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ORIGINAL ARTICLE

Vitamin D and chronotype: is there any relationship in individuals with obesity?

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Abstract

Purpose Chronotype is the attitude to perform most of the daily activities in the morning ("morning chronotype", MC) or in the evening ("evening chronotype", EC). The latter, as well as vitamin D deficiency, has been associated with an increased risk of obesity-related complications, likely through the promotion of insulin resistance. Therefore, we aimed to investigate whether there is any relationship between vitamin D (25-OH-D) and chronotype in individuals with obesity.

Methods In this cross-sectional study, we enrolled 59 individuals (43.1 ± 13 years; 17M/42F) with obesity. Anthropometric parameters, lifestyle habits, personal medical history, chronotype, insulin resistance, and 25-OH-D were assessed.

Results Individuals with EC presented significantly higher BMI than MC ($p < 0.001$), greater waist ($p = 0.012$), and hip circumferences ($p = 0.001$). Individuals with EC showed significantly lower insulin sensitivity ($p = 0.017$) and 25-OH-D than MC. In addition, the prevalence of vitamin D deficiency and impaired fasting glucose was significantly higher in EC than in MC. 25-OH-D directly correlated with chronotype score ($r = 0.351$; $p = 0.019$) whereas inversely with BMI ($r = -0.363$; $p = 0.016$). The regression analysis showed that BMI was most tightly associated with 25-OH-D concentrations ($\beta = -0.323$, $p = 0.032$), followed by chronotype score ($\beta = 0.340$, $p = 0.042$). Using chronotype score as the dependent variable, BMI significantly predicted a lower chronotype score ($\beta = -0.586$, $p < 0.001$).

Conclusion The present study showed that 25-OH-D, as well as chronotype, correlate independently with obesity.

Keywords Chronotype · Vitamin D · Insulin resistance · Obesity · 25-OH-D

Abbreviations

25-OH-D	Vitamin D
BMI	Body mass index
EC	Evening chronotype
HOMA-IR	Homeostasis Model Assessment
MC	Morning chronotype
MEQ	Morningness–Eveningness Questionnaire

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Introduction

Chronobiology refers to several physiological functions modulating circadian rhythm in humans whose behavioral aspect is represented by chronotype [1]. Individuals with morning chronotype present the attitude toward morningness habits (wake up early and perform activities in the morning), whereas those belonging to the evening chronotype are more active during the late afternoon or evening [2]. Therefore, chronotype relies upon behavioral habits (i.e., nutrition, sleep–wake cycle) as well as can influence the health status [3, 4]. Indeed, it has been shown that evening chronotype is associated with unhealthier lifestyle [5–8], i.e., low concentrations of physical activity, low-quality diet (high intake of processed foods, alcoholic beverages, sugary drinks, and low adherence to the Mediterranean diet) and is more prone to develop insulin resistance and type 2 diabetes [9–13] Notably, all these factors have been proven as risk factors for obesity and obesity-related cardiometabolic complications [14, 15].

In addition, individuals with the evening chronotype have been reported to experience sleep disorders. This can be explained, at least in part, by the higher prevalence of obesity and obesity-related complications, i.e., "obstructive sleep apnea" and subclinical inflammation, which have detrimental effects on sleep quality [16, 17].

The main hormone involved in sleep regulation is represented by melatonin. Vitamin D can modulate the conversion of tryptophan into serotonin, a precursor of melatonin [18]. Several studies reported that low vitamin D concentrations are associated with sleep disorders [19]. Furthermore, data from The National Health and Nutrition Examination Survey (NHANES) suggested that adequate vitamin D concentrations are one of the main factors associated with good sleep quality in a large cohort of adults [20].

Notably, the presence of vitamin D receptors also in several regions of the brain supports its role in other important biological functions, which can influence individual behaviors and the central circadian clock [21].

