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The Effect of Dietary Acid Load on Cardiometabolic Risk, Psychological Resilience and Sleep Quality in Adolescents with Obesity

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What is already known on this topic?

Diet composition affects acid-base balance by providing acid or base precursors. High dietary acid load (DAL) may have detrimental effects on cardiovascular health, mental health and sleep quality.

What this study adds?

High DAL was associated with high cardiometabolic risk, insulin resistance, and low psychological resilience and poor sleep quality in adolescent with obesity.

Abstract

Objective: Mild metabolic acidosis may adversely affect cardiovascular risk factors, and diet-dependent acid-base load may impair mental health and sleep quality. The aim of this study was to investigate the effects of dietary acid load (DAL) on cardiometabolic risk factors, psychological resilience, and sleep quality in adolescents with obesity.

Methods: Obese adolescents participated in the study. Biochemical parameters, anthropometric measurements and blood pressures were measured. Three-day retrospective food intake records were collected from the adolescents, and potential renal acid load (PRAL), net endogenous acid production (NEAP), and DAL were derived from food intake records. Psychological resilience was assessed by the Child and Youth Resilience Measure (CYRM-12) and sleep quality was assessed by the Pittsburgh Sleep Quality Index (PSQI).

Results: A total of 205 adolescents with obesity (105 males, 100 females) aged 13-18 years participated. Body mass index, fat mass, fat percentage, fasting insulin, triglyceride, systolic blood pressure, homeostasis model assessment for insulin resistance (HOMA-IR) and PSQI scores were significantly higher and psychological resilience levels were significantly lower in high tertiles of DAL ($p < 0.05$). Adolescents in the lowest tertile of DAL scores had higher consumption of whole grains, vegetables, dairy, legumes, and higher intakes of potassium and calcium than adolescents in the highest tertile of the DAL scores ($p < 0.05$). Red meat, and white meat consumption and sodium intake were higher in adolescents in the high tertiles ($p < 0.05$). Energy intakes were found to be significantly lower in the first tertile of PRAL and DAL scores compared to the other tertiles ($p < 0.05$). A linear regression model ahowed an increase in NEAP, PRAL and DAL scores led to a decrease in psychological resilience score and an increase in PSQI and HOMA-IR scores ($p < 0.05$).

Conclusion: High DAL was associated with high cardiometabolic risk, insulin resistance, and low psychological resilience and poor sleep quality.

Keywords: Dietary acid load, cardiometabolic risk, psychological resilience, sleep quality

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Introduction

The dramatic increase in the prevalence of overweight and obesity in children and adolescents has become an important global public health problem (1). Adolescent obesity is a strong predictor of adult obesity and is associated with higher cardiometabolic risk, mortality and morbidity (2). Studies have shown that, in addition to physical diseases caused by obesity such as insulin resistance, cardiovascular diseases, metabolic syndrome, non-alcoholic liver disease, polycystic ovary syndrome, and respiratory abnormalities during sleep, children and adolescents with high body mass index (BMI) tend to have psychosocial problems, including depression, anxiety and social withdrawal, poor quality of life and sleep and behavioral problems (2,3,4).

There is a close relationship between healthy lifestyle and well-being of individuals. Therefore, teaching activities that increase lifelong well-being is important for healthy lifestyle behavior (5). In recent years, increasing interest in the relationship between healthy life and well-being has provided an opportunity to investigate lifestyle factors related to psychological resilience (6). Psychological resilience is the ability to cope with and adapt to challenging conditions and stress (7). Despite the lack of longitudinal studies specifically designed to associate psychological resilience with health outcomes, evidence suggests that psychological resilience has a positive association with the most common health risk factors (8). Psychological resilience is associated with decreased risk of obesity, cardiovascular disease, type 2 diabetes, cancer and increased life expectancy (8). Similarly, it has been reported that improving the sleep quality of children may be an effective strategy in the prevention and treatment of pediatric obesity (9).

Diet therapy is an important and modifiable environmental factor that may affect adverse health problems, psychological disorders and sleep disorders caused by obesity in adolescents (10). Psychological resilience and sleep quality may be affected by dietary factors and may be a determinant of diet quality (7,10). Although the relationship between dietary habits and some psychological or psychosocial factors has been partially investigated (11), research on diet and psychological resilience is limited (6,7,12) and there are no studies on this subject in adolescents with obesity. It was reported that a Mediterranean-type diet model or vegetable-based diet models, increase in dietary polyphenol or antioxidant intake and diversity in fruit and vegetable consumption were positively associated with psychological resilience and sleep quality (6,9). In another study, adults with high psychological resilience had better diet quality and consumed more seafood, whole grain foods and fruits, and less processed and starchy foods, and sugary and fatty foods (13).

Diet composition may significantly affect the acid-base balance of the body (14). Studies have shown that metabolic acidosis may be associated with obesity (15,16). It has been suggested that acidic diets may increase the risk of some chronic diseases, including obesity, whereas alkaline diets may provide protection from these chronic diseases (17). It has been reported that an acidogenic diet leads to the accumulation of hydrogen ions related with weight gain (18). Excessive consumption of animal products, meat and Western-style dietary patterns leads to higher organic acid production and fatty acid oxidation, especially in individuals with obesity. Plant-based diets reduce the dietary acid load (DAL) (19). In another study, it was also found that high DAL was associated with the risk of depression and anxiety in individuals (20). Furthermore, it has been reported that children with high DAL at baseline had more emotional problems and increased hyperactivity ten years later (21). Low DAL and plant-based diets may have beneficial effects on mental and sleep disorders by suppressing inflammation and reducing oxidative stress because they contain high amounts of antioxidants, phytochemicals, flavonoids, vitamins and minerals (10). However, no study has examined the effect of DAL on psychological resilience and sleep quality in adolescents with obesity. To that end, the aim of this study was to investigate the relationship between DAL and cardiometabolic risk factors, psychological resilience, and sleep quality in adolescents with obesity.

