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Chronotype-specific associations of meal timing patterns with cardiometabolic health in women: a cross-sectional study

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Abstract

Background Although prior studies have examined meal timing and health, few have considered the impact of individual chronotypes and diurnal preference. This study explored how meal distribution and chronotype—morning (M-type) versus evening (E-type)— are associated with cardiometabolic health.

Methods A cross-sectional study was conducted among 574 women in Tehran, Iran. Dietary intake was assessed through three 24-hour recalls and chronotype was determined via the Morningness-Eveningness Questionnaire. Cardiometabolic markers—including blood pressure (BP), glucose, lipids, insulin, and high-sensitivity C-reactive protein (hs-CRP)—were measured.

Results In E-type individuals, higher breakfast energy intake was linearly associated with lower systolic [β 95% CI, -0.03 (-0.05 $_{to}$ -0.01)] and diastolic BP [-0.01 (-0.04 $_{to}$ -0.003)]. Afternoon energy intake was associated with lower BMI [-0.02 (-0.04 $_{to}$ -0.001)] and hs-CRP [-0.001 (-0.002 $_{to}$ -0.0006)] in E-type women. Additionally, U-shaped associations were found between breakfast intake and systolic BP (turning point: 23% of total energy intake (TEI)), and between afternoon intake and BMI (13% TEI) and hs-CRP (12% TEI). In contrast, higher dinner energy intake was linearly associated with greater BMI in the intermediate [-0.01 (-0.02 $_{to}$ -0.002)] and E-type group [0.05 (0.003 $_{to}$ 0.09)], respectively. Eating window was associated with higher fasting blood glucose [0.001 (0.002 $_{to}$ 0.003)] in E-type vs. M-type individuals.

Conclusion Aligning energy intake with wake-up time—rather than delaying meals—may benefit evening chronotypes prone to circadian misalignment. Moderate breakfast and afternoon intake, with lower dinner intake, was related to better cardiometabolic health. Accordingly, longitudinal studies are advocated.

Keywords Chronotype, Mealtime, Circadian misalignment, Diurnal preference, Obesity, Cardiometabolic risk factor

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Introduction

There is compelling evidence linking metabolic health to various eating behaviors, such as, skipping breakfast [1], consuming energy at night [2], and temporal eating patterns (e.g., number of eating occasions (EOs) and the length of the eating window) [3, 4]. Moreover, late evening meals have been shown to worsen postprandial glucose and insulin responses compared with earlier meals [5]. Circadian rhythms, or biological clocks, mechanically control physiological processes, such as food absorption and nutrient metabolism [6], and, as the day progresses, the diurnal rhythm of glucose homeostasis reduces insulin secretion and sensitivity, which consequently lowers glucose tolerance in the evening [5, 7]. Consequently, a misalignment between food intake and the body's circadian timing system may adversely affect metabolic health [8].

The increasing global trend of consuming meals later in the day thus represents not only a public health concern [9], but also a potential contributor to the rising prevalence of metabolic disorders worldwide [10]. In our previous research, we also observed that meal timing patterns and chrono-nutrition components were significantly associated with diet quality [11–13].

An individual's eating habits are influenced by their chronotype [14]; indeed, a person's innate tendency to be most attentive and productive at particular times of the day, such as morning vs. evening, is referred to as their chronotype [15]. Furthermore, people who typically consume their main meals in the evening, often known as those with an evening chronotype (E-type) or a late-oriented circadian phenotype, may be additionally vulnerable to obesity and metabolic disorders [10]. According to a recent meta-analysis, people with an E-type had worse cardiometabolic risk profiles and were more likely to develop diabetes than people with an M-type (morning chronotype) [16]. Additionally, individuals with an E-type chronotype have a major disruption in their circadian rhythms from socially imposed schedules, such as early start hours for work or school [17]. As a result, eating breakfast early because of social obligations could worsen this circadian misalignment [7]. In contrast, eating late at night may have negative metabolic effects on M-type individuals, such as an increased risk of obesity [17]. This is because, as the day progresses, their natural metabolic efficiency decreases, making late-night eating even more detrimental. Additionally, consuming food after dark—when melatonin levels are elevated—has been linked to poorer glucose tolerance and metabolic disturbances [18]. Moreover, evening chronotypes tend to have delayed sleep patterns, which may further impact metabolic regulation [19].

Previous studies on the associations among chronotype, dietary intake, and metabolic health have yielded equivocal results across different countries. While a few studies have explored the relationships among chronotype, dietary intake, and metabolic health [16, 20, 21], no research has, to the author's knowledge, specifically examined this relationship in Iranian women. Given the cultural, dietary, and genetic differences that may influence these factors, understanding how the timing and distribution of daily energy intake relates to cardiometabolic health across different chronotypes in this population could provide novel and valuable insights for personalized dietary recommendations and public health interventions.

Methods

Study design

Iranian women who visited medical facilities in southern Tehran, between November 2024 and January 2025 and who appeared to be in good health, volunteered for this this cross-sectional study. This study sought to investigate various health outcomes, focusing on a required sample of 560 individuals. The required sample size was calculated via the following formula:

$n = z^2p \times (1\text{-}p)/d^2$ (16).

based on the prevalence of metabolic syndrome (63%) in women living in Tehran [22]. The estimation used an error margin of $d = 0.4$ and a significance level of $\alpha = 0.05$. Considering the exclusion of approximately 5% of participants due to under- or overreporting of dietary intake, the final required sample size was estimated to be 588 participants. The participants were selected via a convenient proportion-to-size sampling method from three health centers in the southern region of Tehran. The participants had a body mass index (BMI) between 18.5 and 39.9 kg/m^2, no indication of an acute illness, and ranged in age from 20 to 60 years. We excluded individuals who were pregnant, breastfeeding, working shifts, or who reported inaccurate total calorie intake.

Ethical approval

This study was conducted in collaboration with healthcare centers in southern Tehran. All participants provided written informed consent before taking part. The study protocol was reviewed and approved by the Research Ethics Committee of Islamic Azad University, Tehran Medical Sciences—Pharmacy and Pharmaceutical Sciences Faculty (IR.IAU.REC.1403.487), and conducted in accordance with the Declaration of Helsinki and relevant institutional guidelines.

Data collection

Data were collected from every individual via face–to-face interviews. Sociodemographic characteristics, including age, marriage status (single vs. married), education level (diploma and under diploma vs. educated),

smoking status (no smoker vs. current smoker), menopausal status (premenopausal vs. postmenopausal), and sleep duration were recorded.

Measurements

Socioeconomic status

Principal component analysis (PCA) was used to assess the socioeconomic status (SES) of women on the basis of household income and assets, such as cars, houses, and electronic devices. On the basis of the PCA results, the women were classified into three SES groups: high, medium, and low SES.

Physical activity

Physical activity was measured by the short form of the validated International Physical Activity Questionnaire (IPAQ) [23]. The participants reported the time spent walking or performing moderate- and/or vigorous-intensity activities within the previous seven days. The overall physical activity level was measured in the form of metabolic equivalents per week (MET-minutes/week). MET scores were then categorized into three levels: a point score < 600 MET-min/week indicated low physical activity, a point score 600–3000 MET-min/week indicated moderate physical activity, and a point score > 3000 MET-min/week indicated high physical activity [24].

Morning evening questionnaire (MEQ)

The MEQ was a 19-item scale with several different options developed by Horn and Ostberg, in which the subject was asked to specify the rhythm and habits of life and the hours of sleep and wakefulness at night [25]. The questions had different options and specific scoring methods. The participants were asked about their hours of sleep and wakefulness and their preferences for physical and mental tasks to determine their daily mood. The questionnaire options did not have equal values, and on the basis of the initial analysis of its creators, the possibilities of some questions being given different values than other questions. The range of scores varied from 16 to 86; a higher score indicates morningness, and a lower score indicated eveningness according to the Persian Validation Questionnaire [26]. Scores of 41 and below indicate E-type, scores of 59 and above indicated M-type, and scores between 42 and 58 classified "intermediate types.

Dietary intake assessment, eating occasion, and eating window

Dietary information was collected through three 24-hour dietary recalls on nonconsecutive days conducted by trained dietitians in private interviews. The first recall took place during the participants' initial visit to the health care center. The following information was collected via telephone on random days. The subjects reported the following types of eating occasions in which food was consumed: breakfast, lunch, dinner, or snacks. The definition of the main mealtime of food intake was breakfast as the main meal consumed between 5:00 a.m. and 11:00 a.m.; lunch was what was eaten between 11:00 a.m. and 4:00 p.m.; afternoon snacks were what was consumed between 4:00 p.m. and 6:00 p.m.; and dinner was known as what was consumed after 6:00 p.m. and extended into the early morning [27]. The total and main meal intake of all food items, derived from three 24-hour dietary recalls, were converted into grams per day by using standard portion size and household measures [28]. Energy and nutrient intake values were obtained via Nutritionist IV software (First Databank, San Bruno, CA, USA), modified for Iranian foods.

The number of EOs was defined as events provided at least 50 kilocalories within 15-minute intervals [29]. The eating window duration was defined as the number of hours between the first and last EO on a given day. In addition, regular breakfast, lunch, afternoon snack, and dinner eaters were defined as individuals who reported consuming these meals in all three 24-hour dietary recalls.