Vitamin D deficiency (plasma vitamin D < 20 ng/ml), a common finding in individuals with obesity, has been reported to be associated with cardiometabolic disorders, likely through the promotion of insulin resistance [22–24]. Thus, we aimed to investigate whether there is any relationship between vitamin D concentrations and chronotype categories in individuals with obesity. In addition, the association between vitamin D concentrations and insulin resistance was explored.

Materials and methods

Participants and study design

This cross-sectional study was conducted in compliance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement checklist [25].

From October 2021 to April 2022, all patients referring to *Centro Italiano Per La Cura E Il Benessere del Paziente Con Obesità* (C.I.B.O) of Federico II University Hospital (Naples, Italy) were screened for eligibility according to the following inclusion criteria: both gender, age 18–65 years, body mass index (BMI) > 30 kg/m^2, and stable body weight (change < ± 10% of body weight) for 3 months before the study without any treatment. The exclusion criteria were as follows: women who were breastfeeding or pregnant; night-shift-workers or shift-workers; presence of known cardiovascular and cerebrovascular diseases (defined on the form as coronary heart disease, stroke, or revascularization), kidney and hepatic failure and malignant tumors; type 1 and type 2 diabetes or medications for diabetes and pre-diabetes; alcohol abuse (weekly consumption of alcohol is more than 70 g in women or 140 g in men); current or history of treatment with medications that may cause significant weight gain within 3 months before the study; current or history of treatment with GLP-1 receptor agonist, orlistat, naltrexone/bupropion within 3 months before the study; current or history of treatment with glucocorticoids within 3 months before the study; current or history of treatment with vitamin D supplements within 3 months before the study; major psychiatric disorders and/or current or history of treatment with antipsychotic medications within 3 months before the study; chronic inflammatory diseases. The study has been approved by the Ethical Committee (n. 173/16). All participants were informed about the study design and aim and provided written informed consent.

Lifestyle habits' assessment

Trained nutritionists asked standard questions including demographic information, personal medical history, and lifestyle habits that were assessed according to standard procedures as in previous studies [12, 13, 26]: individuals who smoke at least one cigarette (YES/NO) per day were defined as current smokers, while individuals who reported having quit smoking at least 1 year prior to the survey were be defined as former smokers. Participants who regularly exercised at least 30 min per day (YES/NO) were defined as physically active.

Anthropometric measurements

Anthropometric measurements were performed in the morning, after an overnight fast, and by the same operator (nutritionist experienced in body composition assessment). During the measurements, the individuals wore only light clothing and no shoes. Height was measured by a wall stadiometer, with an accuracy of 0.5 cm, and body weight by a calibrated beam scale, with an accuracy of 0.1 kg. Weight and height were then used to calculate the BMI. BMI was classified according to WHO criteria [27]: normal weight (18.5–24.9 kg/m^2); overweight (25.0–29.9 kg/m^2); obesity grade I (30.0–34.9 kg/m^2); obesity grade II (35.0–39.9 kg/m^2); obesity grade III (≥ 40.0 kg/m^2). Waist circumference (WC) was measured with a non-stretchable tape measure, to the nearest 0.1 cm, according to the National Center for Health Statistics [28].

Chronotype assessment

The Morningness–Eveningness Questionnaire (MEQ) [29] was administered as validated tool to assess participants' chronotype categories, which consists of 19 multiple-choice questions, each with 4 or 5 response options, on sleep habits and daily performance. For example, some questions asked about the time of day when one feels most productive in physical or mental activities, the time of day when one is most tired, and the time of day when one would prefer to wake up for maximum energy. The sum of the individual items provided a score ranging from 16 to 86. In particular, a score of 59–86, 42–58, and 14–41 defined morning, intermediate, and evening chronotype, respectively. Nevertheless, since intermediate chronotype presents mixed behavior and clinical features [30], we considered only individuals belonging to morning and evening chronotype.

Biological sample collection and storage

Sample collection was performed the day after a non-fasting day. After overnight fasting (≥ 10 h), peripheral venous blood samples were drawn and collected. Samples were stored at – 80 °C until analysis. Measurements of plasma glucose and insulin, liver enzymes, creatinine, and vitamin D (25-OH-D) were assessed in this study.