Methods

Study Design, Setting, and Participants

This study was carried out on adolescents with obesity who attended the Pediatric Endocrinology Outpatient Clinic at Gazi University Faculty of Medicine Children's Hospital between February 2022 and May 2022. The inclusion criterion was obesity (BMI ≥95th percentile) in adolescents who did not have any chronic disease diagnosed by a doctor, did not take hormone therapy, and did not use medication. Exclusion criteria were being overweight and having any concomitant chronic medical disease of any type (syndromic, metabolic, neurological) except for metabolic syndrome secondary to obesity, not having clinically normal mental development, having diagnoses of autism spectrum disorder or schizophrenia and related psychotic disorders, and having mental problems that would prevent them from participating in the survey interviews or completing the scales.

Approval was obtained from the Gazi University Faculty of Medicine Ethics Committee (approval number: 230, date: 20.03.2023). Clear explanations were provided with regard to the purpose of the study, after which written informed consent was obtained from the adolescents in accordance with the Declaration of Helsinki.

Data Collection and Evaluation

Data was collected in face-to-face interviews through a questionnaire that included adolescent socio-demographics and dietary habits, the Child and Youth Resilience Measure (CYRM-12), Pittsburgh Sleep Quality Index (PSQI), anthropometric measurements, biochemical findings, and three-day food consumption records (see below).

Anthropometric Measurements and Body Composition Analysis

Body weight and body composition analysis were performed using a bioelectrical impedance analysis device (Javon BC 360 Jawon Medical Co, Ltd. Korea) between 8.00-10.00 in the morning. Height was measured (cm) with feet close together and the head in Frankfurt plane with a portable stadiometer with sensitivity of 0.1 cm. BMI was calculated as weight in kg/height in m^2. BMI standard deviation score (SDS) was calculated according to the standards established for Turkish children (22). Waist circumference (cm) was measured from the midpoint between the lowest rib and the iliac crest. Hip circumference (cm) was measured horizontally at the largest circumference of the hip. Neck circumference (cm) was measured at the midpoint of the neck, between mid-cervical spine and mid-anterior neck, to within 1 mm, using non-stretchable plastic tape with the subjects standing upright. Waist circumference-to-height ratio was computed as the ratio of waist circumference to height.

Biochemical Parameters and Blood Pressure

The fasting blood glucose, fasting insulin, total cholesterol, low-density lipoprotein-cholesterol (LDL-C), high density lipoprotein-cholesterol (HDL-C), and triglyceride levels of the children, which were routinely analyzed by Gazi University, Faculty of Medicine, Department of Pediatric Endocrinology, were recorded. Venous blood samples were obtained from all of the patients from the antecubital region between 08:00 and 08:30 am after an 8-12 hour overnight fast. Fasting glucose was measured with the enzymatic UV (hexokinase method) test method using a Beckman AU5800 (Beckman Coulter Inc, Brea CA, USA). HDL-C, LDL-C, total cholesterol, and triglyceride levels were measured with the enzymatic colorimetric method using the same autoanalyzer. Insulin levels were measured with the one step principle enzymatic immunoassay method using a Beckman UniCel DxI 800 (Beckman Coulter Inc, Brea CA, USA). The BP of each adolescent was measured twice following a 5-minute rest period from the right arm with a 30-second interval. Systolic and diastolic blood pressure Z scores were calculated for adolescents. The adolescent's gender, age, height and blood pressure were used for this calculation, as previously reported (23).

Assessment of Insulin Resistance

The homeostasis model assessment for insulin resistance (HOMA-IR) value was calculated using the "fasting blood glucose (mmol/L) x fasting insulin (μU/mL)/22.5" formula (24). A value of HOMA-IR above 3.16 was used as a cut-off value for both genders for insulin resistance.

Assessment of Psychological Resilience

CYRM-12 was used to determine the psychological resilience levels of adolescents participating in the study. The 28-item original form of the scale, which was developed in the light of data collected from eleven different countries, consists of three subscales and eight sub-dimensions. The short form study of the scale was conducted by Liebenberg et al. (25) in 2013 and a 12-item structure was obtained as a result of two different studies. The factor loading values of the scale ranged between 0.39 and 0.88 and the internal consistency coefficient was found to be 0.84. The scale, which has a five-point Likert scale, is graded between "strongly agree" (5) and "strongly disagree" (1). A high score indicates a high level of resilience. There are no reverse items in the scale. The total score that can be obtained is 60. The scale was adapted to Turkish and reliability and validity study was conducted by Arslan (26) (2015).

Assessment of Sleep Quality

PSQI was used to determine sleep quality. PSQI is a questionnaire consisting of 19 questions evaluating the sleep of individuals during the previous month. PSQI has seven components including sleep duration, sleep disturbance, sleep latency, daytime dysfunction due to sleepiness, sleep efficiency, overall sleep quality, and sleep medication use. The total PSQI score is the sum of the seven components. Each item is evaluated on a 0-3 point scale and the total score varies between 0-21. High scores indicate poor sleep quality. A total PSQI score of ≤5 indicates "good" and >5 indicates "poor" sleep quality. PSQI was developed by Buysse et al. (27) (1989) and adapted to Turkish by Ağargün et al. (28) (1996).

Dietary Intake

Three-day food consumption records were obtained from the participants. Adolescents were trained by the researcher on how to keep food consumption records. The dietary energy and nutrients were analyzed using the Nutrition Information Systems Package Program (BeBiS, Ebispro for Windows, Germany; Turkish version/BeBiS 7.0). The Food and Nutrient Photo Catalogue was used to ensure that patients correctly specified the amount of food they consumed. The daily energy, protein, fat, fiber, whole grain, refined grain, fruit, vegetable, dairy, red meat, white meat, legumes, phosphorus, calcium, potassium, sodium and magnesium intakes of adolescents were calculated from food consumption records.