Anthropometric measurements

Weight was measured via a Seca weighing scale with participants wearing light clothing (Seca and Co. KG; 22 089 Hamburg, Germany; Model: 874 1321009; designed in Germany; made in China). Standing height was measured via a wall stadiometer with a sensitivity of 0.1 cm without shoes. BMI was calculated as weight (in kilograms) divided by height (in meters squared). Waist circumference (WC) was measured via a nonstretchable fiberglass measuring tape at the midpoint between the lower border of the rib cage and the iliac crest, according to the guiding protocol of the WHO [30]. The waist–hip ratio (WHR) was calculated by dividing waist circumference (WC) by hip circumference, both of which were measured in centimeters. This ratio is commonly used to assess body fat distribution and related health risks. The Visceral Adiposity Index (VAI) was based on waist circumference (WC), BMI, triglyceride (TG) level, and high-density lipoprotein (HDL) level, with different formulas for men and women used to indicate visceral fat levels [31].

$$\text{VAI} = \frac{WC\ (cm)}{39.58\ (1.89 \times BMI)} \times \frac{TG\left(\frac{mg}{dl}\right)}{1.03} \times \frac{1.31}{HDL\left(\frac{mg}{dl}\right)}$$

Finally, the body adiposity index (BAI) was a direct measure of body fatness that did not require adjustment for characteristics such as sex or age. The BAI was calculated on the basis of hip circumference (cm) and height (m) [32].

$$\text{BAI} = \frac{Hip\ circumference\ (cm)}{Height^{1.5}(m)} - 18$$

Assessment of blood pressure

Blood pressure (BP) was measured by a digital barometer (BC 08, Beurer, Germany) after at least 10–15 min of rest and sitting. BP was measured twice for each person, and the average BP was reported.

Laboratory investigations

The participants provided a 10 ml fasting blood sample between 7:00 and 10:00 a.m after a 12-hour fast. to ensure consistency in the metabolic measurements. Blood samples were subsequently collected in acid-washed test tubes without anticoagulants. After being stored at room temperature for 30 min and after clot formation, blood samples were centrifuged at 1500 × g for 20 min. The serum samples were stored at − 80 °C until future testing. Fasting blood glucose (FBS) was assayed via the enzymatic (glucose oxidase) colorimetric method via a commercial kit (Pars Azmun, Tehran, Iran). Serum total cholesterol (TC) and HDL were measured via the cholesterol oxidase phenol aminoantipyrine method, and serum TG was measured via the glycerol-3 phosphate oxidase phenol aminoantipyrine enzymatic method. Serum low-density lipoprotein cholesterol (LDL) was calculated via the Friedewald formula [33]. The serum insulin concentration was measured via commercial kits (Insulin AccuBind ELISA, USA; Monobind, Inc.) and enzyme-linked immunosorbent assays (ELISAs). Serum high-sensitivity-reactive protein (hs-CRP) was measured with a commercial kit (hs-CRP, Germany, Roche, Inc.) via the immunoturbidimetric method.

Definition of cardiometabolic outcomes.

The TG-HDL ratio [34] and the TC-HDL ratio [35]; both measured in mg/dl, were used as predictors of cardiovascular risk.

The homeostatic model assessment (HOMA) was used to evaluate insulin resistance (HOMA-IR) and β-cell function among both diabetic and nondiabetic individuals [36]. HOMA-IR was a measure of insulin resistance, whereas HOMA-IS, insulin sensitivity, was considered a good indicator of beta-cell function. Elevated HOMA-IR and reduced HOMA-IS values were associated with glucose intolerance and an increased risk of developing type 2 diabetes. The formulas are as follows:

$$\text{HOMA-IR} = \frac{(\text{fasting insulin } (\mu\,\text{IU/mL}) \times \text{ fasting blood sugar (FBS) (mg/dl)})}{405}$$

$$\text{HOMA-IS} = \frac{(20 \times \text{ fasting insulin } (\mu\,\text{IU/mL}))}{(\text{FBS (mg/dL)} - 3.5)}$$ [37, 38].

Statistical analysis

The statistical analysis was conducted with SPSS version 26 (IBM). Descriptive statistics were primarily reported as the means ± SDs and/or percentages. The χ2 test and one-way analysis of variance (ANOVA) were used for categorical and continuous variables to assess differences between general characteristics and cardiometabolic parameters according to chronotype. We used analysis of covariance (ANCOVA) to examine differences in energy distribution and temporal eating patterns across chronotypes, adjusting for possible confounders.

We used generalized linear regression (GLM) to investigate the associations between meal energy, total energy intake (TEI), number of EOs, eating window, cardiometabolic risk factors and chronotypes, while controlling for confounders, including age, physical activity, smoking status, SES, education, sleep length, supplement intake, and energy intake, with the exception of TEI. Transformations in the outcome variables, HOMA-IR (double-log) and hs-CRP (log transformation) were performed prior to the analyses to achieve a normal distribution, thus meeting the assumptions for regression analyses. Furthermore, the values of insulin ($n = 9$), FBS ($n = 7$), and TG ($n = 6$) were winsorized, i.e., outliers, with the closest value fitting a normal distribution [39].

In addition, the effects of the interaction effect of chronotype on the associations of TEI, energy distribution, number of EOs, and eating window with cardiometabolic risk factors, adiposity indices and metabolic parameters, were examined via the GLM. The crude model was adjusted by age, and further possible adjustments were made for physical activity, smoking status, SES, sleep length, education, supplement intake, and TEI (except for TEI) in analyses involving adiposity indices such as BMI, WHR, VAI, and BAI. For metabolic parameters, including SBP (mmHg), DBP (mmHg), the TG–HDL ratio (mg/dl), the TC–HDL ratio (mg/dl), FBS (mg/dl), HOMA-IR, HOMA-IS, and hs-CRP, the models were additionally adjusted for BMI. To better understand how the distributions of energy intake, temporal eating patterns, and cardiometabolic health were connected, we used GLR models to explore both linear and nonlinear relationships for variables that showed significant associations. We analyzed squared (quadratic; x^2), and cubic (x^3) terms in the associations with significant linear relationships. For any significant quadratic relationships, we calculated the turning point via the formula -b/2a (where b is the coefficient of the linear term and a is the coefficient of the quadratic term) [40]. Furthermore, non-linear relationships were visualized for all significant associations using the quadratic regression formula: $Y = a\,X^2 + b\,X + c$, when where Y is the cardiometabolic outcome, X is meal-specific energy intake (as % of TEI), a represents the quadratic term coefficient, b the linear term coefficient, and c the intercept. These plots visually depict the non-linear (U-shaped or inverse U-shaped) relationships identified in the regression analysis.

Participants were excluded if their reported average daily energy intake was less than 500 kcal or greater than 3500 kcal for women [41]. Among the 586 participants,

we excluded a total of 12 women, 3 individuals for underreporting, and the other 9 participants for overreporting their energy intake. Ultimately, 574 participants were included, figure supplementary 1 (Figure S1).

Additionally, a paired t-test was used to analyze differences in energy intake across meals and daily total, as well as temporal eating patterns, between weekdays and the weekend.

As part of the sensitivity analysis, we examined the interaction effect of age on all associations. Additionally, these associations were analyzed in the overall study population. In addition, the associations of energy distribution and temporal eating patterns with TEI were examined.

We used AI-assisted tools to improve the clarity and grammar of the manuscript while ensuring the accuracy and integrity of the scientific content.

Results

Among the 574 Iranian women who participated in this cross-sectional study, the participants were classified into three chronotype groups: M-type ($n = 268$), intermediate ($n = 199$), and E-type ($n = 107$). Table 1 presents lifestyle characteristics and cardiometabolic risk factors across chronotypes. The median age was 42 years. Most participants had low physical activity levels, with slightly higher activity observed in the M-type group. Education levels were high across all groups, and SES was evenly distributed. The most women were married, nonsmokers, and premenopausal. Furthermore, sleep duration during weekdays was consistent, with slight variations on weekends. The BP was slightly lower in the M-type group, whilst BMI and other adiposity indices were slightly greater in the E-type chronotype, which also indicated elevated lipid ratios and a trend toward greater insulin resistance.

Table S1 shows the mean of dietary intake and eating habits by chronotype. The highest percentage of regular afternoon and dinner eater were E-type in comparison to other chronotypes, while the M-type was more regular breakfast eater. Table 2 presents the differences in the mean energy distribution and temporal eating patterns across chronotypes. Compared with the other groups, the E-type group had significantly a greater mean of TEI, dinner, and afternoon intake, longer eating window and fewer number of EOs. Among all meals' energy intake, only energy intake at lunch did not differ significantly between chronotype groups, ($p > 0.05$). There were no instances of zero intake for any meals among the participants.

Table 3 shows the associations of dietary intake, temporal eating patterns, and cardiometabolic parameters with chronotype. Compared with M-type individuals, E-type individuals had significantly greater TEI [β (95% CI), 262.40 (192.09 $_{to}$ 332.72); $p_{linear} = 0.003$] and dinner energy intake [122.31 (32.30 $_{to}$ 242.33); $p_{linear} = 0.01$] in adjusted models. Afternoon energy intake also approached marginal significance, with higher values observed in the E-type group [48.76 (−4.50 $_{to}$ 100.02); $p_{linear} = 0.05$] in the adjusted model. Additionally, in terms of temporal eating patterns, the intermediate chronotype vs. M-type had fewer EOs [-0.22 (-0.42 $_{to}$ -0.02; $p_{linear} = 0.03$], although these differences were not significant after model adjustments. With respect to cardiometabolic parameters, the E-type group presented a greater DBP in adjusted models [6.59 (1.88 $_{to}$ 11.60); $p_{linear} = 0.01$] than the M-type group.

The interaction effects of chronotype on the associations between daily energy intake and the distribution of energy intake are displayed in Table 4. Higher breakfast energy intake was related to fewer SBP and DBP, particularly in individuals with an E-type compared with those with an M-type, [-0.03 (-0.05 $_{to}$ -0.01); $p_{linear} = 0.002$], and DBP [-0.02 (-0.04 $_{to}$ -0.003); $p_{linear} = 0.01$] in the adjusted model, respectively. Furthermore, the associations between afternoon energy intake and BMI were marginally significantly lower in individuals with an intermediate chronotype and significantly lower in those with an E-type chronotype than in those with an M-type chronotype [-0.01 (-0.04 $_{to}$ -0.001), $p_{linear} = 0.04$]. Greater afternoon energy intake was related to lower hs-CRP in intermediate-type [-0.01 (-0.02 $_{to}$ -0.002); $p_{linear} = 0.04$], and E-type individuals than in M-type individuals [-0.01 (-0.02 $_{to}$ -0.006); $p_{linear} = 0.03$] in the adjusted model. Dinner energy intake was associated with greater BMI, in individuals with intermediate chronotype [-0.01 (-0.02 to -0.002); $p_{linear} = 0.04$] and E-type [0.05 (0.003 $_{to}$ 0.09), $p_{linear} = 0.03$] compared with those with an M-type. The association was significant in both the crude and adjusted models.