Assay methods and calculations

The analyses were done in the central biochemistry laboratory of our institutes. Roche Modular Analytics System was used to perform all biochemical analyses. The Immunolite Diagnostic Products Co, Los Angeles, CA, USA with solid-phase chemiluminescent enzyme immunoassay kit were used to measure fasting insulin concentrations. The intra- and inter-test coefficient of variation (CV) values are < 7% for all tests performed.

Plasma 25-OH-D concentrations were measured with chemiluminescence (Liaison, DiaSorin, Saluggia, Italy). The analytical measurement range of detection was 4–150 ng/ml, whereas the intra-assay CVs were 5.4%, 2.8%, and 4.7%, and the inter-assay CVs were 10.1%, 4.8%, and 7.9% for low, medium, and high points of the standard curve, respectively.

Homeostasis Model Assessment for Insulin Resistance (HOMA-IR) and Homeostasis Model Assessment for β-cell function (HOMA-β) were calculated in accordance with Matthews et al. [31]. Impaired fasting glucose was defined as plasma fasting glucose concentrations between 100 and 126 mg/dL according to the American Diabetes Association [32]. Vitamin D deficiency was defined as a plasma 25-OH-D concentration < 20 ng/mL (50 nmol/L), vitamin D insufficiency between 21 and 29 ng/mL (from 52.5 to 72.5 nmol/L), and normal concentrations ≥ 30 ng/mL [33].

Sample size calculation and statistical analysis

Sample size calculation was performed a priori, since no previous similar studies were available. The calculation included a conventional effect size (0.50) with a type I error of 0.05 and a power of 80%. The total number of individuals to be enrolled was 42 (21 per group). Considering a 40% non-response rate or missing information, we included 59 individuals in the study. The calculation of the sample size was performed using G Power Software. Accordingly, we consecutively enrolled individuals meeting the inclusion criteria and being morning or evening chronotype.

Kolmogorov–Smirnov test was used to test data distribution and variables not normally distributed were analyzed after logarithmic transformation (Log10). Continuous variables with normal distribution were reported as mean ± standard deviation, while categorical variables were expressed as frequency or percentage. Differences between groups were tested by independent sample Student's *t* test using crude means or by Chi-square test for categorical variables. Bivariate associations were assessed by Pearson's correlation. Moreover, linear regression analysis with a stepwise method was also used to test parameters that best predicted the outcomes (used as dependent variable). More in detail, plasma 25-OH-D concentrations and chronotype were used as dependent variable in two different regression models (model A and model B, respectively). Parameters tested as predictors were age, sex, BMI, HOMA-IR, and HOMA-β. In addition, chronotype or plasma 25-OH-D concentrations were added in the model A and model B, respectively.

The *p* values were considered significant at $p < 0.05$ with 95% confidence interval (CI). Statistical analysis was performed according to standard methods using the Statistical

Package for Social Sciences software 26.0 (SPSS/PC; SPSS, Chicago, IL, USA).

Results

According to the sample size calculation, the study population consisted of 59 participants (43.1 ± 13 years), 17 men (28.8%), and 42 women (71.2%). All participants presented obesity (BMI: 45.9 ± 7 kg/m^2), with obesity class II (35–39.9 kg/m^2) and class III (≥ 40 kg/m^2) accounting for 23.7% (n = 14) and 76.3% (n = 45), respectively. Individuals performing physical activity were 10.2% (n = 6), while smokers were 3.4% (n = 2). All the individuals had normal liver and kidney function as demonstrated by the following mean concentrations: aspartate aminotransferase (AST): 23.5 ± 10 (U/L), alanine aminotransferase (ALT): 30.5 ± 15 (U/L), gamma-glutamyl-transpeptidase (GGT): 39.9 ± 24 (U/L), creatinine: 0.74 ± 0.1 mg/dl.

