The association of dietary acid-base load with psychological disorders, sleep and circadian rhythm among obese and overweight women: a cross-sectional study

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Abstract

Background: Epidemiological studies have reported that dietary acid load is associated with psychological disorders through different pathways. We aimed to examine the association of dietary acid-base load with psychological disorders, sleep and circadian rhythm.

Methods: This study was performed on 404 female subjects aged 18 years and above. We evaluated potential renal acid load (PRAL) and net endogenous acid production (NEAP) score by a validated food frequency questionnaire (FFQ) for Iran which contained 147 items. To assess psychological disorders, an Iranian validated version of the depression, anxiety and stress scale (DASS-21) was used. The Pittsburgh Sleep Quality Index (PSQI) and morning-evening questionnaire (MEQ) were applied to evaluate sleep quality and circadian rhythm status, respectively.

Results: After adjustment for a wide range of confounding variables, a significant positive association was observed between dietary acid-base load and severe depression (OR_{PRAL} =1.10, 95% CI=1.01-1.19, p=0.02 and OR_{NEAP}=2.46, 95% CI=1.41-14.61, p=0.02). Women in the high dietary acid base load category had higher anxiety (OR_{PRAL}=1.12, 95% CI=1.02-1.23, p=0.01 and OR_{NEAP}=1.80,95% CI=1.12-10.72, p=0.01). There was a strong positive relationship between dietary acid-base load and sleep disturbance (p<0.05). Additionally, circadian rhythm assessment showed that those with greater commitment to PRAL had 23% higher risk of being completely evening type, while the odds of being completely morning type were decreased by 15% and 12% across higher adherence to PRAL and NEAP.

Conclusion: Women with higher dietary acid-base load score had greater odds for depression, anxiety, psychological distress, sleep disturbance and evening-type circadian rhythm compared to lower ones.

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Key words: dietary acid-base load, psychological disorders, sleep, circadian rhythm, obesity

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Background

According to World Health Organization (WHO) reports,[1] psychological disorders such as depression, anxiety and psychological distress are an ever-growing burden worldwide.[2] In 2015, the reported global prevalence of depressive and anxiety disorders was 4.4% and 3.6%, respectively, with higher prevalence in women.[1,3,4] Moreover, national reports showed that more than 21% of Iranian adults suffer from mental disorders; depression and anxiety are the most common among them.[5]

In recent years, growing evidence has posited that, besides genetic and environmental factors, diet composition can play an important role in the development of the mental disorders, and obesity.[6-15] Most of the studies in this regard have been conducted on single nutrients, food items or energy intakes.[16,17] Consumption of refined grain, red/processed meat and sweet beverages appears to be associated with an increased risk of these common disorders.[18-20] Conversely, protective effects may be gained through a high intake of fruit, vegetables, low-fat dairy products, nuts, legumes and unrefined grains, due to their association with a decreased prevalence of obesity, anxiety and depression.[21-26] Considering circadian rhythm, light is the main synchronizer of the central clock and food is another important factor for modifying circadian rhythm of the peripheral clock.[15] Moreover, it seems that some nutrients, such as glucose, amino acids, some vitamins and minerals, caffeine and ethanol, are capable of modifying circadian rhythms.[15] Epidemiological studies are being conducted to assess the relationship of dietary patterns and dietary quality indices with various diseases.[27] Dietary acid load (DAL) is one of the indices that may be used to assess whole diet quality, whilst potential renal acid load (PRAL) and net endogenous acid production (NEAP) indices may be used to quantify acid–base load of the diet.[28]

PRAL scores, in comparison to NEAP, are better predictors of dietary acid load because they consider calcium, phosphorus, magnesium, protein and potassium, whereas NEAP is only calculated by the ratio of protein and potassium.[29,30] A negative PRAL value is suggestive of a base-forming potential, while a positive value points to an acid-forming potential.[31] In this regard, fruits and vegetables (alkali-rich food groups) have lower PRAL scores and promote alkalinity, while meats, refined grains and cheeses (high-phosphorus food groups) lead to acidity and have higher PRAL.[30] Indeed, western dietary patterns have higher PRAL scores, as compared to vegetarian eating patterns,[32] and are implicated in poorer behavioral outcomes.[33] Additionally, a recent study in diabetic patients found that participants with higher DAL scores and those who consume more animal-based diets, rather than plant-based diets, were more likely to have sleep disturbances and psychological disorders.[34] Another study, in women, showed greater odds for psychological disorders in those with higher dietary acid-base load scores.[35]

To our knowledge, no previous study has examined the association of dietary acid-base load with psychological disorders, sleep and circadian rhythm in overweight/obese women. Therefore, given the higher prevalence of sleep disturbances,[36] depression and anxiety,[36,37] and obesity in women,[38] we sought to assess the association of dietary acid-base load with psychological disorders, sleep and circadian rhythm among obese and overweight women.