Calculation of Dietary Acid Load

The potential renal acid load (PRAL), net endogenous acid production (NEAP) and DAL scores were derived from nutrient intake equations. The PRAL score was calculated using an algorithm described by Remer et al. (29) where PRAL (mEq/d) = 0.49x protein intake (g/day) + 0.037x phosphorus (mg/day) - 0.021 x potassium (mg/day) - 0.013 x calcium (mg/day) - 0.026 x magnesium (mg/day).

In addition, another measure of DAL score was estimated using the algorithm described by Frassetto et al. (30) where NEAP (mEq/d) = [54.5 x protein intake (g/day) + potassium intake (mEq/day)] -10.2.

Higher values of PRAL and NEAP reflect more acidic dietary intake, whereas lower values indicate more alkaline dietary intake.

DAL (mEq/day) = [body surface area (m^2) × 41 (mEq/day) / 1.73 m^2 + PRAL] (31). The DuBois (32) formula: [0.007184 × $height^{0.725}$ × $weight^{0.425}$] was used to calculate body surface area.

Statistical Analysis

The assumptions required for the suitability of the data for parametric tests were examined. Compliance with normal distribution was analyzed by the Shapiro-Wilk test. One-way analysis of variance (ANOVA) was used for variables that met the normal distribution and parametric test specifications, and the Kruskal-Wallis test was used for variables that did not meet the parametric specifications. In cases where there were differences between groups, pairwise comparisons were made using the independent Student's t-test for parametric measurements and the Mann-Whitney U test for non-parametric measurements. In addition to this descriptive information, Linear regression models were established between the independent variables and the dependent variables in order to examine the effect, direction and explanation rates of any obtained relationships. The "crude" model was used when analyzing the linear regression model with only dependent and independent variables, and were calculated separately as an adjusted model with personal characteristics and other variables from the measurements that may affect the relevant variables, respectively. Comments were made on the slope coefficient (β) obtained in all relevant models. Statistical analysis was performed using Statistical Package for the Social Sciences statistics, version 22.0 (IBM Inc., Armonk, NY, USA) and p values <0.05 were considered statistically significant for all data.

Results

The study included 205 adolescents (105 male, 100 female) aged 13-18 years. The mean DAL indices were 5.11 ± 7.1 mEq/d, 46.11 ± 11.9 mEq/d and 51.07 ± 16.8 mEq/d for PRAL, NEAP and DAL, respectively. The mean PSQI and psychological resilience scale scores were 7.94 ± 2.7 and 37.06 ± 9.6, respectively.

Table 1 displays the means and standard deviations for age, anthropometric measures, and biochemical parameters and blood pressure values according to quartile categories of DAL indices. The cutoffs for DAL indices were constructed as follows: tertiles for the PRAL index were <1.81, 1.81 to 8.91, and >8.91 mEq/d, for the NEAP index <38.61, 38.61 to 53.41, and >53.41 mEq/d, and for the DAL index <40.1, 40.1 to 59.61, and >59.61 mEq/d. Table 1 shows that BMI SDS, fat mass, fat percentage, fasting insulin, triglyceride, systolic blood pressure SDS, HOMA-IR values, and PSQI scores were higher and psychological resilience scores were lower in high tertiles of PRAL, NEAP and DAL compared to the low tertiles ($p<0.05$). There was no difference observed between tertiles in other parameters.

Table 2 shows the effects of dietary intakes on DAL. Energy intakes were found to be significantly lower in the 1st tertile of PRAL and DAL scores compared to the other tertiles. Adolescents in the lowest tertile of the three DAL scores had higher intakes of whole grains, vegetables, dairy, legumes, potassium and calcium than adolescents in the highest tertile of the DAL scores ($p<0.05$). Red meat, white meat and sodium consumption were found to be higher in adolescents in the high tertiles ($p<0.05$). There was no difference observed between tertiles in other parameters.

Simple linear regression models of HOMA-IR, psychological resilience and PSQI variables were established with NEAP, PRAL and DAL variables, respectively. Afterwards, these models were organized as the crude model, Model 1, by adding the specified variables respectively. In the next step, Model 2 was obtained by adding the specified variables to Model 1. A one-unit increase in NEAP score led to an average increase of 0.09 units in HOMA-IR levels, an

Table 1. Anthropometric measurements, biochemical findings, psychological resilience levels and sleep quality of adolescents according to PRAL, NEAP and DAL tertiles