Participants with insulin resistance were 86.4% (n = 51), while 22.0% (n = 13) presented impaired fasting glucose. In addition, vitamin D insufficiency (25-OH-D 20–29 ng/ml) and deficiency (25-OH-D < 20 ng/ml) were observed in 16.9% (n = 10) and 47.5% (n = 28) of participants, respectively. According to the chronotype score, 50.8% (n = 30) of individuals belonged to the morning chronotype and 49.2% (n = 29) were evening chronotype.

Although individuals with the morning chronotype and the evening chronotype did not differ for age (p = 0.183), gender distribution (p = 0.533) and lifestyle habits, individuals with the evening chronotype presented significantly higher BMI values than the morning chronotype (p < 0.001), as well as greater waist (p = 0.012) and hip circumferences (p = 0.001), while no difference in waist-to hip ratio (p = 0.524) has been detected (Table 1).

There was no significant difference in the prevalence of obesity class II and class III and complications between the two groups, except for a higher prevalence of impaired fasting glucose in the evening chronotype than in the morning chronotype (p = 0.024) (Fig. 1).

As for the main metabolic parameters, individuals with the evening chronotype were significantly more insulin resistant than individuals with the morning chronotype (p = 0.017), while no difference was observed for β-cell function (p = 0.255). Interestingly, individuals with the evening chronotype showed significantly lower plasma 25-OH-D concentrations than individuals with the morning chronotype (Fig. 2).

This difference remained significant also stratifying the participants according to the obesity classes (Fig. 2). In addition, the prevalence of vitamin D deficiency was significantly higher in the evening chronotype than in the morning chronotype (58.6% vs. 36.7%, p = 0.008).

Table 1 Demographic, clinical, and biochemical parameters of the study participants according to the assessed chronotype

Variables	Morning chronotype (n = 30)	Evening chronotype (n = 29)	p value*
Sex (M/F)	9/21	8/21	0.533
Age (years)	45 ± 13	41 ± 13	0.183
BMI (kg/m^2)	42 ± 5	50 ± 8	< 0.001
Obesity II (n. %)	9 (30)	5 (17)	0.199
Obesity III (n. %)	21 (70)	24 (83)	
Waist circumference (cm)	126 ± 12	136 ± 16	0.012
Hip circumference (cm)	132 ± 11	145 ± 17	0.001
Waist/hip ratio	0.96 ± 0.07	0.94 ± 0.09	0.524
Fasting glucose (mg/dl)	96 ± 29	102 ± 23	0.362
Fasting insulin (μU/ml)	18 ± 8	24 ± 11	0.056
HOMA-IR	4.1 ± 2	5.7 ± 2	0.017
HOMA-β	225 ± 108	276 ± 187	0.255
AST (U/L)	23 ± 10	24 ± 10	0.652
ALT (U/L)	32 ± 15	29 ± 14	0.330
GGT (U/L)	31 ± 27	31 ± 22	0.968
Creatinine (mg/dl)	0.77 ± 0.09	0.72 ± 0.10	0.067

AST aspartate aminotransferase, *ALT* alanine aminotransferase, *BMI* body mass index, *GGT* gamma-glutamyl-transpeptidase, *HOMA-IR* Homeostasis Model Assessment for Insulin Resistance, *HOMA-β* Homeostasis Model Assessment for β-cell function

Data are expressed as mean ± standard deviation or n (%)

*Independent sample Student's t test for continuous variables and χ^2 test for categorical variables

According to the bivariate correlation analyses, plasma 25-OH-D concentration correlated directly with chronotype score (r = 0.351; p = 0.019) whereas inversely with BMI (r = – 0.363; p = 0.016). No significant correlation with age (r = – 0.248; p = 0.104), WC (r = – 0.244; p = 0.115) fasting plasma glucose (r = – 0.097; p = 0.531), insulin (r = – 0.291; p = 0.061), HOMA-IR (r = – 0.242; p = 0.122), and HOMA-β (r = – 0.133; p = 0.482) were observed. In addition, chronotype score inversely correlated with BMI (r = – 0.505; p < 0.001), WC (r = – 0.321; p = 0.016), fasting plasma insulin (r = – 0.300; p = 0.034), and HOMA-IR (r = – 0.314; p = 0.027). No significant correlation with age (r = 0.170; p = 0.199), fasting plasma glucose (r = – 0.098; p = 0.463) and HOMA-β (r = – 0.064; p = 0.729) were observed.