Materials and methods

Study population

In this cross-sectional study, a random sampling method was used to recruit 404 subjects who were referred to 20 health centres affiliated to Tehran University of Medical Sciences (TUMS) in the south of Tehran, Iran between 2016 and 2018. Subjects were selected for inclusion if they: 1) were female; 2) were 20-48 years old; 3) did not have previous diagnosis of disease such as hypertension, cardiovascular diseases, fatty liver, metabolic and malignant disease; 4) did not take specific medications (including those that would affect weight, lipid metabolism, glucose metabolism and blood pressure); 5) were not on a specific diet; 6) were not pregnant; 7) were not menopausal; and 8) had not experienced depression or anxiety during the preceding year. Participants were excluded from the analysis if they had an extremely low or high total energy intake (<800 Kcal/day or >4200 Kcal/day). All participants provided informed consent prior to study commencement. Ethical approval for this protocol was given by TUMS (Ethics Number: IR.TUMS.VCR.REC.1395.1597).

Assessment of anthropometric measures

Body weight was measured, with participants unshod and in minimal clothing, using a calibrated digital scale (SECA 803, Germany). Height was measured while participants were in a standing position, using an unstretched tape measure, to the nearest 0.1 mm. Body mass index (BMI) was calculated as weight divided by height squared (kg/m^2). Waist circumference (WC) was measured at the umbilicus and recorded to the nearest 0.5 cm. A plastic tape measure was used to assess hip circumferences (HC) to the nearest 0.5cm; then the ratio between waist and hip (WHR) circumference was calculated.

Assessment of dietary intake

A 147-item semi-quantitative food frequency questionnaire (FFQ), which has been shown to be valid and reliable for the Iranian population, was used to determine dietary intakes over the preceding year.[39] All participants filled out the amount and frequency of consumption of each food item on a daily, weekly or monthly basis for the previous year. The reported portion sizes of consumed foods were converted to grams per day. Nutritionist IV software (Version 7.0; N-Squared Computing, Salem, OR, USA), which was adapted for Iranian foods, was used for analysis of nutrients.

Assessment of dietary acid load

Dietary acid load was calculated based on the PRAL[29,40] and NEAP methods.[41]

PRAL (mEq/d) = (protein [g/d] × 0.49) + (phosphate [mg/d] × 0.037) – (K [mg/d] × 0.021) – (Ca [mg/d] × 0.013) – (mg [mg/d] × 0.026).

Estimated NEAP; mEq/d = (54.5 × protein intake [g/d]/potassium intake [mEq/d])-10.2.

Assessment of other variables

Socio-demographic information, including age, education level, economic status, occupation, income level and supplement use, were assessed by questionnaire. Physical activity levels were recorded over seven days and expressed as metabolic equivalent hours per week (MET h/wk).[42]

Biochemical markers, including fasting blood sugar (FBS), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C) and triglyceride (TG), were obtained from the participants' blood sample.

Circadian rhythm assessment

The circadian rhythm was evaluated by using the morning-evening questionnaire (MEQ), which is a self-reported questionnaire consisting of 19 items focused on sleep pattern and waking habits, and with scores ranging from 16-86 points. The classification of these points is as follows: absolute evening type, which is rated 16 to 30; relative evening type for scores 31 to 41; intermediate for scores 42 to 58; relative morning type for scores 59 to 69; and absolute morning type for scores 70 to 86.[43] Reliability and validity of the MEQ questionnaire have been assessed, and approved, in the Iranian population.[44]

Assessment of psychological disorders: stress, anxiety and depression

To assess psychological disorders, we used the Iranian validated version of the depression, anxiety stress scale (DASS-21),[45,46] which is a 21-item structured questionnaire. This questionnaire consists of three self-evaluation subscales, including depression,