The interaction effect of chronotype on the number of EOs in relation to cardiometabolic health is shown in Table 5. However, we did not find an interaction effect of chronotype on the association between the number of EOs and cardiometabolic risk in adjusted model.

The interaction effect of chronotype on the association between the duration of the eating window and cardiometabolic health is presented in Table 6. Only a longer eating window was associated with higher FBS [0.01 (0.002 $_{to}$ 0.02); $p = 0.008$] in the E-type group, compared with M-types.

Our findings revealed a U-shaped association between breakfast energy intake and SBP among E-type individuals [0.05 (0.02 $_{to}$ 0.10); $p_{quadratic} = 0.02$], with a turning point at 23% TEI. These results suggest that both low and high breakfast energy intake may be linked to greater SBP, emphasizing the importance of balanced morning intake. In the E-type group, afternoon energy intake

Table 1 Lifestyle characteristic and cardiometabolic risk factors of chronotype ($n=574$, Iranian women)

Variables	Total ($n=574$)	Chronotypes		
		M-type ($n=268$)	Intermediate ($n=199$)	E-type ($n=107$)
Age (year)	42 (35–52)	42 (35–51)	42 (35–53)	42 (35–51)
Physical activity n (%)				
Low level (< 600 MET-min/week)	306 (53.31)	133 (49.26)	114 (57.28)	59 (55.14)
Medium level (600–3000 MET-min/week)	213 (37.10)	109 (40.67)	67 (33.66)	37 (34.54)
High level (> 3000 MET-min/week)	55 (9.59)	26 (10.07)	11 (5.06)	11 (10.32)
Education n (%)				
Diploma and under diploma	199 (34.66)	81 (30.33)	77 (38.70)	41 (38.32)
Educated [1]	375 (65.44)	187 (69.77)	122 (61.30)	66 (61.68)
Marriage status n (%)				
Single	106 (18.47)	51 (19.03)	34 (17.09)	21 (19.65)
Married	468 (81.5)	217 (80.97)	165 (82.91)	86 (80.35)
Socio economic status (SES) n (%)				
Low SES	193 (33.61)	92 (34.22)	69 (34.70)	32 (29.90)
Medium SES	204 (35.49)	100 (37.33)	65 (32.65)	39 (36.41)
High SES	177 (30.90)	76 (28.45)	65 (32.65)	36 (33.59)
Smoking status n (%)				
No smoker	554 (96.51)	258 (96.24)	194 (97.48)	102 (95.32)
Current smoker	20 (3.49)	10 (3.76)	5 (2.52)	5 (4.68)
Menopausal status n (%)				
Postmenopausal	233 (40.60)	108 (40.29)	84 (42.21)	41 (38.32)
Premenopausal	341 (59.40)	160 (59.71)	115 (57.79)	66 (61.68)
Sleep duration on weekdays (h: m)	7:00 (6:00–7:30)	6:30 (6:00–7:30)	7:15 (6:59–7:30)	7:00 (6:30–8:00)
Sleep duration on weekends (h: m)	8:30 (7:30–9:30)	8:00 (7:30–9:00)	8:30 (8:00–9:30)	8:45 (8:15–10:00)
BMI (kg/m2)	26.33 (23.78–29.41)	26.09 (23.59–29.13)	26.22 (24.00–29.34)	26.63 (23.91–30.22)
WC (cm)	85 (80–92.25)	84 (80–90)	85 (80–93)	86 (80–98)
WHR (cm)	0.84 (0.80–0.94)	0.84 (0.79–0.88)	0.85 (0.80–0.93)	0.86 (0.80–0.96)
VAI	4.39 (3.25–6.48)	4.25 (3.21–6.19)	4.40 (3.33–6.43)	4.73 (3.40–7.41)
BAI	32.83 (28.87–36.88)	32.83 (29.22–36.86)	32.84 (28.61–36.35)	32.83 (28.42–37.96)
SBP (mmHg)	120 (110–125)	118 (116–120)	122 (110–130)	125 (110–130)
DBP (mmHg)	80 (70–80)	80 (70–80)	80 (70–85)	80 (70–90)
TG-HDL ratio (mg/dl)	2.44 (1.85–3.53)	2.33 (1.78–3.39)	2.47 (1.88–3.48)	2.73 (1.90–4.09)
TC-HDL ratio (mg/dl)	3.80 (3.14–4.47)	3.76 (3.10–4.38)	3.80 (3.13–4.56)	3.97 (3.33–4.80)
FBS (mg/dl)	100 (93–110)	98 (92–108.05)	101 (93–113)	102 (96–109.65)
HOMA-IR	2.68 (1.74–3.93)	2.62 (1.73–4.05)	2.66 (1.67–4.06)	2.87 (1.90–3.72)
HOMA-IS	1.95 (1.28–2.97)	2.05 (1.35–3.08)	1.89 (1.23–2.94)	1.76 (1.20–2.74)
hs-CRP	0.12 (0.08– 0.27)	0.09 (0.08–0.25)	0.14 (0.08–0.29)	0.12 (0.08–0.30)

Values are number (percentage) for categorical variables or median (25th- 75th) for continuous variables

[1]Educated means bachelor's degree and upper degree

Abbreviations

M-type, morning chronotype; E-type, evening chronotype; SES, socio-economic status: BMI, body mass index; WC, waist circumference; WHR, waist circumference to hip circumference ratio; VAI, visceral adiposity index; BAI, body adiposity index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein; HOMA-IR, homeostatic model assessment for insulin resistance; FBS, fasting blood glucose; HOMA-IS, homeostatic model assessment for insulin sensitivity; hs-CRP, high sensitive c-reactive protein

was quadratically associated with BMI [0.09 (0.02 $_{\text{to}}$ 0.19); $p_{quadratic} = 0.001$], with a turning point at 13% TEI. Similarly, a quadratic relationship was found between afternoon energy intake and hs-CRP [0.08 (0.04 $_{\text{to}}$ 0.13); $p_{quadratic} = 0.01$], with a turning point at 12% TEI, Fig. 1. These findings indicate that excessive afternoon energy intake may have adverse effects on metabolic health. Cubic terms were not significantly associated with any of the examined outcomes.

In the sensitivity analysis, the interaction by age was examined, but no significant interactions were observed. In the total population, we analyzed all associations and found no significant association (Table S2). Additionally, the associations between energy intake distribution and temporal eating patterns with total energy intake (TEI)

Table 2 Differences in mean of the energy distribution and Temporal eating patterns across chronotypes ($n=574$)

Variables	M-type ($n=268$) Mean ± SD	Intermediate ($n=199$) Mean ± SD	E-type ($n=107$) Mean ± SD	*P* value†
Total energy intake (TEI) (kcal/day)	1714.45 ± 306.04	1733.58 ± 315.04	1780.74 ± 376.34	**0.02**
Breakfast energy (%TEI)[1]	25.62 ± 6.84	25.26 ± 6.42	23.99 ± 6.67	**0.002**
Lunch energy (%TEI)[2]	30.86 ± 8.14	31.16 ± 7.56	30.33 ± 7.66	0.45
Afternoon energy (%TEI)[3]	14.42 ± 8.21	14.34 ± 8.39	16.14 ± 9.56	**0.002**
Dinner energy (%TEI)[4]	28.46 ± 8.21	29.20 ± 7.56	30.81 ± 7.75	**0.03**
Eating window (h: m)	13:50 ± 1:01	14:15 ± 1:22	14:45 ± 1:36	**< 0.001**
Number of EOs (n/day)	6.49 ± 0.83	6.39 ± 0.89	6.10 ± 0.89	**< 0.001**

Analysis of covariance (ANCOVA) was used to examine the associations between chronotype and energy distribution/temporal eating patterns, P-value < 0.05 indicates significant level, significant values are in **bold**

†The model was adjusted for age, physical activity, smoking status, SES, education, sleep duration, TEI, and BMI, TEI was not adjusted for itself when analyzed

[1] All energy intake consumed between 5:00–11:00 am

[2] All energy intake consumed between 11:00 a.m.– 4:00 p.m

[3] All energy intake consumed between 4:00–6:00 p.m

[4] All energy intake consumed after 6:00 p.m

Abbreviations

n, number; M-type, morning chronotype; E-type, evening chronotype; TEI, total energy intake; kcal, kilocalorie; EOs, eating occasions; BMI, body mass index; SES, socio-economic status

are presented in Table S3, which indicate a significant negative association between breakfast energy intake and TEI in the total population. Furthermore, we did not observe a statistically significant difference in daily and meals energy intake and temporal eating patterns between weekdays and the weekend (Table S5).

Discussion

In the present study, we sought to identify, for the first time how the timing and distribution of daily energy intake associated with cardiometabolic health across different chronotypes in Iranian women. Accordingly, we found that women with an E-type chronotype, in comparison with M-type chronotypes, had significantly greater TEI, afternoon, and dinner energy intake. Higher breakfast energy intake was linked to lower SBP and DBP in a linear and nonlinear (U-shape) manner, among E-type than among M-type individuals. Afternoon energy intake was linearly associated with lower BMI, and hs-CRP levels and showed nonlinearly association with both BMI and hs-CRP among E-type in compared to M-type women. Furthermore, dinner energy intake was related to increased BMI among intermediate and E-type in compared to M-type chronotype only linearly. Furthermore, longer eating window was linearly related to elevated FBS in E-type compared to M-type chronotype.

Similar to our findings, a cross-sectional study revealed that the E-type was related to increased TEI in medical students [42]. However, a recent systematic review examined the relationships among chronotype, eating behaviors, and dietary intake in healthy adults (> 18 years old). Although overall energy and macronutrient intakes were similar across chronotypes, E-type individuals consumed more of their energy later in the day [43].