The regression analysis (Table 2) showed that BMI was most tightly associated with plasma 25-OH-D concentrations (β = – 0.323, p = 0.032), followed by chronotype score (β = 0.340, p = 0.042), whereas age (β = 0.287, p = 0.073), HOMA-IR (β = – 0.139, p = 0.392), and HOMA-β (β = – 0.063; p = 0.711) were not predictors of plasma 25-OH-D concentrations and respectively). Using chronotype score as dependent variable, BMI significantly

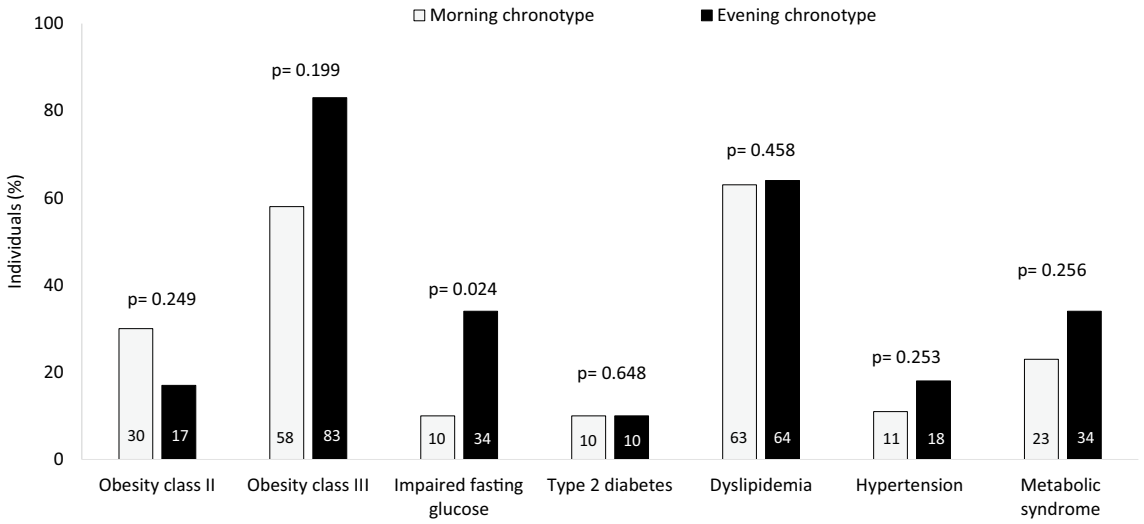

Fig. 1 Prevalence of diseases in the two groups

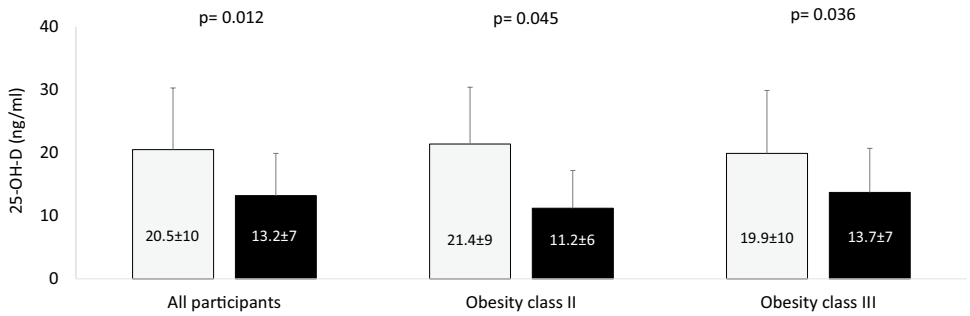

Fig. 2 Plasma 25-OH- D concentrations in the two groups

Table 2 Regression models using plasma 25-OH-D concentrations and chronotype as dependent variables