Table 1. Study participant characteristics between high and low acid load scores

Variables		Total n=404	PRAL median Low (≤–19.98) N=146	PRAL median High (>–19.98) N=258	P value	P value adjusted†	NEAP median Low (<–9.03) N=146	NEAP median High (>–9.03) N=258	P value	P value adjusted†
Demography										
Age (years)		36.67±9.10	35.77±8.78	37.17±9.25	0.14	0.29	35.44±8.78	37.36±9.22	**0.04**	0.11
Physical activity (MET-minutes/week)		1202.05±2085.34	854.07±919.3	1560.98±2782.47	**0.006**	**0.02**	88.83±944.30	1538.56±2789.83	**0.01**	**0.04**
Anthropometric assessment										
Weight (kg)		80.28±11.05	79.64±10.36	80.64±11.43	0.13	0.30	79.60±10.46	80.66±11.37	0.36	0.78
Height (cm)		161.22±5.87	161.49±6.08	161.06±5.74	0.38	**0.02**	161.53±6.10	161.04±5.74	0.42	0.21
HC (cm)		105.65±8.18	105.66±6.05	105.65±9.16	0.99	0.83	105.65±6.10	105.66±9.14	0.98	0.56
WC (cm)		99.16±9.42	98.98±9.49	99.27±9.40	0.77	0.002	98.90±9.44	99.31±9.43	0.67	**0.01**
BMI (kg/m^2)		30.98±3.90	30.70±3.89	31.14±3.90	0.28	0.22	30.66±3.86	30.16±3.91	0.22	0.26
WHR		1.16±4.54	0.93±0.53	1.29±5.69	0.45	0.001	0.93±0.05	1.029±5.69	0.45	**0.004**
Biochemical factors										
FBS (mg/dl)		87.49±9.64	87.33±9.26	87.62±10.01	0.81	0.51	87.46±9.87	87.51±9.47	0.96	0.21
TG (mg/dl)		118.10±58.88	119.95±61.94	116.42±56.15	0.63	0.17	120.57±61.93	115.80±56.03	0.52	0.13
TC (mg/dl)		185.30±35.77	183.25±3.25	187.04±3.08	0.41	0.86	182.97±3.22	187.45±3.10	0.31	0.70
LDL (mg/dl)		95.30±24.12	94.51±24.56	95.96±23.82	0.84	0.97	95.54±23.16	95.07±23.16	0.87	0.92
HDL (mg/dl)		46.58±10.86	47.77±9.77	45.51±11.68	**0.04**	0.31	47.65±9.57	45.59±11.88	0.13	0.31
Qualitative variables										
Supplement intake	Yes	159(39.4)	67(42.1)	92(57.9)	0.10	0.11	67(42.1)	92(57.9)	0.11	0.17
	No	179(44.3)	60(33.5)	119(66.5)			60(33.5)	119(66.5)		
Job status	Employed	161(39.9)	58(36.0)	103(46.0)	0.87	0.61	56(34.8)	105(65.2)	0.62	0.31
	Jobless	231(57.2)	69(64)	108(54)			131(65.2)	106(34.8)		
Economic status										
Low level		88(21.8)	34(38.6)	54(61.4)	0.42	0.31	32(36.4)	56(63.6)	0.34	0.47
Moderate level		184(45.5)	72(39.1)	112(60.9)			72(39.1)	112(60.9)		
High level		110(27.2)	35(31.8)	75(68.2)			35(31.8)	75(68.2)		
Education level										
Illiterate		4(1)	25(1)	3(75)	0.84	0.48	1(25)	3(75)	0.73	0.48
Below diploma		49(12.1)	17(34.7)	32(65.3)			16(32.7)	33(67.3)		
Diploma		124(30.7)	54(35.3)	99 (64.7)			54(35.3)	99(64.7)		
Masters and higher		218(54)	73(38.6)	116(61.4)			74(39.2)	115(60.8)		
Marital status										
Single		286(70.8)	35(32.1)	74(67.9)	0.40	0.69	33(30.3)	76(69.7)	0.29	0.69
Married		109(27)	110(38.5)	176(61.5)			112(39.2)	174(60.8)		
Income status	Low	107(26.5)	57(53.3)	50(46.7)	0.90	0.78	53(49.5)	54(50.5)	0.24	0.33
	High	126(31.2)	68(54)	58(46)			72(57.1)	54(42.9)		
House owner	Yes	237(58.7)	62(40.3)	92(59.7)	0.22	0.46	63(40.9)	91(59.1)	0.15	0.09
	No	154(41.3)	81(34.2)	156(65.8)			80(33.8)	157(66.2)		

HC, hip circumference; WC, waist circumference; BMI, body mass index; PRAL, potential renal acid load; NEAP, net endogenous acid production; WHR, waist to hip ratio; TC, total cholesterol; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; TG, triglycerides; FBS, fasting blood sugar.
All variables adjusted according to age, energy intake, physical activity, BMI and economic status.
Values are mean ±SD for crude models, and qualitative variables are presented as n (%).

Table 2. Dietary intakes of study population through the medians of dietary acid load scores