Concordant with our reported negative association between breakfast energy intake and blood pressure, the meta-analysis of Ueda et al. revealed that skipping breakfast, particularly among women, was associated with increased SBP and DBP [44]. Additionally, another meta-analysis suggested that regular breakfast consumption could help reduce the risk of hypertension, underscoring the potential benefits of eating breakfast for blood pressure management [45]. Previous studies have indicated that breakfast consumption might reflect overall lifestyle habits [46], with those who skip breakfast often being more likely to smoke, engage in less physical activity, have irregular dinner times, and snack more frequently [47]. However, chronotype was not assessed in these studies. A moderate energy intake of approximately 23% of TEI at breakfast was associated with favorable BP levels, whereas both lower and higher intakes were linked to adverse outcomes, particularly among E-type individuals. We did not observe any association between morning intake and obesity. In contrast to our results, a cross-sectional study involving 800 older adults revealed that higher energy intake at breakfast was associated with lower BMI among M-type individuals, however, in this study, morning intake was defined as consumption within two hours after waking up [21].

Higher energy intake during the afternoon was linked to a linear decrease in BMI and hs-CRP levels and quadratic assertions in E-type individuals compared with M-type women, independent of TEI. Afternoon energy intake comprising approximately 12–13% of TEI was related to reduced BMI and hs-CRP levels, suggesting

Table 3 Association of chronotype with dietary intake, Temporal eating patterns, and cardiometabolic metabolic parameters ($n=574$, Iranian women)

Variables	Models	M-type ($n=268$)	Intermediate ($n=199$)		E-type ($n=107$)	
		Ref.	β (95% CI)	P value†	β (95% CI)	P value†
	Daily dietary intake					
Total energy intake (TEI) (kcal/day)	Crude[1]	Ref.	-52.58 (-126.32 to 21.41)	0.16	186.26 (13.42 to 359.11)	**0.03**
Total energy intake (TEI) (kcal/day)	Adjusted[2]	Ref.	-8.52 (-66.56 to 49.52)	0.83	262.40 (192.09 to 332.72)	**0.003**
Protein (% of TEI)	Crude[1]	Ref.	-0.24 (-0.90 to 0.41)	0.46	-1.33 (-2.57 to 0.51)	0.18
Protein (% of TEI)	Adjusted[2]	Ref.	-0.33 (-0.95 to 0.31)	0.33	-1.03 (-2.01 to 0.55)	0.19
Fat (% of TEI)	Crude[1]	Ref.	-0.64 (-2.04 to 0.80)	0.38	-0.33 (-3.71 to 3.04)	0.84
Fat (% of TEI)	Adjusted[2]	Ref.	-0.26 (-1.77 to 1.20)	0.72	0.39 (-3.06 to 3.81)	0.82
Carbohydrate (% of TEI)	Crude[1]	Ref.	1.16 (-0.37 to 2.70)	0.13	1.84 (-1.71 to 5.44)	0.31
Carbohydrate (% of TEI)	Adjusted[2]	Ref.	0.87 (-0.71 to 2.48)	0.27	1.24 (-2.41 to 4.95)	0.53
Saturated fatty acid (SFA) (% of TEI)	Crude[1]	Ref.	-0.07 (-0.57 to 1.80)	0.78	0.63 (-0.54 to 1.80)	0.29
Saturated fatty acid (SFA) (% of TEI)	Adjusted[2]	Ref.	0.03 (-0.48 to 0.55)	0.89	0.77 (-0.41 to 1.97)	0.20
Fiber (g/1000 kcal)	Crude[1]	Ref.	0.41 (-0.50 to 1.32)	0.38	1.28 (-0.84 to 3.42)	0.23
Fiber (g/1000 kcal)	Adjusted[2]	Ref.	0.38 (-0.56 to 1.33)	0.42	0.88 (-1.31 to 3.03)	0.42
Sugar (% of TEI)	Crude[1]	Ref.	-0.19 (-1.30 to 0.96)	0.74	-0.04 (-2.76 to 2.66)	0.97
Sugar (% of TEI)	Adjusted[2]	Ref.	-0.53 (-1.71 to 0.66)	0.38	-0.91 (-3.62 to 1.89)	0.51
	Meal and temporal eating patterns					
Energy intake in the breakfast (% of TEI)	Crude[1]	Ref.	-9.07 (-43.12 to 25.00)	0.36	37.14 (-42.81 to 116.74)	0.62
Energy intake in the breakfast (% of TEI)	Adjusted[2]	Ref.	-2.22 (-37.08 to -32.35)	0.91	52.35 (-23.80 to 133.91)	0.20
Energy intake in the lunch (% of TEI)	Crude[1]	Ref.	-25.80 (-66.70 to 15.09)	0.21	10.66 (-84.86 to 106.90)	0.82
Energy intake in the lunch (% of TEI)	Adjusted[2]	Ref.	-13.48 (-55.93 to 28.96)	0.52	29.39 (-66.68 to 126.08)	0.54
Energy intake in the afternoon (% of TEI)	Crude[1]	Ref.	16.77 (-5.25 to 38.80)	0.13	40.15 (-11.21 to 91.60)	0.12
Energy intake in the afternoon (% of TEI)	Adjusted[2]	Ref.	22.78 (-0.73 to 45.33)	0.07	48.76 (−4.50–98.02)	0.05
Energy intake in the dinner (% of TEI)	Crude[1]	Ref.	26.54 (-15.44 to 67.82)	0.21	100.88 (3.78 to 199.11)	**0.04**
Energy intake in the dinner (% of TEI)	Adjusted[2]	Ref.	39.96 (-2.06 to 84.00)	0.06	122.31 (32.30 to 242.33)	**0.01**
Temporal eating patterns						
Number of eating occasions (EOs) (n/day)	Crude[1]	Ref.	-0.22 (-0.42 to -0.02)	**0.03**	-0.39 (-0.89 to -0.08)	0.10
Number of eating occasions (EOs) (n/day)	Adjusted[2]	Ref.	-0.16 (-0.37 to 0.04)	0.12	-0.31 (-0.81 to -0.17)	0.20
Eating window (hours: minutes)	Crude[1]	Ref.	-0.84 (-223.81 to 543.21)	0.23	248 (-76.43 to 573.25)	0.13
Eating window (hours: minutes)	Adjusted[2]	Ref.	-55.13 (-190.54 to -91.83)	0.44	268.46 (-65.63 to 573.50)	0.11
	Cardiometabolic risk					
SBP (mmHg)	Crude[1]	Ref.	1.67 (-1.67 to 4.98)	0.31	5.61 (-2.08 to 13.34)	0.15
SBP (mmHg)	Adjusted[3]	Ref.	2.20 (-1.12 to 4.13)	0.19	6.15 (-1.97 to 7.36)	0.10
DBP (mmHg)	Crude[1]	Ref.	1.24 (-0.91 to 3.38)	0.25	5.77 (0.75 to 10.79)	**0.02**
DBP (mmHg)	Adjusted[3]	Ref.	1.58 (-3.66 to 2.83)	0.15	6.59 (1.88 to 11.60)	**0.01**
BMI (kg/m2)	Crude[1]	Ref.	0.05 (-0.88 to 1.003)	0.90	0.15 (-2.05 to 2.35)	0.89
BMI (kg/m2)	Adjusted[3]	Ref.	0.11 (-0.82 to 1.08)	0.82	0.45 (-1.77 to 2.74)	0.69
VAI	Crude[1]	Ref.	0.44 (-0.29 to 1.17)	0.23	0.63 (-1.08 to 2.35)	0.46
VAI	Adjusted[3]	Ref.	0.58 (-0.18 to 1.34)	0.13	0.73 (-1.08 to 2.48)	0.41
BAI	Crude[1]	Ref.	-0.44 (-1.50 to 0.63)	0.42	0.28 (-2.20 to 0.04)	0.82
BAI	Adjusted[3]	Ref.	-0.20 (-1.32 to 0.90)	0.41	1.05 (-1.52 to 3.63)	0.72
WC (cm)	Crude[1]	Ref.	2.99 (-2.30 to 8.30)	0.28	0.62 (-1.62 to 2.89)	0.58
WC (cm)	Adjusted[3]	Ref.	0.86 (-1.41 to 3.24)	0.46	3.58 (-1.84 to 8.90)	0.19
WHR (cm)	Crude[1]	Ref.	0.01 (-0.005 to 0.02)	0.18	0.02 (-0.02 to 0.06)	0.34
WHR (cm)	Adjusted[3]	Ref.	0.007 (-0.01 to 0.02)	0.41	0.01 (-0.03 to 0.05)	0.61
TG-HDL ratio (mg/dl)	Crude[1]	Ref.	0.24 (-0.14 to 0.64)	0.21	0.32 (-0.59 to 1.23)	0.49
TG-HDL ratio (mg/dl)	Adjusted[3]	Ref.	0.31 (-0.07 to 0.72)	0.13	0.37 (-0.59 to 1.24)	0.45
TC-HDL ratio (mg/dl)	Crude[1]	Ref.	0.12 (-0.11 to 0.36)	0.31	0.34 (-0.22 to 0.91)	0.23
TC-HDL ratio (mg/dl)	Adjusted[3]	Ref.	0.17 (-0.07 to 0.41)	0.16	0.36 (-0.29 to 0.93)	0.21
FBS (mg/dl)	Crude[1]	Ref.	2.37 (-1.82 to 6.59)	0.27	-1.27 (-7.34 to 5.59)	0.80
FBS (mg/dl)	Adjusted[3]	Ref.	2.82 (-1.25 to 7.39)	0.18	0.69 (-2.86 to 3.84)	0.91

Table 3 (continued)

Variables	Models	M-type (*n* = 268)	Intermediate (*n* = 199)		E-type (*n* = 107)	
		Ref.	β (95% CI)	P value†	β (95% CI)	P value†
HOMA-IR	Crude[1]	Ref.	1.16 (-1.56 to 3.33)	0.36	1.47 (-4.91 to 7.34)	0.62
HOMA-IR	Adjusted[3]	Ref.	2.05 (-0.39 to 4.35)	0.08	2.56 (-1.76 to 3.23)	0.19
HOMA-IS	Crude[1]	Ref.	-0.34 (-0.77 to 0.09)	0.12	-0.73 (-1.74 to 0.27)	0.15
HOMA-IS	Adjusted[3]	Ref.	-0.27 (-0.72 to 0.17)	0.22	-0.61 (-1.65 to 0.39)	0.21
hs-CRP (mg/l)	Crude[1]	Ref.	0.03 (-0.01 to 0.07)	0.21	0.01 (-0.09 to 0.12)	0.84
hs-CRP (mg/l)	Adjusted[3]	Ref.	0.02 (-0.02 to 0.07)	0.99	0.001 (-0.10 to 0.11)	0.28