	β (95% CI)	p value
25-OH-D concentrations		
Chronotype score	0.340 (– 0.307 to 0.471)	0.042
Age	0.287 (– 0.053 to 0.350)	0.073
Sex	0.271 (– 0.528 to 1.153)	0.072
BMI	– 0.323 (– 0.420 to – 0.511)	0.032
HOMA-IR	– 0.139 (– 1.484 to 0.859)	0.392
HOMA-β	– 0.063 (– 1.378 to 0.953)	0.711
Chronotype score		
25-OH-D concentrations	0.078 (– 0.230 to 0.354)	0.440
Age	0.089 (– 0.155 to 0.204)	0.378
Sex	– 0.019 (– 5.714 to 0.516)	0.237
BMI	– 0.586 (– 1.502 to – 0.751)	<0.001
HOMA-IR	– 0.172 (– 1.781 to 0.185)	0.103
HOMA-β	– 0.182 (– 1.927 to 0.194)	0.273

BMI: body mass index, HOMA-IR: Homeostasis Model Assessment for Insulin Resistance, HOMA-β: Homeostasis Model Assessment for β-cell function

predicted lower chronotype score (evening chronotype, $\beta = -0.586$, $p < 0.001$), whereas age ($\beta = 0.089$, $p = 0.378$), plasma 25-OH-D concentrations ($\beta = 0.078$, $p = 0.440$), HOMA-IR ($\beta = -0.171$, $p = 0.103$), and HOMA-β ($\beta = -0.182$; $p = 0.273$) were not associated with chronotype score (Table 2).

Discussion

The main finding of our study was that individuals with the evening chronotype have significantly lower plasma 25-OH-D concentrations than individuals with the morning chronotype. In addition, the prevalence of vitamin D deficiency was significantly higher in individuals with the evening chronotype than individuals with the morning chronotype. As previously reported [9–13], we found that individuals with the evening chronotype had significantly higher BMI and WC than individuals with the morning chronotype. Indeed, De Amicis et al. [34] performed

a cross-sectional study in 416 adults finding a negative association between chronotype score (assessed by reduced MEQ, rMEQ) and WC; in particular, they found a lower WC (−0.06 cm) for every 1 point of rMEQ score and that individuals with the evening chronotype have + 2 cm of WC than individuals with the morning chronotype, after adjustment for gender, age, BMI, physical activity, and adherence to the Mediterranean Diet.

As well known, worsen anthropometric parameters in individuals with the evening chronotype could be due to their attitude to eat fewer, larger, and unhealthy food that result in a lower adherence to the Mediterranean Diet compared to other chronotype categories. We previously carried out a cross-sectional study [35] including 172 middle-aged adults (71.5% women; 51.8 ± 15.7 years) during a campaign to prevent obesity called the OPERA (Obesity, Programs of nutrition, Education, Research, and Assessment of the best treatment) Prevention Project that was held in Naples on 11–13 October 2019. Interestingly, we found that individuals with the evening chronotype were more prone to follow unhealthy lifestyle, to be less regular in performing physical activity, and were more frequently smokers than individuals with the morning chronotype. In addition, the lowest adherence to the Mediterranean Diet has been reported by individuals with the evening chronotype compared to individuals with the morning chronotype. The lower the chronotype score, the higher BMI values were detected in the whole population [7]. Individuals with the evening chronotype are more prone to develop sleep disturbances that in turn have been reported to increase the risk of developing obesity [16, 17]. Furthermore, unhealthy food usually consumed by individuals with the evening chronotype negatively influences the quality of sleep [5, 6, 8]. Conversely, high adherence to the Mediterranean Diet as assessed by Prevención con Dieta Mediterránea (PREDIMED) score has been associated with a better sleep quality assessed by the Pittsburgh Sleep Quality Index (PSQI) in a study carried out in 172 middle-aged adults [7].