Variables	PRAL median		P value adjusted†	NEAP median		P value adjusted†
	Low (<19.98) n=146	High (>-19.98) n=258		Low (<-9.03) n=146	High (>-9.03) n=258	
Food groups						
Cereals (g/d)	1258.95±16.39	1357.70±16.87	**<0.001**	1256.23±16.23	1361.47±16.89	**<0.001**
Fruit (g/d)	1676.69±22.31	652.15±23.89	**<0.001**	1668.69±22.42	1395.42±23.28	**<0.001**
Vegetables (g/d)	497.74±2012	294.69±19.59	**<0.001**	487±20.55	305.59±19.84	**<0.001**
Legumes (g/d)	263.40±3.78	261.41±3.88	0.52	264.23±3.57	260.49±3.70	0.47
Nuts (g/d)	144.98±1.37	138.81±1.41	**0.002**	144.09±1.38	139.72±1.43	**0.03**
Dairy (g/d)	1272.09±21.60	1234.64±21.32	0.26	1272.09±20.66	1244.64±21.37	0.36
Eggs (g/d)	19.77±1.28	23.94±1.31	**0.02**	19.11±1.26	24.68±19.11	**0.003**
Meat^ (g/d)	350.42.39±4.53	366.12±4.66	**0.01**	349.40±4.66	367.36±4.66	**0.007**
Macronutrients						
Energy (kcal)	2515.59±66.65	2703.51.45	**0.02**	2530.33±66.75	2694.62±51.52	**0.05**
Carbohydrates (g/d)	370.85±42.57	330.47±46.58	**<0.001**	369.86±3.81	331.67±3.96	**<0.001**
Fat (g/d)	99.93±0.51	112.69±0.39	**<0.001**	100.55±1.71	112.12±1.77	**<0.001**
Protein (g/d)	92.00±0.21	93.28±0.16	0.56	91.40±0.21	93.94±0.16	0.25
Micronutrients						
Total fibre (g/d)	44.32±1.35	49.40±1.04	**0.05**	43.83±1.22	47.13±1.23	**0.06**
MUFA (g/d)	33.98±0.71	30.87±0.55	**<0.001**	33.72±0.72	29.20±0.73	**<0.001**
PUFA (g/d)	30.87±0.55	21.87±0.62	**0.002**	21.58±0.64	18.60±0.64	**0.001**
SFA (g/d)	27.51±0.47	29.97±0.61	**<0.001**	29.69±0.63	26.87±0.64	**0.002**
Linoleic acid (g/d)	18.44±0.66	15.89±0.68	**0.009**	18.47±0.66	15.84±0.69	**0.007**
Linolenic acid(g/d)	1.26±0.04	1.13±0.05	**0.06**	1.24±0.04	1.15±0.05	0.21
EPA (g/d)	0.035±0.00	0.032±0.00	0.59	0.037±0.00	0.031±0.00	0.21
DHA (g/d)	0.11±0.01	0.10±0.01	0.48	0.12±0.01	0.09±0.01	0.14
Minerals						
Iron (mg/d)	18.88±1.52	31.30±1.17	0.09	18.60±0.24	18.82±0.25	0.53
Zinc (mg/d)	12.70±0.21	13.84±0.16	**0.08**	12.74±0.19	13.11±0.19	0.17
Calcium (mg/d)	1151.11±32.71	1339.63±25.29	0.19	1234.98±25.38	1205.600±25.66	**0.05**
Magnesium (mg/d)	504.41±6.14	428±7.96	**<0.001**	490.45±6.84	428.44v6.77	**<0.001**
Potassium (mEq/d)	4931.33±63.14	2499.4±209.9	**<0.001**	4993.33±67.53	3690.11±66.79	**<0.001**
Sodium (mg/d)	4347.68±108.48	4852.55	0.18	4360.44±98.48	4679.05±102.48	**0.02**
Phosphate (mg/d)	1633.98±25.98	1700.7±20.07	0.68	1624.61±25.42	1658.69±25.70	0.35
Vitamins						
Vitamin C (mg/d)	216.63±6.19	141.18±8.01	**<0.001**	250.43v8.38	145.16±8.29	**<0.001**
Vitamin E (mg/d)	18.38±0.68	16.23±0.52	0.24	18.36±0.73	16.51±0.74	**0.08**
Vitamin A (mg/d)	887.79±30.03	673.3±29.70	**<0.001**	888.46±29.94	672.71±29.61	**<0.001**
Thiamin (mg/d)	2.18±0.04	2.12±0.03	**0.001**	2.00±0.03	2.18±0.2	**<0.001**
Riboflavin (mg/d)	2.18±0.04	2.33±0.03	0.44	2.17±0.04	2.25±0.04	0.23
Niacin (mg/d)	38.59±0.52	39.54±0.40	0.94	38.33±0.50	40.21±0.51	**0.01**
Vitamin B6 (mg/d)	2.04±0.03	2.29±0.02	**<0.001**	2.07±0.03	2.27±0.03	**<0.001**
Folate (mcg/d)	648.23±9.10	612.54 ±7.03	**0.008**	643.00±8.98	617.42±8.99	**0.06**
Vitamin B12 (mcg/d)	13.50±0.18	14.00±0.14	**0.06**	13.50±0.18	14.01±0.18	**0.05**
Other						
Caffeine (mg/d)	162.93±16.07	315.66±53.44	**0.008**	161.72±13.52	205.25±14.10	**0.02**

PRAL, potential renal acid load; NEAP, net endogenous acid production, EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid. SFA, saturated fatty acid
Values are expressed as mean ±SE. Nutrients and food groups were adjusted for age, BMI, physical activity and total energy intake.
^ Meat alternatives included meat, poultry, and kinds of seafood. †Adjusted p value obtained from the analysis of ovariance.

anxiety and psychological distress. Answers to each item are based on a four-point Likert scale rated as 0 (never), 1 (little), 2 (sometimes) and 3 (always). Participants rated the extent to which they had experienced each of the statuses during the last week. Each subscale received a score of 0-21. For depression, a total score between 0-9 is considered normal, whereas scores above 9 indicate increasing severity of depression. For anxiety, a total score between 0-7 is normal, and a score above 7 suggests an elevated anxiety level. For stress, a total score of 0-14 is normal, and scores greater than 14 are defined as having excess stress.[47,48]