Variables	Total	PRAL			p	NEAP			p	DAL			p
		1st tertile < 1.81 n = 66	**2nd tertile 1.81-8.91 n = 69**	**3rd tertile > 8.91 n = 70**		**1st tertile < 38.61 n = 68**	**2nd tertile 38.61-53.41 n = 69**	**3rd tertile > 53.41 n = 68**		**1st tertile < 40.1 n = 69**	**2nd tertile 40.1-59.61 n = 67**	**3rd tertile > 59.61 n = 69**	
Age (years)	14.76 ± 1.94	14.74 ± 1.81	14.71 ± 1.99	14.83 ± 2.06	0.933*	14.61 ± 1.79	14.83 ± 1.74	14.83 ± 2.28	0.788*	14.67 ± 1.75	14.69 ± 1.82	14.91 ± 2.25	0.775*
Sleep duration (hours)	8.18 ± 1.31	8.18 ± 1.09	7.94 ± 1.28	8.42 ± 1.53	0.267*	8.12 ± 1.16	8.14 ± 1.19	8.27 ± 1.58	0.823*	8.17 ± 1.16	8.06 ± 1.17	8.3 ± 1.6	0.763*
BMI SDS	2.08 ± 0.2	1.97 ± 0.3[a]	1.96 ± 0.2[a]	2.23 ± 0.5[b]	**0.002**	1.99 ± 0.1[a]	2.11 ± 0.3[a,b]	2.18 ± 0.5[b]	**0.029***	1.99 ± 0.7[a]	2.06 ± 0.2[a,b]	2.14 ± 0.3[b]	**0.021**
Hip circumference (cm)	108.42 ± 13.53	108.91 ± 10.38	105.98 ± 10.09	110.47 ± 18.46	0.073*	107.41 ± 10.18	108.77 ± 10.25	109.05 ± 18.73	0.475*	108.43 ± 10.34	107.44 ± 10.02	109.42 ± 18.76	0.385*
Waist circumference (cm)	99.42 ± 11.27	97.35 ± 11	98.48 ± 9.75	102.48 ± 12.53	0.071	97.27 ± 11.15	99.98 ± 11.09	100.99 ± 11.48	0.263	97.55 ± 11.22	99.02 ± 11.12	101.71 ± 11.33	0.201
WHtR	0.63 ± 0.05	0.62 ± 0.06	0.62 ± 0.10	0.64 ± 0.06	0.125	0.64.0.08	0.62 ± 0.09	0.64 ± 0.07	0.291	0.63 ± 0.10	0.65 ± 0.08	0.63 ± 0.05	0.213
Fat mass (kg)	27.08 ± 9.1	25,82 ± 7.9[a]	25.11 ± 8.1[a]	30.38 ± 10.4[b]	**0.024***	24.72 ± 8.3[a]	26.66 ± 8.28[a]	29.86 ± 10.09[b]	**0.023**	25.27 ± 8.23	26.42 ± 8.49	29.56 ± 10.14	0.148*
Fat percentage (%)	34.96 ± 7.1	34.45 ± 6.23	33.82 ± 7.34	36.65 ± 7.49	0.13	33 ± 6.74[a]	35.11 ± 7.47[a,b]	36.76 ± 6.7[b]	**0.044***	33.58 ± 6.72	35.22 ± 7.2	36.06 ± 7.3	0.236
Fat free mass (kg)	43.5 ± 8.27	45.23 ± 10.43[a]	44.07 ± 9.22[a]	44.82 ± 7.34[b]	0.231	43.66 ± 5.13[a]	44.53 ± 6.11[a,b]	44.31 ± 9.19[b]	0.340	44.65 ± 5.14[a]	44.91 ± 2.28[a]	43.20 ± 4.69[b]	0.322
Fasting glucose (mg/dL)	90.82 ± 11.98	88.62 ± 7.83	92.01 ± 11.37	91.77 ± 15.46	0.408*	90.67 ± 9.33	89.31 ± 7.88	92.53 ± 16.9	0.796*	89.45 ± 8.61	90.09 ± 9.11	92.94 ± 16.59	0.581*
Fasting insulin (IU/mL)	24.25 ± 16.45	19.94 ± 11.58[a]	24.67 ± 13.93[a,b]	28.11 ± 21.55[b]	**0.02***	19.18 ± 11.79[a]	22.49 ± 11,14[a]	31.15 ± 22.11[b]	**< 0.001***	18.31 ± 11[a]	23.39 ± 11.83[a]	31.07 ± 22[b]	**< 0.001***
LDL-C (mg/dL)	92.75 ± 22.15	90.24 ± 22.1	92.58 ± 23.53	95.45 ± 20.85	0.299*	91.82 ± 20.51	93.49 ± 22.32	92.92 ± 23.94	0.934	91.18 ± 20.78	93.48 ± 21.75	93.57 ± 24.2	0.843
HDL-C (mg/dL)	45.64 ± 9.85	46.32 ± 9.43	45.8 ± 9.23	44.8 ± 10.99	0.468*	47 ± 10.79	45.24 ± 9,1	44.7 ± 9.69	0.489*	47.31 ± 9.28	45.09 ± 10.4	44.55 ± 9.81	0.182*
Total-C (mg/dL)	162.08 ± 32.59	159.13 ± 26.91	160.87 ± 36.71	166.28 ± 33.48	0.551	157.94 ± 27.17	161.35 ± 34.59	166.97 ± 35.37	0.409	158.14 ± 24.38	160.81 ± 36.19	167.33 ± 35.69	0.383
Triglyceride (mg/dL)	124.6 ± 77.53	104.98 ± 47.83[a]	129 ± 103.73[a,b]	139.64 ± 66.32[b]	0.026*	102.17 ± 57.3[a]	128.56 ± 92.1[a,b]	142.92 ± 74.5[b]	**0.012***	99.36 ± 55.47[a]	131.96 ± 95.12[a,b]	142.17 ± 70.84[b]	**0.004***
Systolic blood pressure SDS	1.34 ± 0.86	1.33 ± 0.87	1.36 ± 0.83	1.35 ± 0.78	0.194	1.35 ± 0.77[a]	1.37 ± 0.89[a]	1.74 ± 0.43[b]	**0.011***	1.32 ± 0.79[a]	1.34 ± 0.91[a]	1.66 ± 0.71[b]	**0.018***
Diastolic blood pressure SDS	0.89 ± 0.71	0.89 ± 0.44	0.93 ± 0.46	0.96 ± 0.80	0.245	0.93 ± 0.74	0.97 ± 0.90	1.03 ± 0.63	**0.147***	0.95 ± 0.62	0.98 ± 0.75	1.01 ± 0.89	**0.109***
HOMA-IR	5.46 ± 3.74	4.39 ± 2.63[a]	5.6 ± 3.31[a,b]	6.38 ± 4.78[b]	**0.019***	4.32 ± 2.71[a]	4.99 ± 2.66[a]	7.08 ± 4.93[b]	**< 0.001***	4.05 ± 2.48[a]	5.24 ± 2.83[a,b]	7.09 ± 4.9[b]	**< 0.001***
Psychological resilience	37.06 ± 9.59	42.52 ± 1.04[a]	37.87 ± 1.32[a]	30.76 ± 1.28[b]	**< 0.001***	41.8 ± 1.16[a]	38.29 ± 1.38[a]	31.04 ± 1.19[b]	**< 0.001**	43 ± 0.87[a]	38 ± 1.43[b]	30.09 ± 1.13[c]	**< 0.001**
PSQI scores	7.94 ± 2.78	6.11 ± 0.29[a]	8.27 ± 0.40[b]	9.43 ± 3.60[b]	**< 0.001***	6.35 ± 0.35[a]	7.85 ± 0.36[b]	9.63 ± 0.36[c]	**< 0.001**	6.06 ± 0.31[a]	8.02 ± 0.36[b]	9.74 ± 0.36[c]	**< 0.001**

