-proficient (C3H) and melatonin-deficient (C57BL) mice. Accordingly, a previous study investigated three clock gene proteins, PER1, BMAL1, and CRY2, in the adrenal cortex of mice and medulla and found that C3H, PER1, and CRY2 mice increased to the maximum level in the light phase, while BMAL1 soared at the dark phase. These levels of clock gene protein pointed to day/night changes in the adrenal and medullary cortex. Identical patterns were observed in the adrenal cortex of C57BL mice; however, in the adrenal cortex of C57BL mice, the protein level of the clock gene consistently remained less than that in C3H mice and stayed unchanged with the passage of time [47]. The impact of polyphenols on sleep measures can be mediated using their antioxidant content, decreasing oxidative stress and enhancing sleep quality [48]. According to St-Onge, plant-based diets can enhance sleep quality [49]. Moreover, polyphenol-rich food supplementation managed to improve sleep quality significantly by 43% [50]. An opposite relationship between the consumption of fruits and vegetables and poor quality of sleep was observed [51], while minor intake of vegetables and fish, high intake of confectionary and noodles, and unhealthy eating habits corresponded autonomously to poor quality of sleep [52]. The initial possible mechanism of how polyphenols derived from the consumption of fruits and vegetables might impact sleep measures is through the gut–brain axis via serotonin and \(\gamma\)-aminobutyric

### Table 4: Association between sleep quality and circadian rhythm with modify Nordic diet (\(n = 399\))

| Variable                      | Nordic diet score |                 |                 |
|-------------------------------|-------------------|----------------|-----------------|
|                               | Crude model       | Adjust model    |                 |
|                               | OR      | 0.95% CI | \(p\) value | OR      | 0.95% CI | \(p\) value |
| PSQI score                    |            |            |                 |            |            |                 |
| Poor sleep quality \(a\)     | 0.81     | 0.68–0.96 | 0.02            | 0.80     | 0.66–0.96 | 0.01            |
| Good sleep quality            | –        | –         | –               | –        | –         | –               |
| MEQ score                     |            |            |                 |            |            |                 |
| Completely morning type       | 1.23     | 0.71–2.13 | 0.44            | 1.80     | 0.54–6.00 | 0.03            |
| Relatively morning type       | 1.15     | 0.94–1.42 | 0.16            | 1.06     | 0.8–1.39  | 0.67            |
| Normal \(b\)                  | –        | –         | –               | –        | –         | –               |
| Relatively evening type       | 0.77     | 0.58–1.02 | 0.078           | 0.73     | 0.49–1.07 | 0.10            |
| Completely evening type       | 0.52     | 0.15–1.77 | 0.29            | 0.16     | 0.002–5.41 | 0.02            |

**PSQI** Pittsburgh sleep questionnaire index, **MEQ** morningness eveningness questionnaire

\(p\) value \(< 0.05\) is significant

\(\ast\) \(p\) value present result from multi nominal logistic regression for crude model without adjustment

\(\ast\) \(p\) value present result from multi nominal logistic regression with adjustment for economic status, total energy intake, BMI, age, physical activity

\(a\) The reference category for sleep quality “poor sleep”

\(b\) The reference category is “normal” circadian rhythm
acid (GABA) receptors, thus influencing the nocturnal secretion of melatonin [53]. Polyphenols in red cabbage extracts reduced Sleep Onset Latency (SOL) and prolonged sleep duration via γ aminobutyric acid GABA receptors in mice [54]. Low protein intake (<16% of energy from protein) corresponded to poor sleep quality and marginally to difficulty initiating sleep, while high protein intake (>19% of energy from protein) was related to difficulty maintaining sleep. Low carbohydrate intake (<50% of energy from carbohydrate) was partially linked to difficulty maintaining sleep, and these associations were considerable in only men [55]. Higher meat consumption corresponded to the incidence of snoring and low sleep quality [52]. Augmented fish intake is related to greater improvement of sleep quality [56], while dietary fat and protein, and too much smaller carbohydrates, causes cholecystokinin (CCK) release in the duodenum and jejunum [57]. Further, post prandial CCK release may stimulate the drowsiness of healthy adults two to three hours after high fat and low carbohydrate meal [58]. Ultimately, this study points to the high consumption of fish, root vegetable, cabbages, apple pear, vegetables, fruits, Eicosapentaenoic acid (EPA), Docosahexaenoic acid (DHA), potassium, magnesium, calcium, zinc, iron, B6, vitamin C, fat, and carbohydrate as the justifiable reasons behind the effect of modified Nordic diet on increasing the quality of sleep.

What is already known on this subject?

Recent studies show that the modified Nordic diet has emerged as a healthy eating option. Before the present study, very limited studies have been conducted on the association between modified Nordic diet and sleep. The reason we investigated the association between the modified Nordic diet and sleep is largely due to the reduction of sleep duration over the past 60 years [5], in addition to the 10–20% prevalence of insomnia [6]. Data from the current study suggest that those who had good quality sleep had higher adherence to a modified Nordic diet.

What does this study add?

No previous studies have been conducted relating to the modified Nordic diet and sleep in the Iranian population. We provide hitherto unseen evidence that it may be a suitable predictor of the relationship between diet and sleep.

Limitations and strengths

The present study is deemed to be cross-sectional and, therefore, causality could not be evaluated. Our sample was not large enough with the same-sex participants which limit the generalizability of our results. FFQ questionnaire intended for dietary assessment leads to over- or under-reporting food intake, largely because of the subjective nature of the assessment. However, the FFQ used in this study has been validated for this population. Because of insignificant compliance of the Iranian population with Nordic diet in, we refused to employ the original Nordic diet score and substituted the modified Nordic diet score; this should be acknowledged in future research. Because of various culture and dietary intakes, our outcomes fail to be generalizable beyond the borders of Iran. As far as we are concerned, no studies have previously analyzed the relationship between the changed Nordic diet with sleep quality and circadian rhythm in the Iranian population; accordingly, a novel piece of evidence is given so as to point to one favorable predictor of the relation between diet and sleep quality.

Conclusion

This study determined that lower odds of poor sleep quality were associated with significant compliance with a modified Nordic diet. Furthermore, the completely morning type was related to greater compliance with a modified Nordic diet in circadian rhythm and also, the completely evening type was related to insignificant compliance with a modified Nordic diet. Based on our findings, the altered Nordic diet could cause poor sleep quality and circadian rhythm in obese women. It is required to perform clinical trials shed light on the role of greater compliance with the modified Nordic diet in ensuring better sleep quality. Given that the current study is the first one to consider the modified Nordic diet as a measurement tool for diet quality, we believe that further research is needed to confirm the veracity of these outcomes through replication among different populations.

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Declarations

Conflict of interest All authors declare that they have no potential conflicts of interest.

Ethical approval The study protocol was approved by the Ethics Commission of Tehran University of Medical Sciences (Ethics Number: IR.TUMS.MEDICINE.REC.1399.637).

Informed consent A written informed consent was signed by all individuals.
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