Assessment of sleep

The Pittsburgh Sleep Quality Index (PSQI) questionnaire measures the quality and pattern of sleep over the preceding month. It consists of nine items, differentiating from poor to good on a 0 to 3 scale (0, not in the past month; 1, less than once per week; 2, once or twice per week; and 3, three or more times per week). These items cover sleep latency, duration and efficiency, use of sleep medication, sleep disturbances and daytime dysfunction. PSQI scores range between 0 and 21. A score of five and above indicates poor sleep quality. The reliability and validity of the PSQI questionnaire has been assessed, and confirmed, in the Iranian population.[49,50]

Statistical analysis

The Kolmogorov–Smirnov test was used to assess the distribution of the data. Continuous variables were represented by mean ± standard deviations (SDs), and categorical information was represented by percentage and number. To avoid classification errors, we calculated the energy-adjusted PRAL and NEAP using the residual method and then, based on the median, dichotomized participants into low or high dietary acid load. Baseline characteristics of participants were compared by independent sample t-tests between the median of PRAL and NEAP, and chi squared (χ^2) tests for categorical variables. Also, we adjusted variables for confounders, such as age, physical activity, BMI, total energy intake, supplement consumption, education status, economic status, job status, marital status, housing ownership, incoming status, and omega-3 fatty acids and caffeine intake. Multinomial logistic regression was used to evaluate the association between dietary acid load and the subscale of mental health, sleep quality and circadian rhythm. Data were analyzed using IBM SPSS version 25.0 (SPSS, Chicago, IL, USA) and p values less than 0.05 were considered, *a priori*, to represent statistical significance.

Results

Study population characteristics, and quantitative and qualitative variables across PRAL and NEAP medians

Among the studied population, 47.5%, 59.5% and 51.1% were depressed, anxious and stressed, respectively. Furthermore, 48.3% of participants had poor sleep quality. 24.8% were relatively morning-type (M-types), 13% were evening-type (E-types), while 59.2% were identified as being intermediate type. Of this population, 27.6% of individuals were married and 55.2% had a high educational level.

Further participant characteristics, and the differences between quantitative and qualitative variables across the medians of PRAL and NEAP, are presented in Table 1. The mean age, weight, BMI and physical activity of individuals were 36.67 years, 80.28 kg, 30.98 kg/m^2 and 1202.05 (MET-minutes/week), respectively. In the adjusted model (for age, energy intake, physical activity, BMI and economic status), participants included in the higher category of dietary acid-base load had greater physical activity (PPRAL=0.02, P_{NEAP}=0.04), WHR (P_{PRA}=0.001, P_{NEAP}=0.004) and WC (P_{PRAL}=0.002, P_{NEAP}=0.01). In the crude model, HDL-C level was significantly higher in those with lower PRAL scores (p=0.04), but after adjustment for potential confounders there was no significant difference of HDL-C based on the medians of PRAL (p=0.31). Regarding qualitative variables, there was no significant differences across PRAL and NEAP medians (p>0.05).

Dietary intake across PRAL and NEAP medians

Table 2 presents the mean intake of some food groups and macro/micronutrients through the medians of PRAL and NEAP scores. We observed that mean intake of, cereals (P_{PRAL}<0.001, P_{NEAP}<0.001), egg (P_{PRAL}=0.02, P_{NEAP}=0.003), meat (P_{PRAL}=0.01, P_{NEAP}=0.007), energy (P_{PRAL}=0.02, P_{NEAP}=0.05), fat (P_{PRAL} <0.001, P_{NEAP}<0.001), vitamin B6 (P_{PRAL}<0.001, P_{NEAP}<0.001) and caffeine (P_{PRAL}=0.008, P_{NEAP}=0.02) were higher, and fruit (P_{PRAL} <0.001, P_{NEAP}<0.001), nuts (P_{PRAL}=0.002, P_{NEAP}=0.03), carbohydrates (P_{PRAL}<0.001, P_{NEAP}<0.001), MUFA (P_{PRAL} <0.001, P_{NEAP}<0.001), PUFA (P_{PRAL}=0.002, P_{NEAP}<0.001), linoleic acid (P_{PRAL}=0.009, P_{NEAP}=0.007), magnesium (P_{PRAL} <0.001, P_{NEAP} <0.001), potassium (P_{PRAL}<0.001, P_{NEAP}<0.001), vitamin C (P_{PRAL} <0.001, P_{NEAP}<0.001) and vitamin A (P_{PRAL}<0.001, P_{NEAP}<0.001) were significantly lower in participants assigned to the highest category of PRAL and NEAP. However, vegetable intake was higher in those who had lower PRAL (p<0.001) and NEAP scores (p<0.001).