*Kruskal-Wallis test statistic.
**There is no difference between groups containing the same letter.
BMI SDS: body mass index standard deviation score, WHtR: waist circumference-to-height ratio, LDL-C: low-density lipoprotein-cholesterol, HDL-C: high-density lipoprotein-cholesterol, HOMA-IR: homeostasis model assessment for insulin resistance, PSQI: Pittsburgh Sleep Quality Index, PRAL: potential renal acid load, NEAP: net endogenous acid production, DAL: dietary acid load

Table 2. Daily dietary intakes of adolescents according to PRAL, NEAP and DAL tertiles

Variables	Total	PRAL				NEAP				DAL			
		1st tertile < 1.81 n = 66	2nd tertile 1.81-8.91 n = 69	3rd tertile > 8.91 n = 70	p	1st tertile < 38.61 n = 68	2nd tertile 38.61-53.41 n = 69	3rd tertile > 53.41 n = 68	p	1st tertile < 40.1 n = 69	2nd tertile 40.1-59.61 n = 67	3rd tertile > 59.61 n = 69	p
Energy (kal)	2047.55 ± 241.62	1947.39 ± 209.53[a]	2063.81 ± 245.29[b]	2130.74 ± 236.59[b]	**< 0.001**	1996.39 ± 231.72	2077.19 ± 254.85	2067.78 ± 234.04	0.213	1941.61 ± 228.97[a]	2111.44 ± 227.2[b]	2086.83 ± 237.88[b]	**< 0.001**
Carbohydrates (%)	48.96 ± 4.44	48.12 ± 4.4	49.86 ± 4.5	48.87 ± 4.31	0.162	49.42 ± 4.56	49.1 ± 4.16	48.35 ± 4.61	0.497	48.96 ± 4.4	49.06 ± 4.61	48.86 ± 4.38	0.977
Proteins (%)	16.5 ± 4.93	17.09 ± 4.82	15.9 ± 4.42	16.53 ± 5.53	0.503	16.5 ± 4.49	16.54 ± 4.61	16.46 ± 5.71	0.997	16.73 ± 4.79	16.6 ± 4.51	16.16 ± 5.53	0.846
Fats (%)	34.54 ± 3.71	34.79 ± 3.43	34.25 ± 4.03	34.6 ± 3.71	0.772	34.08 ± 3.46	34.36 ± 3.98	35.19 ± 3.65	0.332	34.31 ± 3.41	34.34 ± 3.94	34.98 ± 3.8	0.622
Fiber (g)	18.8 ± 3.56	18.79 ± 3.37	18.87 ± 3.73	18.75 ± 3.64	0.986	18.97 ± 3.76	19.18 ± 3.37	18.24 ± 3.56	0.416	19.16 ± 3.53	18.94 ± 3.76	18.31 ± 3.41	0.497
Whole grains (g)	56.3 ± 18.99	64.02 ± 22.83[a]	54.66 ± 15.85[b]	50.29 ± 15.14[b]	**0.002**	62.38 ± 22.23[a]	57.81 ± 18.08[a]	48.64 ± 13.33[b]	**0.002**	64.21 ± 23.22[a]	55.94 ± 16.05[a,b]	48.77 ± 13.54[b]	**< 0.001**
Refined grains (g)	370.12 ± 82.36	360.25 ± 75.26	370.88 ± 89.02	379.18 ± 82.64	0.547	367.18 ± 79.72	356.74 ± 77.52	387.01 ± 88.49	0.197	368.29 ± 78.54[a,b]	350.18 ± 75.31[b]	392.74 ± 88.94[a]	0.042
Fruits (g)	287.57 ± 153.47	324.46 ± 171.66	282.91 ± 158.55	255.54 ± 120.68	0.094	327.55 ± 174.14	280.29 ± 145.64	255.18 ± 132.33	0.071	319.25 ± 172.35[a]	303.94 ± 153.11[a,b]	238.79 ± 121.73[b]	**0.027**
Vegetable (g)	283.81 ± 102.3	320.05 ± 106.75[a]	282.3 ± 100.37[a,b]	249.15 ± 88.53[b]	**0.003**	312.26 ± 108.85[a]	285.5 ± 96.33[a,b]	253.6 ± 94.99[b]	**0.021**	336.32 ± 101.39[a]	255.06 ± 90.49[b]	261.31 ± 96.31[b]	**< 0.001**
Dairies (g)	412.08 ± 112.82	456.2 ± 79.14[a]	395.27 ± 113.8[b]	385.5 ± 128.52[b]	**0.004**	441.96 ± 97.75[a]	422.46 ± 110.77[a,b]	371.37 ± 119.27[b]	**0.007**	453.26 ± 77.7[a]	416.42 ± 126[a,b]	366.37 ± 113.18[b]	**< 0.001**
Red meat (g)	87.07 ± 31.26	75.33 ± 25.58[a]	86.31 ± 31.43[a]	99.61 ± 32.11[b]	**< 0.001**	72.41 ± 27.35[a]	93.1 ± 32.59[b]	95.43 ± 28.84[b]	**< 0.001**	69.87 ± 22.79[a]	96.04 ± 34.44[b]	94.91 ± 28.46[b]	**< 0.001**
White meat (g)	67.21 ± 31.4	49.76 ± 23.51[a]	67 ± 29.35[b]	84.87 ± 31.01[c]	**< 0.001**	55.65 ± 25.3[a]	60.42 ± 28.97[b]	85.85 ± 31.42[b]	**< 0.001**	51.65 ± 23.31[a]	61.44 ± 29.3[a,b]	88.78 ± 29.08[a]	**< 0.001**
Legumes (g)	23.73 ± 15.89	30.1 ± 15.46[a]	24.43 ± 15.94[a]	16.63 ± 13.5[b]	**< 0.001**	31.49 ± 16.79[a]	22.65 ± 14.52[b]	17.09 ± 13.04[b]	**< 0.001**	32.59 ± 16.17[a]	21.64 ± 13.98[b]	17.05 ± 13.55[b]	**< 0.001**
Phosphorus (mg)	983.36 ± 177.92	976.15 ± 182.85	997.71 ± 174.12	975.6 ± 179.86	0.791	1004.19 ± 203.39	997.75 ± 160.23	947.52 ± 166.2	0.247	1002.54 ± 202.27	1006.86 ± 167.02	939.67 ± 157.54	0.126
Potassium (mg)	3457.9 ± 529.39	3647.3 ± 523.29[a]	3507.27 ± 507.52[a]	3216.98 ± 473.51[b]	**< 0.001**	3655.89 ± 469.63[a]	3542.71 ± 460.28[a]	3171.41 ± 540.55[b]	**< 0.001**	3723.26 ± 456.62[a]	3478.83 ± 482.74[b]	3170.7 ± 506.96[c]	**< 0.001**
Calcium (mg)	977.87 ± 164.8	1044.75 ± 194.39[b]	955.33 ± 140.68[a]	935.38 ± 135.94[a]	**0.003**	1037.72 ± 158.83[b]	972.52 ± 160.23[a,b]	923.6 ± 158.58[a]	**0.003**	1040.05 ± 161.51[b]	951.9 ± 170.36[a]	942.79 ± 146.85[a]	**0.007**
Magnesium (mg)	329.81 ± 67.56	335.59 ± 66.99	334.06 ± 70.66	319.61 ± 65.09	0.458	332.23 ± 69.34	327.33 ± 68	329.78 ± 66.63	0.941	341.67 ± 68.39	332.15 ± 66.22	315.11 ± 66.73	0.157
Sodium (mg)	4.46 ± 0.7	4.22 ± 0.66[a]	4.41 ± 0.7[a]	4.76 ± 0.64[b]	**< 0.001**	4.22 ± 0.67[a]	4.41 ± 0.7[a]	4.77 ± 0.63[b]	**< 0.001**	4.12 ± 0.58[a]	4.51 ± 0.74[b]	4.76 ± 0.61[b]	**< 0.001**