In this study, individuals with the evening chronotype had higher values of insulin resistance and more frequently impaired fasting glucose. Our finding was in agreement with our previous studies reporting an increased risk of having derangements of glucose metabolism in post-menopausal women with the evening chronotype, as well as individuals with obesity with the evening chronotype [7, 12, 13]. As known, individuals with the evening chronotype have shown alterations of the adrenocortical circadian rhythm that results in an inadequate synchronization with a potential consequent negative effect on glucose metabolism [36–39].

Additionally, we found that individuals with the evening chronotype had significantly lower concentrations of 25-OH-D. Interestingly, we found a significant association between plasma 25-OH-D concentrations with chronotype score suggesting that as low 25-OH-D concentrations as high the chance to be evening chronotype. The regression analysis highlighted that BMI was most tightly associated with plasma 25-OH-D concentrations, followed by chronotype score, whereas age was not a predictor of plasma 25-OH-D concentrations. Conversely, using chronotype score as outcome, higher BMI significantly predicted lower chronotype score, whereas age and plasma 25-OH-D concentrations were not significantly related with chronotype. Therefore, our results suggest that obesity is responsible for both evening chronotype and hypovitaminosis D in our study population. Consequently, instead of hypothesizing a cause–effect of these two variables, we hypothesized that both conditions are an effect of increased body size.

Finally, we observed that 25-OH-D concentrations were inversely associated with insulin resistance. This finding is in line with a recent meta-analysis of 38 observational studies showing a significant inverse association between 25-OH-D concentrations and HOMA-IR in non-diabetic individuals with obesity (BMI > 30 kg/m^2) [40]. Nevertheless, our results might lead to hypothesize that individuals with the evening chronotype might further worsen their insulin resistance state if there is the coexistence of low 25-OH-D concentrations.

A limitation of the present study is the cross-sectional design that does not allow to establish any cause–effect relationship between the evaluated parameters. Furthermore, this was a single-center study and, therefore, the participants belong to the same geographical area and had similar exposure to factors affecting 25-OH-D concentrations (ethnicity, duration of sunlight exposure, eating habits, etc.). In addition, we enrolled only individuals with obesity and not normal weight individuals. However, in our study, we considered individuals with obesity and the morning chronotype as control group, since it has been demonstrated to present less obesity-related cardiometabolic complications than those with obesity and the evening chronotype. Further, we demonstrated that the association of vitamin D and chronotype categories remained significant also stratifying the participants according to the obesity classes. Furthermore, all questionnaires used in this study were translated in Italian from the English version with no forward–backward translation method to guarantee the conceptual equivalence [41]. Nevertheless, the participants were interviewed by expert operators, thus increasing the reliability of the collected data.

Finally, no information on dietary composition was collected in the present study. However, this is the first study investigating the relationship between chronotype categories and vitamin D in individuals with obesity.

Conclusion

In conclusion, both low 25-OH-D concentrations and evening chronotype are independently associated to obesity. However, further studies are needed to understand if the coexistence of both evening chronotype and low 25-OH-D concentrations could have a synergic detrimental impact on obesity-related cardiometabolic complications.

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Author contributions CV, LB, and GM were responsible for conceptualisation; CV and LB conducted the statistical analysis and wrote the manuscript; LV, AD, and SA contributed to the methodology, including data collection and data management. SS, AC, and GM provided a critical review of the paper. All authors contributed to the critical review and agreed on the final version of the paper.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest None of the authors had a conflict of interest.

Research involving human participants and/or animals The study has been approved by the Ethical Committee (n. 173/16).

Informed consent All participants were informed about the study design and aim and provided written informed consent.