Association between psychological disorders, sleep quality and circadian rhythm plus PRAL and NEAP scores

We conducted multi-nominal logistic regression in crude and adjusted models (age, physical activity, BMI, total energy intake, supplement consumption, education status, economic status, job status, marital status, housing ownership, incoming status, omega-3 fatty acids and caffeine intake) (Table 3). In the adjusted models, the results revealed that the odds ratio (OR) of severe stress was 1.03 and 2.47 times higher in those who had greater adherence to PRAL and NEAP, respectively (OR_{PRAL} =1.03, 95% CI=1.01-1.04, p=0.04), (OR_{NEAP}=2.47,95% CI=1.48-12.67, p=0.01), in comparison to those who were in the normal group. Moreover, a significant positive association was observed between high dietary acid-base load indices and moderate (ORPRAL=1.04, 95% CI=1.01-1.11, p=0.01, OR_{NEAP}=1.40, 95% CI=1.00-6.62, p=0.05) and severe (ORPRAL=1.10, 95% CI=1.01-1.19, p=0.02, OR_{NEAP}=2.46, 95% CI=1.41-14.61, p=0.02) depression in the adjusted model versus normal group, respectively. Further, compared with the normal group,

Table 3. Association between mental health components, sleep quality plus circadian rhythm and dietary acid load scores

Variable	PRAL						NEAP					
	Crude model			Adjusted model			Crude model			Adjusted model		
	OR^	95% CI	P value	OR	95% CI	P value adjusted*	OR	95% CI	P value	OR	95% CI	P value adjusted*
Stress subscale [b]												
Normal [a]	–	–	–	–	–	–	–	–	–	–	–	–
Mild	0.98	0.96–1.00	0.05	1.01	0.13–1.17	0.09	0.29	0.08-1.02	**0.05**	2.75	0.12-1.58	0.09
Moderate	1.00	0.98–1.01	0.82	1.003	0.81-1.03	0.81	1.48	1.01-3.00	**0.04**	1.44	1.76-23.57	**0.02**
Severe	1.01	0.99–1.03	0.60	1.03	1.01-1.04	**0.04**	1.76	0.86-3.59	0.11	2.47	1.48-12.67	**0.01**
Extremelysevere	0.99	0.97–1.02	0.90	1.02	0.98-1.04	**0.07**	0.77	0.18-3.28	0.72	1.12	0.008-20.44	**0.09**
Depression [c] **subscale**												
Normal [a]	–	–	–	–	–	–	–	–	–	–	–	–
Mild	1.01	0.98–1.01	0.99	1.03	1.01,1.12	0.38	1.32	0.62-2.78	0.45	0.20	0.02-1.96	0.17
Moderate	1.03	0.98–1.01	0.74	1.04	1.01-1.11	**0.01**	1.17	0.56-2.42	0.66	1.40	1.00-6.62	**0.05**
Severe	1.01	0.98–1.03	0.84	1.10	1.01-1.19	**0.02**	0.98	0.30-2.72	0.87	2.46	1.41-14.61	**0.02**
Extremelysevere	1.01	0.98–1.03	0.37	1.01	0.99-1.03	0.08	1.60	0.69-3.67	0.26	2.05	1.19-21.99	**0.01**
Anxiety [d] **subscale**												
Normal [a]	–	–	–	–	–	–	–	–	–	–	–	–
Mild	1.01	0.98–1.03	0.42	1.03	0.92-1.16	0.52	2.00	0.79-5.03	0.14	1.35	0.11-15.50	0.80
Moderate	0.99	0.98–1.01	0.74	1.03	0.96-1.09	0.34	0.86	0.34-2.16	0.76	1.11	1.01-10.2	**0.03**
Severe	1.01	1.00–1.03	**0.04**	1.12	1.02-1.23	**0.01**	2.60	1.15-5.90	**0.02**	1.80	1.12-10.72	**0.01**
Extremely severe	1.01	0.98–1.02	0.40	1.11	1.01-1.15	**0.02**	1.40	0.54-3.62	0.47	1.00	0.69-6.46	0.66
PSQI score [e]												
Poor sleep quality [a]	0.99	0.98-1.01	0.72	1.01	1.00-1.25	**0.05**	0.83	0.41-1.67	0.60	2.59	1.12-54.59	**0.02**
Good sleep quality	–	–	–	–	–	–	–	–	–	–	–	–
MEQ score [f]												
Completely evening type	0.98	0.90-1.05	0.60	1.23	1.00-1.45	**0.05**	0.38	0.00-53.29	0.70	1.21	1.07-1.32	0.09
Completely morning type	0.99	0.94-1.03	0.68	0.85	0.65-0.98	**0.04**	0.32	0.01-8.09	0.49	0.88	0.71-0.98	**0.04**
Normal [a]	–	–	–	–	–	–	–	–	–	–	–	–
Relatively evening type	0.99	0.97-1.01	0.69	0.99	0.97-1.02	0.90	0.55	0.14-2.19	0.55	0.46	0.10-2.05	0.31
Relatively morning type	1.01	1.00-1.02	**0.05**	1.00	0.98-1.02	0.85	1.28	0.60-2.73	0.52	0.92	0.38-2.18	0.85