*ANOVA.
**There was no difference between groups marked with the same superscript letter.
PRAL: potential renal acid load, NEAP: net endogenous acid production, DAL: dietary acid load

average increase of 0.116 units in PSQI scores, and an average decrease of 0.412 units in psychological resilience. A one-unit increase in PRAL score resulted in an average increase of 0.150 units in HOMA-IR levels, an average increase of 0.204 units in PSQI scores and an average decrease of 0.692 units in psychological resilience. Finally, a one-unit increase in DAL score led to an average increase of 0.072 units in HOMA-IR levels, an average increase of 0.095 units in PSQI scores, and an average decrease of 0.332 units in psychological resilience. Linear regression model results with adjustment variables are shown in Table 3.

Discussion

In this cross-sectional study of Turkish adolescents with obesity, high DAL was positively associated with anthropometric markers, including BMI, body weight, waist circumference, fat percentage and fat mass and biochemical markers, such as fasting insulin, HOMA-IR score, triglyceride levels, and systolic blood pressure. Similarly, it has been reported that an acidogenic diet was associated with a higher risk of overweight/obesity, and abdominal obesity and adiposity related to body fat percentage in children and adolescents (33). In the present study, adolescents with obesity and high scores of PRAL, NEAP and DAL had significantly higher fat mass, higher fat percentage, and lower fat free mass. In addition, waist circumference, which is a marker of abdominal obesity, increased as the DAL of adolescents increased. Mirzababaei et al. (17) reported that high DAL scores were negatively related with resting metabolic rate and directly related with waist circumference in women who were overweight and who had obesity. In one study, it was found that high PRAL scores were positively correlated with waist circumference and BMI in young Japanese women, while in another study, a positive correlation was observed between high NEAP scores and hip circumference, BMI, fat mass and body adiposity index (34). Sorraya et al. (33) showed a direct correlation between neck circumference, which is an indicator of subcutaneous adipose tissue distribution, and NEAP, whereas no such correlation was observed in other anthropometric markers. In the present study, no relationship was found between waist and hip circumferences and DAL scores, whereas adolescents had significantly higher BMI levels at higher scores of DAL indicators. According to the results of a meta-analysis, an increase in PRAL scores in women and NEAP scores in men was associated with higher BMI (35). Fatahi et al. (36) found a relationship between DAL scores and BMI, whereas no significant relationship was observed between PRAL and NEAP scores and BMI. These differences in the studies may be attributed to race and ethnicity, sample size, age range and health status of the study population, measurement of DAL by different methods, differences in