† Calculated by generalized linear regression (GLM), GLM was used to obtain beta (β) and 95% confidence interval (CI), and P-value < 0·05 indicates significant level, significant values are in **bold**

[1]The crude model was adjusted by age

[2]The model for dietary intake and temporal eating patterns was adjusted additionally by physical activity, smoking status, SES, education, sleep length, supplement intake, and energy intake, except for TEI

[3]The model for metabolic parameters was additionally controlled for BMI, except for BMI, VAI, BAI, WC, and WHR

Abbreviations

n, number; M-type, morning chronotype; E-type, evening chronotype; TEI, total energy intake; kcal, kilocalorie; EOs, eating occasions; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; VAI, visceral adiposity index; SES, socio economic status; BAI, body adiposity index; WC, waist circumference; WHR, waist circumference-hip circumference ratio; TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein; FBS, fasting blood glucose; HOMA-IR, homeostatic model assessment for insulin resistance; HOMA-IS, homeostatic model assessment for insulin sensitivity; hs-CRP, high sensitive c-reactive protein

metabolic benefits. In contrast, both insufficient and excessive intake were linked to unfavorable outcomes, particularly among evening-type (E-type) individuals.

These findings, while aligned with some prior research, contrast with other reports in the literature. A cross-sectional study revealed that consuming more than 33% of daily energy intake between 11:00 a.m. and 5:00 p.m. was associated with a lower BMI [48], whereas eating more calories after 5:00 p.m. was linked to higher CRP levels and weight gain. The study reported that a 10% increase in calorie consumption during the evening (5 p.m. to midnight) was associated with a 3% increase in CRP levels [49]. Research has also explored how afternoon snacking influences overall intake. Some studies reported that pleasure-focused midafternoon snacks in children led to significantly lower daily energy consumption [50]. Similarly, women who had an afternoon berry snack consumed less energy at dinner than those who had a sweet snack [51]. Moreover, a study on healthy adults revealed that those who ate a hummus and pretzel snack in the afternoon reduced their dessert intake by 20% and improved appetite control compared with other snack patterns [52]. While several studies suggest that shifting energy intake toward the evening may be associated with adverse metabolic outcomes [53, 54]. the evidence remains mixed [55]. One study of 872 middle- to older-aged adults, assessed over a year using six 24-hour dietary recalls, energy intake was categorized into four time windows relative to individual sleep timing (morning, night, and two midday periods). The results showed that higher nighttime energy intake was associated with increased odds of obesity, particularly among individuals with a later chronotype [21]. Conversely, Murakami et al. reported that evening energy intake was linked to increased obesity risk, regardless of chronotype, in a longitudinal design [56].

These discrepancies may stem from variations in study design, population characteristics, definitions of eating windows, as well as the composition and quality of the diet consumed during these windows, and the role of chronotype. Several physiological mechanisms may precipitate the association between a later chronotype and adverse metabolic outcomes. Indeed, evening-type individuals tend to exhibit increased appetite and a higher preference for energy-dense, high-fat foods during the evening, which may contribute to weight gain [57]. Additionally, diet-induced thermogenesis (DIT) and energy expenditure decrease in the evening, leading to decreased energy utilization [58]. Meal timing plays a crucial role in aligning peripheral circadian rhythms, such as gene expression in adipose tissue, even without altering central clock markers like melatonin or cortisol [59]. Moreover, the association of the E-type chronotype with weight gain and obesity might be mediated by elevated levels of CRP and an increased cortisol stress response [60].

No significant associations were observed between number of EOs and metabolic health. Previous research has reported inconsistent findings in this regard. For example, data from the 2005 Korean National Health and Nutrition Examination Survey indicated that higher meal frequency was associated with a reduced risk of metabolic syndrome (MetS) among younger adults [55]. While another Iranian-based study linked more frequent meals and snacks to increased MetS risk [56]. These inconsistencies may stem from variations in meal timing assessments across studies [21]. In the present study, a shorter eating window was associated with reduced

Table 4 The interaction between chronotype of total energy intake, and energy distribution, with adiposity indices and metabolic parameters in women ($n=574$)

Variables	M-type	Intermediate				E- type			
		Crude[1]		Adjusted		Crude[1]		Adjusted	
		β (95% CI)	*P* value†	β (95% CI)	*P* value†	β (95% CI)	*P* value†	β (95% CI)	*P* value†
	Total energy intake (TEI)								
Adiposity indices[2]									
BMI (kg/m2)	Ref.	0.001 (-0.002 to 0.003)	0.57	0.001 (-0.002 to 0.004)	0.38	0.002 (-0.004 to 0.003)	0.21	0.001 (-0.004 to 0.004)	0.27
WHR (cm)	Ref.	0.0001 (-0.0004 to 0.004)	0.96	0.00002 (-0.0004 to 0.00004)	0.95	0.0003 (-0.00007 to 0.0007)	0.12	0.0003 (-0.00007 to 0.008)	0.11
VAI	Ref.	0.001 (-0.001 to 0.003)	0.52	0.001 (-0.001 to 0.003)	0.45	0.001 (-0.001 to 0.003)	0.47	0.001 (-0.001 to 0.003)	0.46
BAI	Ref.	0.001 (-0.002 to 0.004)	0.63	0.001 (-0.002 to 0.004)	0.51	0.001 (-0.002 to 0.004)	0.49	0.001 (-0.002 to 0.004)	0.37
Metabolic parameters[3]									
SBP (mmHg)	Ref.	0.002 (-0.007 to 0.01)	0.61	0.002 (-0.008 to 0.01)	0.74	-0.003 (-0.01 to 0.006)	0.52	-0.002 (-0.01 to 0.007)	0.72
DBP (mmHg)	Ref.	0.002 (-0.005 to 0.008)	0.61	0.002 (-0.005 to 0.008)	0.60	-0.001 (-0.007 to 0.005)	0.68	-0.001 (-0.003 to 0.005)	0.74
TG-HDL ratio (mg/dl)	Ref.	0.0 (-0.001 to 0.002)	0.39	0.00 (-0.001 to 0.002)	0.40	0.00 (-0.001 to 0.001)	0.50	0.00 (-0.001 to 0.001)	0.41
TC-HDL ratio (mg/dl)	Ref.	0.0 (-0.001 to 0.0)	0.56	0.00 (-0.001 to 0.001)	0.68	0.00 (-0.001 to 0.0)	0.64	0.0 (-0.001 to 0.001)	0.75
FBS (mg/dl)	Ref.	0.003 (-0.01 to 0.01)	0.70	0.003 (-0.01 to 0.02)	0.71	-0.003 (-0.01 to 0.009)	0.60	-0.003 (-0.02 to 0.009)	0.61
HOMA-IR	Ref.	0.0 (-0.007 to 0.007)	0.95	-0.001 (-0.008 to 0.007)	0.87	-0.003 (-0.009 to 0.004)	0.41	-0.003 (-0.009 to 0.004)	0.43
HOMA-IS	Ref.	-0.001 (-0.002 to 0.001)	0.36	-0.001 (-0.001 to 0.001)	0.37	0.00 (-0.001 to 0.001)	0.74	-0.006 (-0.001 to 0.001)	0.90
hs-CRP	Ref.	0.0002 (0.0 to 0.01)	0.72	0.0001 (0.00 to 0.00)	0.81	-0.006 (0.00 to 0.00)	0.95	0.001 (0.00 to 0.00)	0.83
	Breakfast energy intake								
Adiposity indices[2]									
BMI (kg/m2)	Ref.	0.005 (-0.001 to 0.01)	0.10	0.005 (-0.001 to 0.01)	0.07	-0.001 (-0.007 to 0.004)	0.61	-0.001 (-0.007 to 0.004)	0.64
WHR (cm)	Ref.	-0.0003 (-0.009 to 0.009)	0.95	0.0002 (-0.009 to 0.009)	0.96	-0.0003 (-0.0007 to 0.004)	0.45	-0.0004 (-0.00 to 0.005)	0.39
VAI	Ref.	-0.001 (-0.005 to 0.004)	0.78	0.001 (-0.003 to 0.005)	0.61	0.002 (-0.002 to 0.006)	0.35	-0.001 (-0.005 to 0.003)	0.58
BAI	Ref.	0.002 (-0.004 to 0.009)	0.47	0.002 (-0.004 to 0.008)	0.50	0.00 (-0.006 to 0.007)	0.94	0.002 (-0.006 to 0.007)	0.89
Metabolic parameters[3]									
SBP (mmHg)	Ref.	0.005 (-0.01 to 0.02)	0.57	− 0.001 (-0.02 to 0.02)	0.72	-0.02 (-0.04 to -0.007)	**0.008**	-0.03 (-0.05 to -0.01)	**0.002**
DBP (mmHg)	Ref.	0.002 (-0.01 to 0.01)	0.81	0.00 (-0.01 to 0.01)	0.97	-0.01 (-0.03 to -0.02)	**0.04**	-0.02 (-0.04 to -0.003)	**0.01**
TG-HDL ratio (mg/dl)	Ref.	0.00 (-0.003 to 0.002)	0.67	-0.001 (-0.003 to 0.001)	0.35	0.001 (-0.001 to 0.003)	0.39	0.001 (-0.002 to 0.003)	0.58
TC-HDL ratio (mg/dl)	Ref.	-0.001(-0.001 to 0.001)	0.13	-0.001(-0.003 to 0.0003)	0.06	-0.0003 (-0.001 to 0.001)	0.95	0.00 (-0.002 to 0.001)	0.72
FBS (mg/dl)	Ref.	0.02 (-0.002 to 0.05)	0.06	0.02 (-0.002 to 0.05)	0.06	0.007 (-0.02 to 0.03)	0.63	0.003 (-0.02 to 0.03)	0.84
HOMA-IR	Ref.	0.00 (-0.01 to 0.01)	0.95	0.001 (-0.01 to 0.01)	0.88	-0.01 (-0.02 to 0.03)	0.19	-0.01 (-0.02 to 0.005)	0.18
HOMA-IS	Ref.	-0.002 (-0.004 to 0.001)	0.14	-0.002 (-0.005 to 0.00)	0.06	0.00 (-0.003 to 0.002)	0.80	-0.001 (-0.003 to 0.002)	0.68
hs-CRP	Ref.	0.00 (-0.00003 to 0.001)	0.08	0.00 (-0.0006 to 0.00)	0.12	-0.0005 (0.00 to 0.00)	0.69	0.0001 (0.00 to 0.00)	0.91
	Lunch energy intake								