PRAL, potential renal acid load; NEAP, net endogenous acid production; MEQ, Morningness- Eveningness questionnaire; PSQI, Pittsburgh Sleep Quality Index
*Adjusted for age, physical activity, BMI, total energy intake, supplement consumption, education status, economic status, job status, marital status, housing ownership, income status, and omega-3 fatty acids and caffeine intake
^OR 0.95% CI p value
[a] as a reference group for mental health subgroups and sleep quality categories and circadian rhythm types.
[b] mild stress (15-18), moderate stress (19-25), severe stress (26-33), extremely severe stress (⩾ 34). [c] mild depression (10-13), moderate depression (14-20), severe depression (21- 27), extremely severe depression (⩾ 28). [d] mild anxiety (8-9), moderate anxiety (10-14), severe anxiety (15-19), extremely severe anxiety (⩾ 20).
[e] Poor sleep quality>=5
[f] score 70-86. " Definitely morning type", score 59-69; " Moderately morning type", score 42-58; neither type, score 31-41." Moderately evening type " and score 16-30 "Definitely evening type".
As a reference group, [b] the odds ratios (ORs) have been reported pattern scores tested by multinominal logistic regression P values less than 0.05 were considered statistically significant

participants with higher adherence to NEAP and PRAL values were more likely to be categorized as severely anxious (OR_{PREAL}=1.01, 95% CI=1.00–1.03, p=0.04 and OR_{NEAP}=2.60, 95% CI=1.15-5.90, p=0.02) in the crude model, and this remained significant in the adjusted model (p<0.05). Additionally, circadian rhythm assessment showed that those with greater PRAL scores had 23% higher risk of being completely E-type (OR_{PRAL} =1.23, 95% CI=1.00-1.45, p=0.05), while odds of being completely M-type were decreased by 15% and 12% across higher adherence to PRAL (OR_{PRAL}=0.85, 95% CI=0.65-0.98, p=0.04), and NEAP (ORNEAP=0.88, 95% CI=0.71-0.98, p=0.04), respectively. Regarding sleep quality, we observed a higher risk of sleep disturbance in higher PRAL (OR=1.01, 95% CI=1.00-1.25, p=0.05) and NEAP (OR=2.59, 95% CI=1.12-54.59, p=0.02) intake, in comparison to those with good sleep quality, respectively.

Discussion

In the current study, a significant positive association was observed between dietary acid load indices (PRAL and NEAP) and psychological disorders, disruption of sleep quality and late chronotype. These associations remained unchanged after adjustment for a wide range of confounding factors. To the best

of our knowledge, this is the first study comprehensively considering the association between dietary acid-base load and mental disorders, sleep quality and circadian rhythm among obese and overweight women.

Mental disorders and poor sleep quality are highly prevalent among overweight and obese women. They are concurrently associated with cardiovascular disease (CVD), diabetes and other chronic diseases.[51] Several studies suggest an association between obesity, sleep quality and depressive symptoms;[52,53] indeed, mental health could be affected by environmental factors such as dietary intake.[54] Previous studies have extensively investigated the association between dietary patterns and mental disorders.[21,55] However, only a few studies have investigated DAL and its association with the development of psychological disorders.[56,57] To the authors' knowledge, previous studies in this field have primarily focused on children, diabetic patients and normal-weight women.[34,56] The present study was conducted on overweight and obese females, thereby providing a novel insight and addition to the literature.

The results of the current study are concordant with previous cross-sectional studies showing that participants with higher adherence to DAL have greater odds of psychological disease.[34,56] A recent meta-analysis, by Saghafian *et al*, concluded that an inverse relationship was evident between fruit and vegetable intake and risk of depression.[59] Moreover, several studies have reported that wholegrain and dietary patterns rich in fruits and vegetables are inversely associated with psychological disorders.[60]

One of the purported mechanisms involved in the effect of DAL on mental disorders is the regulation of inflammation. With increasing plasma H+ concentration, inflammatory markers will, necessarily, increase.[61,62] Based on a previous finding in obese women, greater consumption of healthy plant foods might be useful for reducing inflammation factors, such as hs-CRP (64).[63] Indeed, this assertion has been supported by a number of studies that suggest psychological disorders and sleep disturbance are related to altered indicators of inflammation.[64-66] Moreover, cortisol concentration has been positively associated with acidosis conditions,[67] and a positive association between cortisol and psychological disorders has routinely been reported.[68,69] Furthermore, some authors have revealed that gamma aminobutyric acid (GABA) neuron activity may be disrupted by metabolic acidosis. It has been posited that this deficiency might lead to psychological disorders, such as depression, anxiety and insomnia, in acidotic environments.[70-72] Our study revealed women with higher DAL scores had higher abdominal obesity; other researchers have suggested that obesity may alter metabolism and circadian rhythms, leading to sleep disturbances. Additionally, fat accumulation could be another factor that contributes to sleep disorders.[73,74]