Table 3. Linear models of dietary acid loads with risk of insulin resistance, psychological resilience and sleep quality

		HOMA-IR				Psychological resilience				PSQI scores			
Variables		Beta	95% CI (LB; UB)	p*	R^2	Beta	95% CI	p*	R^2	Beta	95% CI	p*	R^2
NEAP	Crude model	0.090	(0.04; 0.141)	0.001	0.083	-0.412	(-0.528; -0.296)	0.000	0.262	0.116	(0.082; 0.15)	0.000	0.249
	Model 1	0.091	(0.038; 0.143)	0.001	0.103	-0.376	(-0.494; -0.257)	0.000	0.105	0.099	(0.066; 0.133)	0.000	0.129
	Model 2	0.058	(0.005; 0.111)	0.031	0.146	-0.299	(-0.419; -0.18)	0.000	0.147	0.081	(0.047; 0.115)	0.000	0.156
PRAL	Crude model	0.150	(0.065; 0.235)	0.001	0.081	-0.692	(-0.888; -0.496)	0.000	0.261	0.204	(0.148; 0.261)	0.000	0.271
	Model 1	0.159	(0.067; 0.25)	0.001	0.308	-0.624	(-0.831; -0.416)	0.000	0.291	0.171	(0.113; 0.229)	0.000	0.365
	Model 2	0.100	(0.012; 0.188)	0.027	0.359	-0.545	(-0.743; -0.348)	0.000	0.346	0.143	(0.086; 0.2)	0.000	0.380
DAL	Crude model	0.072	(0.037; 0.108)	0.000	0.106	-0.332	(-0.41; -0.254)	0.000	0.338	0.095	(0.072; 0.118)	0.000	0.330
	Model 1	0.075	(0.038; 0.113)	0.000	0.343	-0.308	(-0.391; -0.226)	0.000	0.342	0.082	(0.059; 0.105)	0.000	0.394
	Model 2	0.049	(0.011; 0.087)	0.012	0.390	-0.272	(-0.354; -0.189)	0.000	0.390	0.070	(0.046; 0.094)	0.000	0.419

*Calculated by linear regression.
- Crude model: Simple linear regression.
- Model 1: All models are adjusted for age, BMI, gender, physical activity, sleep duration.
- Model 2: All models are adjusted for age, BMI, gender, physical activity, sleep duration, energy, carbohydrates, proteins, fats, fiber, phosphorus, potassium, calcium, magnesium, sodium.
BMI: body mass index, PRAL: potential renal acid load, NEAP: net endogenous acid production, DAL: dietary acid load, PSQI: Pittsburgh Sleep Quality Index, HOMA-IR: homeostasis model assessment for insulin resistance, CI: confidence irterval

the evaluation of dietary intake, and differences observed in the dietary habits and lifestyles of the participants.

Several possible mechanisms have been proposed to explain the relationship between DAL and obesity. Accumulation of hydrogen ions due to an acidogenic diet results in body weight gain (18). Diet-induced acidosis decreases the production of adipokines such as leptin, adiponectin and resistin, which may prevent appetite suppression and provide energy balance.

DAL is associated with metabolic changes and obesity prevalence in adults (17,18) and tends to induce a chronic low-grade metabolic acidosis in children, which is associated with the formation of systemic acidosis and its metabolic consequences (37). Animal product foods, such as meat, fish, chicken, eggs, cheese and cereals are rich in sulphur-containing amino acids, phosphorus and chloride and are potentially acid forming, whereas fruits and vegetables are rich in malate, citrate and glutamate and are potentially base forming (14,15). Excessive consumption of animal foods, except milk which has a neutral DAL since the amount of phosphorus is compensated by the amount of calcium, and Western-style dietary patterns lead to higher organic acid production and fatty acid oxidation, insulin resistance, increased blood pressure and cortisol levels and decreased insulin sensitivity, especially in individuals with obesity (17,19,35). In the current study, red and white meat and sodium consumption were significantly greater in the adolescents with the highest dietary acid scores, whereas whole grain, legumes, calcium and potassium consumption were significantly higher in those with the lowest dietary acid scores. Similarly, Mirzababaei et al. (17) found that individuals with high DAL scores had higher intakes of eggs, meat, sodium, grain, fat and energy. In this study, fasting insulin levels of obese adolescents were significantly higher in the higher tertiles of PRAL, NEAP and DAL, and fasting insulin, triglyceride, systolic blood pressure and HOMA-IR levels were significantly higher in the higher tertiles of NEAP and DAL. In another study, it was found that children and adolescents with obesity who had insulin resistance had higher PRAL and NEAP scores than those without insulin resistance, and one unit increase in DAL scores increased insulin resistance by approximately 3% (38). Similarly in the present study, a one point increase in NEAP, PRAL and DAL scores increased insulin resistance by 9, 15 and 5% respectively. In a study conducted in young Japanese women, it was found that high PRAL scores were positively associated with systolic and diastolic blood pressure, and total and LDL cholesterol levels (34). A meta-analysis reported that high PRAL scores were associated with high triglyceride levels, whereas no relationship was observed between dietary acid scores and other serum lipid parameters (35). Rezazadegan et al. (15) reported that high PRAL and NEAP scores were associated with high fasting blood glucose and high PRAL scores were associated with high triglyceride levels in children and adolescents with obesity, which is similar to the findings of the present study. In another study, high DAL scores were found to be associated with insulin resistance but not with fasting blood glucose and hemoglobin A1c levels (39). These differences in findings may again be due to differences in the study population and sample size, differences in the calculation of DAL or various uncontrolled confounders.