Table 4 (continued)

Variables	M-type	Intermediate				E- type			
		Crude[1]		Adjusted		Crude[1]		Adjusted	
		β (95% CI)	*P* value†	β (95% CI)	*P* value†	β (95% CI)	*P* value†	β (95% CI)	*P* value†
Adiposity indices[2]									
BMI (kg/m2)	Ref.	-0.001 (-0.005 to 0.004)	0.74	0.00007 (-0.005 to 0.005)	0.97	-0.001 (-0.006 to 0.004)	0.71	0.00 (-0.005 to 0.004)	0.83
WHR (cm)	Ref.	0.0006 (-0.001 to 0.00)	0.10	0.003 (-0.0005 to 0.00)	0.47	0.002 (-0.0005 to 0.00)	0.48	0.0005 (-0.0002 to 0.00)	0.18
VAI	Ref.	0.003 (-0.001 to 0.006)	0.15	0.003 (0.00 to 0.007)	0.07	0.002 (-0.002 to 0.006)	0.27	0.002 (-0.002 to 0.002)	0.37
BAI	Ref.	-0.002 (-0.007 to 0.003)	0.43	-0.001 (-0.007 to 0.004)	0.60	0.001 (-0.004 to 0.006)	0.73	0.002 (-0.003 to 0.007)	0.48
Metabolic parameters[3]									
SBP (mmHg)	Ref.	0.00006 (-0.0001 to 0.00)	0.10	0.008 (-0.009 to 0.02)	0.35	0.00002 (-0.00005 to 0.00)	0.48	0.00 (-0.01 to 0.01)	0.96
DBP (mmHg)	Ref.	0.006 (-0.004 to 0.01)	0.23	0.007 (-0.004 to 0.01)	0.20	-0.002 (-0.01 to 0.009)	0.69	-0.002 (-0.01 to 0.009)	0.74
TG-HDL ratio (mg/dl)	Ref.	0.002 (0.00 to 0.003)	0.10	0.002 (0.00004 to 0.004)	0.04	0.001 (-0.001 to 0.003)	0.35	0.001 (-0.001 to 0.003)	0.43
TC-HDL ratio (mg/dl)	Ref.	0.001 (-0.001 to 0.002)	0.91	0.001 (0.00 to 0.002)	0.88	0.00 (-0.001 to 0.001)	0.72	0.001 (0.00 to 0.002)	0.22
FBS (mg/dl)	Ref.	0.001 (-0.02 to 0.02)	0.91	0.001 (-0.02 to 0.02)	0.94	-0.006 (0.02 to 0.01)	0.62	-0.006 (-0.03 to 0.01)	0.61
HOMA-IR	Ref.	0.003 (-0.009 to 0.01)	0.59	0.002 (-0.01 to 0.01)	0.78	-0.008 (0.02 to 0.004)	0.19	-0.009 (-0.02 to 0.004)	0.17
HOMA-IS	Ref.	0.002 (0.00 to 0.004)	0.09	0.002 (0.00 to 0.004)	0.06	0.001 (-0.001 to 0.003)	0.27	0.001 (-0.001 to 0.003)	0.27
hs-CRP	Ref.	-0.0003 (0.00 to 0.00)	0.78	0.0006 (0.00 to 0.00)	0.99	0.0002 (0.00 to 0.00)	0.80	0.00003 (0.00 to 0.00)	0.76
	Afternoon energy intake								
Adiposity indices[2]									
BMI (kg/m2)	Ref.	-0.01 (-0.03 to 0.001)	0.07	-0.02 (-0.05 to 0.00)	**0.05**	-0.01 (-0.03 to 0.001)	0.06	-0.02 (-0.04 to -0.001)	**0.04**
WHR (cm)	Ref.	0.00 (-0.001 to 0.00)	0.41	0.00 (-0.001 to 0.00)	0.49	0.00 (-0.001 to 0.00)	0.18	0.00 (-0.001 to 0.003)	0.36
VAI	Ref.	0.01 (-0.004 to 0.02)	0.15	0.01 (-0.002 to 0.03)	0.08	0.009 (-0.006 to 0.02)	0.24	0.01 (-0.005 to 0.02)	0.16
BAI	Ref.	-0.001 (-0.02 to 0.20)	0.81	-0.006 (-0.03 to 0.01)	0.57	-0.03 (-0.05 to 0.02)	0.11	-0.05 (-0.03 to 0.01)	0.28
Metabolic parameters[3]									
SBP (mmHg)	Ref.	0.01 (-0.05 to 0.08)	0.66	0.04 (-0.03 to 0.11)	0.27	0.005 (-0.06 to 0.07)	0.88	0.03 (-0.04 to 0.10)	0.38
DBP (mmHg)	Ref.	-0.01 (-0.05 to 0.03)	0.57	-0.01 (-0.06 to 0.02)	0.55	-0.01 (-0.06 to 0.02)	0.44	-0.01 (-0.06 to 0.03)	0.46
TG-HDL ratio (mg/dl)	Ref.	0.006 (-0.002 to 0.01)	0.16	0.009 (0.00 to 0.01)	0.06	0.005 (-0.003 to 0.01)	0.24	0.007 (-0.001 to 0.015)	0.09
TC-HDL ratio (mg/dl)	Ref.	0.00 (-0.005 to 0.005)	0.91	0.00 (-0.005 to 0.005)	0.88	0.001 (-0.004 to 0.006)	0.78	0.00 (-0.005 to 0.005)	0.85
FBS (mg/dl)	Ref.	0.02 (-0.07 to 0.12)	0.58	0.02 (-0.08 to 0.12)	0.66	-0.01 (-0.11 to 0.08)	0.77	-0.01 (-0.11 to 0.08)	0.71
HOMA-IR	Ref.	0.002 (-0.05 to 0.05)	0.94	0.002 (-0.05 to 0.05)	0.92	0.003 (-0.04 to 0.06)	0.89	0.004 (-0.05 to 0.05)	0.87
HOMA-IS	Ref.	0.00 (-0.009 to 0.009)	0.94	0.001 (-0.008 to 0.01)	0.78	0.001 (-0.008 to 0.01)	0.85	0.002 (-0.007 to 0.01)	0.70
hs-CRP	Ref.	-0.01 (-0.02 to −0.003)	**0.02**	-0.01 (-0.02 to -0.002)	**0.04**	-0.01 (-0.02 to −0.006)	**0.03**	-0.01 (-0.02 to -0.006)	**0.03**
	Dinner energy intake								
Adiposity indices[2]									
BMI (kg/m2)	Ref.	0.02 (-0.006 to 0.05)	0.41	0.02 (-0.006 to 0.06)	0.39	0.05 (0.001 to 0.09)	**0.02**	0.05 (0.003 to 0.09)	**0.03**
WHR (cm)	Ref.	-0.0005 (0.00 to 0.0002)	0.19	-0.0005 (0.00 to 0.00002)	0.20	-0.0007 (0.00 to 0.00001)	0.07	-0.0007 (0.00 to 0.00001)	0.08
VAI	Ref.	0.00 (-0.003 to 0.004)	0.89	0.00 (-0.003 to 0.004)	0.87	0.002 (-0.001 to 0.006)	0.24	0.001 (-0.002 to 0.005)	0.42
BAI	Ref.	-0.002 (-0.06 to 0.003)	0.45	-0.002 (-0.07 to 0.003)	0.33	-0.003 (-0.008 to 0.003)	0.32	-0.003 (-0.008 to 0.002)	0.24

Table 4 (continued)

Variables	M-type	Intermediate				E- type			
		Crude[1]		Adjusted		Crude[1]		Adjusted	
		β (95% CI)	*P* value†	β (95% CI)	*P* value†	β (95% CI)	*P* value†	β (95% CI)	*P* value†
Metabolic parameters[3]									
SBP (mmHg)	Ref.	-0.003 (-0.01 to 0.01)	0.76	-0.004 (-0.02 to 0.01)	0.63	-0.009 (-0.03 to 0.008)	31	-0.009 (-0.02 to 0.008)	0.29
DBP (mmHg)	Ref.	-0.006 (-0.01 to 0.004)	0.23	-0.007 (-0.01 to 0.003)	0.17	-0.008 (-0.01 to 0.002)	0.12	-0.01 (-0.02 to 0.001)	0.07
TG-HDL ratio (mg/dl)	Ref.	0.001 (0.001 to 0.003)	0.57	0.001 (-0.001 to 0.002)	0.53	0.001 (0.00 to 0.003)	0.13	0.001 (-0.001 to 0.003)	0.22
TC-HDL ratio (mg/dl)	Ref.	0.00 (-0.002 to 0.001)	0.48	0.00 (-0.001 to 0.001)	0.60	0.001 (-0.001 to 0.002)	0.39	0.00 (-0.001 to 0.002)	0.57
FBS (mg/dl)	Ref.	-0.002 (-0.02 to 0.02)	0.89	-0.01 (-0.03 to 0.01)	0.38	-0.007 (-0.03 to 0.01)	0.57	-0.004 (-0.02 to 0.01)	0.71
HOMA-IR	Ref.	-0.001 (-0.01 to 0.01)	0.92	-0.001 (-0.01 to 0.01)	0.84	0.008 (-0.004 to 0.02)	0.17	0.009 (-0.003 to 0.02)	0.15
HOMA-IS	Ref.	-0.001 (-0.003 to 0.001)	0.42	-0.001 (-0.003 to 0.001)	0.38	0.0007 (-0.002 to 0.002)	0.99	0.00 (-0.002 to 0.002)	0.79
hs-CRP	Ref.	-0.009 (0.00 to 0.00)	0.40	-0.0006 (0.00 to 0.00)	0.56	0.00 (0.00 to 0.00)	0.38	0.0001 (0.00 to 0.00)	0.92