The present results demonstrated a significant association between diet-induced acidosis and poor-quality sleep: greater adherence to DAL was associated with a 59% higher odds of sleep disturbance. A similar conclusion was reached by Daneshzad *et al*, who reported that higher DAL scores and lower adherence to plant-based diets were significantly associated with poor quality sleep.[34] Other previous studies showed that adherence to diets high in fruits and vegetables might have a beneficial effect on sleep quality.[75,76]

In our study, greater commitment to PRAL was associated with a higher risk of being completely E-type. Most previous studies, which have been conducted mainly in adults, indicated that E-type individuals were more susceptible to eating fewer vegetables and fruits.[78,79] There appears to be a significant relationship among evening-type chronotypes and unhealthy dietary choices, including higher consumption of fast-foods and snacks, and lower consumption of fruits and vegetables.[78,79] In addition, being demarcated as a late chronotype was significantly associated with having a higher BMI, compared to early chronotype.[77]

As a multifactorial condition, circadian rhythm may also be determined by hormonal factors, genetic variation and environmental conditions, including dietary intake, which is believed to play an important role in the regulation of sleep wellness.[80] Individuals with higher dietary acid load had a higher intake of cereals, fat, caffeine, energy intake, and animal source foods such as eggs and meat. Also, lower consumption of fruit, nuts, carbohydrates, MUFA, PUFA, linoleic acid, magnesium, potassium and vitamin C was observed with greater adherence to DAL diets. Contemporary research shows that individuals who eat mainly animal source foods are more likely to have sleep disorders and suffer from psychological diseases.[34,56] Additionally, some authors have reported that adherence to an acid-based diet can increase urinary magnesium excretion in obese women. Emerging data suggest that one of the main enzyme cofactors involved in biochemical reactions is magnesium, which plays a crucial role in regulating circadian rhythms and sleep quality.[8] Recent research posits a significant inverse relationship between magnesium intake in diet and mental disorders among overweight women.[81] A clinical study in an Iranian population has highlighted the potential benefits of magnesium on sleep quality, morning awakening and regulation of sleep-inducing hormone.[82] It is also possible that there are negative effects of lower magnesium consumption in higher DAL intake on psychological disorders and poor-quality sleep.

Circadian rhythm is also known to be influenced by melatonin, which is found in different kinds of foods, such as fruits, vegetables and nuts.[83] People with greater adherence to DAL tend to have lower consumption of melatonin-rich foods. In our study, women with greater adherence to DAL had a significantly greater consumption of caffeine, which is universally accepted to negatively impact sleep quality and psychological health.[84-86]

A series of recent studies have indicated a significant relationship between total and saturated fat consumption and disruption of sleep quality, especially in women.[87,88] It seems that DHA may help to maintain a normal circadian rhythm of morning-type people. Other regulators of circadian rhythm are omega-3 sources and nuts, which are high in tryptophan. In our study, people with high DAL intake had greater fat, and lower MUFA, PUFA and linoleic acid, intake.

Key messages

- High dietary acid-base load indices are associated with an increased risk of psychological diseases.
- High dietary acid-base load indices are associated with poor sleep quality
- High dietary acid-base load indices are associated with late chronotype

The present study provides a novel addition to the literature, where information pertaining to the association of dietary acid-base load with psychological disorders, sleep and circadian rhythm among obese and overweight women was hitherto unavailable. However, despite the novelty of this study, several limitations should be considered in the interpretation of the current study. First, the FFQ and MEQ questionnaires were dependent on patient memory, which may have resulted in recall bias. Second, because of the cross-sectional design, causal inferences cannot be made. Third, both PSQI and MEQ scores are affected by gender and nationality;[89] since our sample was Iranian females, our results may have some specific restrictions, and should be interpreted with reference to this population. Finally, it is commonly acknowledged that obese individuals, especially women, are more likely to under-report, which may have contributed to inconsistent results.[90]

Conclusion

In conclusion, our results suggested that high dietary acid-base load indices are associated with an increased risk of psychological diseases and poor sleep quality in overweight and obese women. We report the novel finding that there may be an association between greater adherence to dietary acid-base load diets and a higher risk of being completely E-type. However, further studies are needed to assess this association in a larger population, and to clarify the precise mechanism(s) of action.

Conflict of interest The authors declare that they have no competing interests.

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Ethics approval and consent to participate The study protocol was approved by the ethics committee of Endocrinology and Metabolism Research Center of Tehran University of Medical Sciences (TUMS) with the following identification: IR.TUMS.VCR.REC. 1395.1597.

Consent for publication Each participant was completely informed about the study protocol and provided a written informed consent form before taking part in the study.

Availability of data and materials The data that support the findings of this study are available from Khadijeh Mirzaei but restrictions apply to the availability of these data, which were used under licence for the current study, and so are not publicly available. Data are available from the authors upon reasonable request and with permission of Khadijeh Mirzaei.

Authors' contributions The project was designed and implemented by KhM. SM and AM drafted the first manuscript. Data were analyzed and interpreted by AM. SM, FSH, FA, SH and CC critically revised the manuscript. KhM supervised the overall project. All authors read and approved the final manuscript.

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