There are several possible mechanisms explaining the relationship between DAL and cardiometabolic risk factors. Metabolic acidosis increases glucocorticoid secretion and plasma cortisol concentrations, which may induce insulin resistance (40). High consumption of fruits and vegetables leads to higher intake of carotenoids and antioxidants (hence lower DAL) and has a protective role against inflammation and oxidative stress leading to obesity and metabolic disorders (17). In addition, animal foods with high DAL are proinflammatory and may increase inflammatory cytokines that are associated with lipid disorders and insulin resistance, especially in individuals with obesity (15).

It has been reported that there is a relationship between unhealthy dietary patterns and the mental health of children and adolescents and that healthy foods, such as vegetables, fruits, oil seeds and whole grain products have protective effects on depressive symptoms, mental health and sleep disorders (10,21). It has also been reported that prolonged exposure to high DAL caused unfavorable somatic effects (21). In a study conducted in an adult population, adherence to a Mediterranean diet or vegetable-based dietary pattern were associated with high levels of psychological resilience and consumption of processed meat was associated with low levels of psychological resilience (6), but the effects of DAL on psychological resilience have not been examined in previous studies. In the present study, it was observed that psychological resilience levels of adolescents with obesity were significantly lower in the higher tertiles of DAL scores. Beezhold et al. (41) found that compliance with a vegetarian diet and less consumption of animal-based foods in diets were associated with a better mood and Daneshzad et al. (10) found that high DAL scores in women with diabetes and high consumption of animal-based diets compared to plant-based diets increased mental health problems such as anxiety, depression and stress. In a study involving Australian university students, higher resilience score was significantly associated with higher serves per day of vegetables and fruit, higher frequency of breakfast consumption, and lower frequencies of soft drink, cordial or sports drink and takeaway food (12). In the present study, a one point increase in NEAP, PRAL and DAL scores decreased psychological resilience by 41, 69, 33% respectively.

It has been reported that dietary factors play a role in the etiology and treatment of sleep problems, low consumption of vegetables and high consumption of foods with high fat and energy density are associated with sleep disorders (42). We found that adolescents with high DAL had significantly lower sleep quality and to the best of our knowledge, there is only one study investigating DAL and sleep quality, and in that study, similar to our study, it was observed that women with diabetes who were in the highest group of PRAL and NEAP scores had worse sleep quality (10). In a study conducted on individuals aged 12-18 years, it was reported that unhealthy foods such as sugar-sweetened beverages, prepackaged products, confectionery and fast-foods were associated with poor sleep quality (43). In the present study, DAL increased and sleep quality worsened in adolescents with obesity as their energy, refined grain, meat and sodium consumption increased.

Vegetable-based diets with low DAL and high amounts of antioxidants, phytochemicals, flavonoids, vitamins and minerals provide beneficial effects on mental health and sleep disorders by suppressing inflammation and reducing oxidative stress (10,20). Inflammation may trigger melancholic symptoms through the activation of inflammatory pathways in the brain (10). In addition, vegetables and fruits contain high amounts of magnesium, folate, zinc, antioxidants and flavonoids, which have been suggested to help mental disorders (10,21). Legumes and beans are high in tryptophan, the precursor of melatonin and serotonin, which play a role in sleep patterns (44). High DAL leads to an increase in the development of insulin resistance and causes higher blood pressure. Insulin resistance and high blood pressure are associated with deterioration of mental health and sleep quality in the general population (10). In the present study, both insulin resistance and high blood pressure levels in adolescents with high DAL may have contributed to the decrease in psychological resilience and sleep quality scores.

Study Limitations

This study has some limitations. The fact that a healthy control group was not included in our study could not reveal the relationship between obesity and DAL. The cross-sectional nature of the study did not allow cause and effect analyses. Categorization of DAL scores into tertiles may lead to misclassification of the data. The small sample size of the study may reduce the power of statistical tests. In addition, laboratory markers of acid-base balance were not collected in this study, which is another limitation. However, our study has some strengths. This is the first study to examine the effect of DAL on psychological resilience and sleep quality in adolescents with obesity. In most studies on DAL, only one or two indicators were used, whereas in our study, all three indicators were evaluated, leading to more accuracy and reliability in the findings. In addition, the use of three-day food consumption records instead of food consumption frequency questionnaire and the use of sleep quality and psychological resilience scales, which are validated and reliable tools, are other strengths.

Conclusion

Our findings showed that high DAL was positively associated with body weight, fat mass and percentage, BMI, waist circumference, insulin resistance, fasting insulin, triglyceride levels, blood pressure levels, and negatively associated with psychological resilience and sleep quality. Implementation of strategies to reduce the acid load of the diet with nutritional interventions may have a positive effect on health. Adopting an adequate and balanced dietary model, as opposed to the Western-style dietary model, may be important in reducing the DAL. Thus, both cardiometabolic risk factors will be reduced and the psychological resilience level and sleep quality of the individual will increase. Therefore, it would be beneficial to provide nutrition education to children and adolescents with obesity about the consumption of healthy foods, such as vegetables, fruits, and whole grain products, instead of foods with high energy, saturated fat, sugar, and salt content and to advise them about appropriate eating habits. In addition, well-planned and long-term studies are needed to clarify the relationship between DAL and cardiometabolic risk, psychological resilience and sleep quality in children and adolescents with obesity.

Ethics

Ethics Committee Approval: Approval was obtained from the Gazi University Faculty of Medicine Ethics Committee (approval number: 230, date: 20.03.2023).

Informed Consent: Clear explanations were provided with regard to the purpose of the study, after which written informed consent was obtained from the adolescents in accordance with the Declaration of Helsinki.

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Footnotes

Authorship Contributions

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