† Calculated by generalized linear regression (GLM), GLM was used to obtain beta (β) and 95% confidence interval (CI), and P-value < 0.05 indicates significant level, significant values are in **bold**

[1]The crude model was adjusted by age

[2]The model was adjusted additionally by physical activity, smoking status, SES, education, sleep length, supplement intake, number of EOs, and energy intake, except for TEI

[3]The model was additionally controlled for BMI

Abbreviations

n, number; M-type, morning chronotype; E-type, evening chronotype; TEI, total energy intake; kcal, kilocalorie; EOs, eating occasions; SES, socio-economic status; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; VAI, visceral adiposity index; BAI, body adiposity index; WC, waist circumference; WHR, waist circumference-hip circumference ratio; TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein; FBS, fasting blood glucose; HOMA-IR, homeostatic model assessment for insulin resistance; HOMA-IS, homeostatic model assessment for insulin sensitivity; hs-CRP, high sensitive c-reactive protein

FBS in the E-type chronotype compared with the M-type chronotype, suggesting a chronotype-specific benefit. This finding aligns with previous research indicating that time-restricted eating (TRE), which limited the daily eating period, has been shown to improve glucose and lipid metabolism by lowering fasting and postprandial glucose levels, reducing insulin levels, and increasing insulin sensitivity [61]. However, a study revealed that a shorter eating window improved the glycemic response in diabetes patients regardless of chronotype [62]. Altering the fasting–eating cycle might impact peripheral clocks in tissues, such as the liver and adipose tissue. This effect may be due to changes in metabolic hormones, such as insulin and oxyntomodulin, following meals, which help regulate these clocks and influence metabolic processes [63, 64]. Collectively, these findings support the utility of chronotype-aligned, time-targeted dietary strategies for improving cardiometabolic health, especially among populations vulnerable to circadian misalignment, such as shift workers. However, further research is needed to validate these associations in larger and more diverse populations to strengthen the generalizability of our findings and support the broader use of chrono-nutritional approaches in preventive health strategies.

Strengths and limitations

We used 24-hour dietary recalls as a short-term dietary assessment method, which provides more detailed information about food types and amounts than long-term methods do [65]. While all self-reported dietary assessments have measurement errors, 24hDRs are generally more accurate than food frequency questionnaires (FFQs) and allow for meal-specific analysis [66]. The study was conducted over a 3-month period without seasonal variation, which may have introduced bias in assessing average dietary patterns. Although misreporting—particularly among overweight and obese individuals—is a known limitation of self-reported dietary data [66], under-reporting does not appear to be a major concern here, as only 12 women were excluded for under- or over-reporting energy intake. Moreover, as a cross-sectional study, its design precludes the ability to establish causality in the observed associations [67], and limited generalizability due to the homogeneous sample of Iranian women. Due to the exploratory nature of the study and interrelated outcomes, no correction for multiple comparisons was applied; thus, findings should be interpreted cautiously, with emphasis on overall patterns rather than isolated significant results. In this study, we standardized and defined meals using clock-time according to previous research rather than self-report,

Table 5 The interaction between chronotype of number of eating occasions (EOs) with adiposity indices and metabolic parameters in women ($n = 574$)

Variables	Number of eating occasion (EOs) (*n*/day)								
	M-type	Intermediate				E- type			
Adiposity indices[2]		Crude[1]		Adjusted		Crude[1]		Adjusted	
		β (95% CI)	P value†	β (95% CI)	P value†	β (95% CI)	P value†	β (95% CI)	P value†
BMI (kg/m2)	Ref.	0.94 (0.10 to 1.72)	**0.02**	0.88 (-0.06 to 1.72)	0.05	0.32 (-1.36 to 1.84)	0.19	0.72 (-0.35 to 1.81)	0.18
WHR (cm)	Ref.	0.004 (-0.01 to 0.01)	0.61	0.005 (-0.01 to 0.02)	0.48	0.00 (-0.02 to 0.01)	0.97	0.002 (-0.01 to 0.02)	0.81
VAI	Ref.	0.51 (-0.14 to 1.17)	0.10	0.45 (-0.21 to 1.11)	0.14	0.67 (-0.17 to 1.52)	0.09	0.61 (-0.25 to 1.48)	0.11
BAI	Ref.	0.10 (-0.86 to 1.07)	0.83	0.10 (-0.85 to 1.06)	0.83	0.75 (-0.49 to 2.00)	0.23	0.93 (-0.32 to 2.18)	0.14
Metabolic parameters[3]									
SBP (mmHg)	Ref.	-0.33 (-3.28 to 2.61)	0.82	-0.58 (-3.53 to 2.37)	0.70	0.44 (-3.36 to 4.25)	0.81	0.41 (-3.43 to 4.25)	0.83
DBP (mmHg)	Ref.	-0.25 (-2.18 to 1.66)	0.79	-0.11 (-2.06 to 1.83)	0.90	0.66 (-1.82 to 3.14)	0.60	0.94 (-1.58 to 3.47)	0.46
TG-HDL ratio (mg/dl)	Ref.	0.33 (-0.01 to 0.68)	0.07	0.25 (-0.10 to 0.60)	0.16	0.40 (-0.04 to 0.85)	0.25	0.33 (-0.12 to 0.78)	0.15
TC-HDL ratio (mg/dl)	Ref.	0.08 (-0.12 to 0.30)	0.41	0.04 (-0.17 to 0.25)	0.68	0.22 (-0.05 to 0.49)	0.11	0.14 (-0.13 to 0.42)	0.31
FBS (mg/dl)	Ref.	2.53 (-1.16 to 6.65)	0.23	2.77 (-1.45 to 7.00)	0.19	-3.27 (-8.62 to 2.07)	0.23	-3.16 (-8.68 to 2.34)	0.26
HOMA-IR	Ref.	0.29 (-1.94 to 2.52)	0.79	-0.07 (-2.34 to 2.19)	0.94	-0.71 (-3.59 to 2.16)	0.62	-1.28 (-4.02 to 1.70)	0.40
HOMA-IS	Ref.	0.005 (-0.38 to 0.39)	0.98	-0.11 (-0.50 to 0.27)	0.57	0.09 (-0.40 to 0.59)	0.72	-0.05 (-0.56 to 0.45)	0.82
hs-CRP	Ref.	0.03 (-0.003 to 0.08)	0.07	0.03 (-0.01 to 0.06)	0.09	0.02 (-0.03 to 0.07)	0.29	0.02 (-0.03 to 0.07)	0.37

† Calculated by generalized linear regression (GLM), GLM was used to obtain beta (β) and 95% confidence interval (CI), and P-value < 0·05 indicates significant level, significant values are in **bold**

[1]The crude model was adjusted by age

[2]The model was adjusted additionally by physical activity, smoking status, SES, sleep length, supplement intake, and energy intake

[3]The Adjusted models for metabolic parameters were additionally controlled for BMI

Abbreviations: n, number; M-type, morning chronotype; E-type, evening chronotype; TEI, total energy intake; kcal, kilocalorie; EOs, eating occasions; SES, socio economic status; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; VAI, visceral adiposity index; BAI, body adiposity index; WC, waist circumference; WHR, waist circumference-hip circumference ratio; TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein; FBS, fasting blood glucose; HOMA-IR, homeostatic model assessment for insulin resistance; HOMA-IS, homeostatic model assessment for insulin sensitivity; hs-CRP, high sensitive c-reactive protein

which may misclassify intake for participants with evening chronotypes; however, data on wake-up and sleep times were available for each day of the dietary report. Nevertheless, to our knowledge, this is the first study to assess energy distribution and temporal eating patterns in relation to cardiometabolic health across chronotype differences in Iranian women. By assessing both linear and non-linear associations, and exploring meal timing patterns across chronotypes, this study provides a more nuanced understanding of the complex interplay between chrono-nutrition and metabolic health in Iranian women.

Conclusion

This study highlights the critical role of chronotype and meal timing in managing and improving cardiometabolic health. Women with an E-type chronotype exhibited higher total energy intake, particularly during dinner, which was associated with adverse metabolic outcomes. In contrast, moderate energy intake at breakfast and in the afternoon was linked to more favorable outcomes, including lower BMI and reduced inflammation, especially among E-type individuals.

Shifting eating patterns to better align with individualized circadian rhythms—such as moving energy intake earlier in the day—has emerged as a practical, nonpharmacological approach for managing weight and improving metabolic health. Future research should focus on long-term studies to investigate the lasting effects of chronotype-aligned meal timing on cardiometabolic health. These studies could provide more definitive evidence of how meal timing was associated with weight, glucose regulation, and lipid metabolism over time. Additionally, exploring the biological mechanisms behind the interaction between chronotype, meal timing, and metabolic health, especially how circadian misalignment affects hormone secretion, would offer valuable insights into the broader implications of these findings.

Table 6 The interaction between chronotype of eating window with adiposity indices and metabolic parameters in women ($n=574$)

Variables	Eating window (hours /day)							
	M-type	Intermediate				E- type			
		Crude[1]		Adjusted		Crude[1]		Adjusted	
		β (95% CI)	P value†	β (95% CI)	P value†	β (95% CI)	P value†	β (95% CI)	P value†
Adiposity indices[2]									
BMI (kg/m2)	Ref.	0.0002 (-0.001 to 0.001)	0.9	0.001 (-0.001 to 0.001)	0.88	0.001 (0.001 to 0.001)	0.91	-0.001 (-0.001 to 0.001)	0.84
WHR (cm)	Ref.	0.00001 (-0.00002 to 0.00004)	0.40	0.00001 (-0.00002 to 0.00005)	0.44	0.0002 (-0.0002 to 0.00005)	0.07	0.0002 (-0.0002 to 0.0005)	0.07
VAI	Ref.	0.00 (-0.00002 to 0.00)	0.12	0.00 (-0.00001 to 0.00)	0.07	0.00007 (-0.001 to 0.001)	0.86	-0.0001 (-0.001 to 0.001)	0.82
BAI	Ref.	-0.000001 (-0.0001 to 0.0001)	0.98	-0.00006 (-0.0002 to 0.0001)	0.64	-0.00003 (-0.0002 to 0.000)	0.74	-0.0004 (-0.002 to 0.001)	0.48
Metabolic parameters[3]									
SBP (mmHg)	Ref.	-0.0002 (-0.001 to 0.0003)	0.38	-0.0002 (-0.001 to 0.0003)	0.43	-0.0003 (-0.001 to 0.00004)	0.88	0.0005 (-0.001 to 0.001)	0.83
DBP (mmHg)	Ref.	0.0004 (-0.001 to 0.004)	0.78	0.0004 (-0.0003 to 0.0009)	0.80	0.003 (0.0002 to 0.001)	0.05	0.003 (-0.0008 to 0.001)	0.06
TG-HDL ratio (mg/dl)	Ref.	-0.005 (-0.004 to 0.0004)	0.97	0.0006 (-0.003 to 0.0004)	0.88	-0.001 (-0.003 to 0.003)	0.92	0.003 (-0.003 to 0.006)	0.74
TC-HDL ratio (mg/dl)	Ref.	-0.0006 (-0.003 to 0.0002)	073	-0.0006 (-0.003 to 0.0002)	0.70	-0.0003 (-0.001 to 0.0002	0.94	0.0002 (-0.0002 to 0.0003)	0.90
FBS (mg/dl)	Ref.	0.001 (0.002 to 0.003)	**0.04**	0.001 (0.00 to 0.002)	0.05	0.001 (-0.001 to 0.001)	0.12	0.001 (0.002 to 0.003)	**0.02**
HOMA-IR	Ref.	0.003 (-0.001 to 0.001)	0.15	0.003 (-0.008 to 0.001)	0.12	0.003 (-0.004 to 0.001)	0.08	0.003 (-0.0002 to 0.001)	0.06
HOMA-IS	Ref.	-0.007 (-0.001 to 0.001)	0.05	-0.006 (-0.0001 to 0.0007)	0.09	-0.002 (-0.008 to 0.0004)	0.53	-0.001 (-0.007 to 0.0005)	0.71
hs-CRP	Ref.	0.003 (-0.005 to 0.006)	0.72	0.001 (-0.006 to 0.008)	0.78	0.002 (-0.006 to 0.009)	0.79	0.0004 (-0.006 to 0.0008)	0.86

† Calculated by generalized linear regression (GLM), GLM was used to obtain beta (β) and 95% confidence interval (CI), and P-value < 0·05 indicates significant level, significant values are in **bold**

[1]The crude model was adjusted by age

[2]The model was adjusted additionally by physical activity, smoking status, SES, sleep length, supplement intake, EOs, and TEI

[3]The Adjusted models for metabolic parameters are additionally controlled for BMI

Abbreviations

n, number; M-type, morning chronotype; E-type, evening chronotype; SES, socio economic status; EOs, eating occasions; TEI, total energy intake; Ref; reference; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; VAI, visceral adiposity index; BAI, body adiposity index; WC, waist circumference; WHR, waist circumference-hip circumference ratio; TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein; FBS, fasting blood glucose; HOMA-IR, homeostatic model assessment for insulin resistance; HOMA-IS, homeostatic model assessment for insulin sensitivity; hs-CRP, high sensitive c-reactive protein

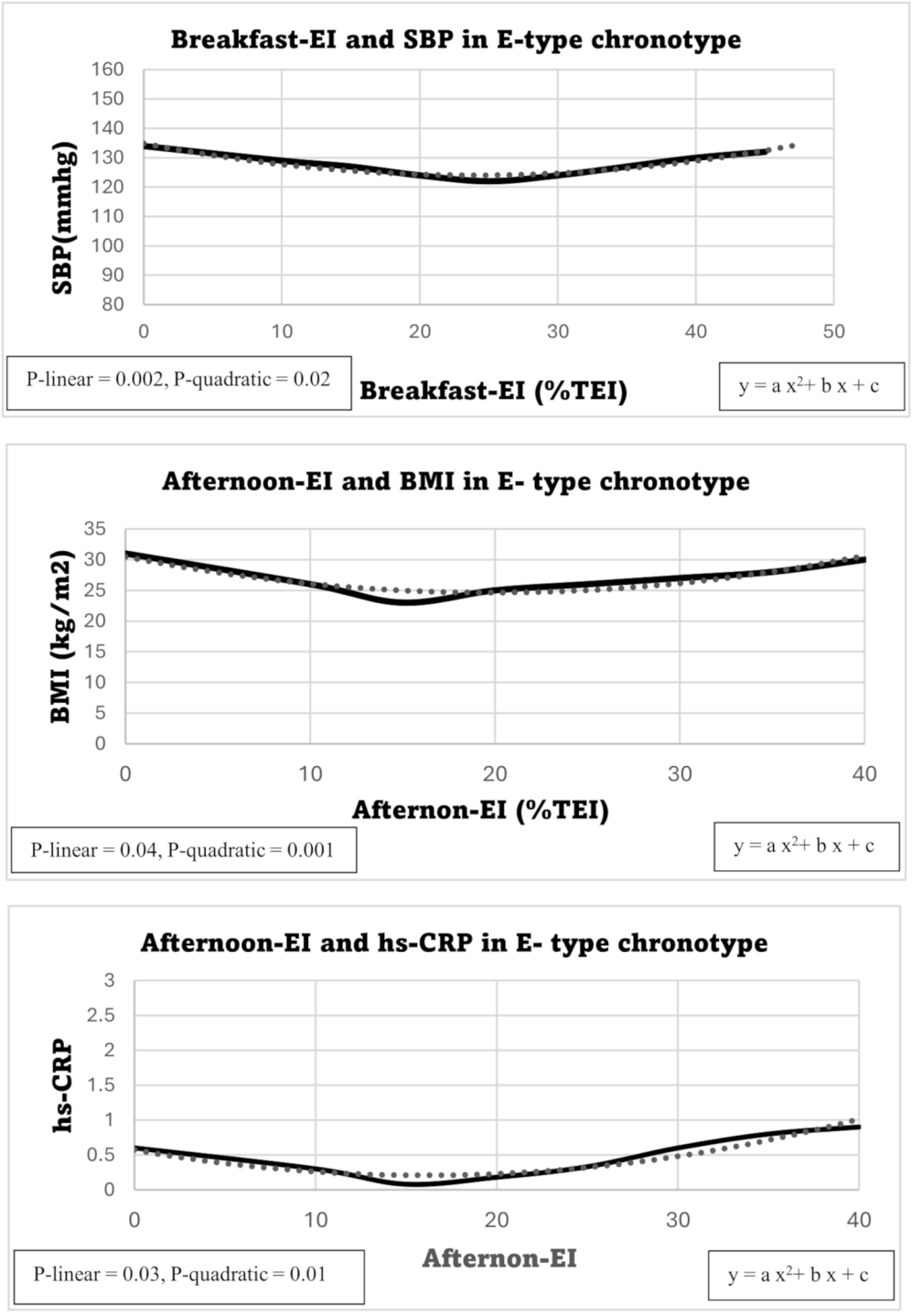

Fig. 1 Significant quadratic associations between meal energy intake and cardiometabolic health outcomes in evening (E-type) chronotype
The non-linear model was adjusted for age, physical activity, education level, SES, marital status, menopausal status, smoking status, sleep duration, supplement intake, and TEI
a = linear term, b = quadratic term, c = intercept
Abbreviation: E-type, evening chronotype; EI, energy intake; SES, socioeconomic status; TEI, total energy intake; SBP, systolic blood pressure; BMI, body mass index; hs-CRP, high sensitive c-reactive protein

Abbreviations

ANOVA	analysis of variance
ANCOVA	analysis of covariance
BAI	Body Adiposity Index
BMI	body mass index
BP	blood pressure
hs-CRP	high-sensitivity c-reactive protein
EOs	eating occasions
E-type	evening chronotype
FBS	fasting blood glucose
HDL	high-density lipoprotein cholesterol
HOMA-IR	homeostatic model assessment for insulin resistance
HOMA-IS	homeostatic model assessment for insulin sensitivity
IPAQ	international physical activity questionnaire, GLM, generalized linear regression
LDL	low-density lipoprotein cholesterol, M-type, morning chronotype, MEQ, morningness-eveningness questionnaire
MET/min	metabolic equivalent of task per minute
PCA	principal component analysis
SES	socioeconomic status
SFA	saturated fatty acid
TEI	total energy intake
TG	triglyceride
TC	total cholesterol
VAI	visceral adiposity index
WC	waist circumference
WHO	world health organization
WHR	waist circumference to hip circumference ratio

Supplementary Information

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Supplementary Material 1

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Author contributions

A.L., and M.M. contributed to the conception/design of the research; A.L. and M.M. contributed to the acquisition, analysis, or interpretation of the data; A.L. drafted the manuscript; N.S., C.C., B.B, F.G., and M.M. critically revised the manuscript; and agreed to be fully accountable for ensuring the integrity and accuracy of the work. All the authors have read and approved the final manuscript.

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Data availability

The datasets used and analyzed in this study can be obtained from the corresponding author upon reasonable request.

Declarations

Ethical approval

The study protocol was reviewed and approved by the Research Ethics Committee of Islamic Azad University, Tehran Medical Sciences—Pharmacy and Pharmaceutical Sciences Faculty (IR.IAU.REC.1403.487), and conducted according to Declaration of Helsinki and relevant institutional guidelines. All participants provided written informed consent before taking part in the study.

Competing interests

The authors declare no competing interests.

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