References

1. Stenvers DJ, Scheer FAJL, Schrauwen P, la Fleur SE, Kalsbeek A (2019) Circadian clocks and insulin resistance. Nat Rev Endocrinol 15:75–89. https://doi.org/10.1038/s41574-018-0122-1
2. Han H, Dou J, Hou Q, Wang H (2021) Role of circadian rhythm and impact of circadian rhythm disturbance on the metabolism and disease. J Cardiovasc Pharmacol. https://doi.org/10.1097/FJC.0000000000001178
3. Makarem N, Paul J, Giardina EGV, Liao M, Aggarwal B (2020) Evening chronotype is associated with poor cardiovascular health and adverse health behaviors in a diverse population of women. Chronobiol Int 37:673–685. https://doi.org/10.1080/07420528.2020.1732403
4. Lotti S, Pagliai G, Colombini B, Sofi F, Dinu M (2021) Chronotype differences in energy intake, cardiometabolic risk parameters, cancer and depression: a systematic review with meta-analysis of observational studies. Adv Nutr. https://doi.org/10.1093/advances/nmab115
5. Lucassen EA, Zhao X, Rother KI, Mattingly MS, Courville AB, de Jonge L et al (2013) Evening chronotype is associated with changes in eating behavior, more sleep apnea, and increased stress hormones in short sleeping obese individuals. PLoS ONE 8:e56519. https://doi.org/10.1371/journal.pone.0056519
6. Muñoz JSG, Cañavate R, Hernández CM, Cara-Salmerón V, Morante JJH (2017) The association among chronotype, timing of food intake and food preferences depends on body mass status. Eur J Clin Nutr 71:736–742. https://doi.org/10.1038/ejcn.2016.182
7. Muscogiuri G, Barrea L, Aprano S, Framondi L, Di Matteo R, Laudisio D et al (2020) Chronotype and adherence to the mediterranean diet in obesity: results from the opera prevention project. Nutrients. https://doi.org/10.3390/nu12051354
8. Xiao Q, Garaulet M, Scheer FAJL (2019) Meal timing and obesity: interactions with macronutrient intake and chronotype. Int J Obes (Lond) 43:1701–1711. https://doi.org/10.1038/s41366-018-0284-x
9. McMahon DM, Burch JB, Youngstedt SD, Wirth MD, Hardin JW, Hurley TG et al (2019) Relationships between chronotype, social jetlag, sleep, obesity and blood pressure in healthy young adults. Chronobiol Int 36:493–509. https://doi.org/10.1080/07420528.2018.1563094
10. Roenneberg T, Allebrandt KV, Merrow M, Vetter C (2012) Social jetlag and obesity. Curr Biol 22:939–943. https://doi.org/10.1016/j.cub.2012.03.038
11. Parsons MJ, Moffitt TE, Gregory AM, Goldman-Mellor S, Nolan PM, Poulton R et al (2015) Social jetlag, obesity and metabolic disorder: investigation in a cohort study. Int J Obes (Lond) 39:842–848. https://doi.org/10.1038/ijo.2014.201
12. Barrea L, Vetrani C, Altieri B, Verde L, Savastano S, Colao A, Muscogiuri G (2021) The importance of being a "Lark" in postmenopausal women with obesity: a ploy to prevent type 2 diabetes mellitus? Nutrients 13(11):3762. https://doi.org/10.3390/nu13113762
13. Barrea L, Verde L, Vetrani C, Savastano S, Colao A, Muscogiuri G (2022) Chronotype: a tool to screen eating habits in polycystic ovary syndrome? Nutrients 14(5):955. https://doi.org/10.3390/nu14050955
14. Muzurović E, Peng CC, Belanger MJ, Sanoudou D, Mikhailidis DP, Mantzoros C (2022) Nonalcoholic fatty liver disease and cardiovascular disease: a review of shared cardiometabolic risk factors. Hypertension. https://doi.org/10.1161/HYPERTENSIONAHA.122.17982
15. Chartrand DJ, Murphy-Després A, Alméras N, Lemieux I, Larose E, Després JP (2022) Overweight, obesity, and CVD risk: a focus on visceral/ectopic fat. Curr Atheroscler Rep 24(4):185–195. https://doi.org/10.1007/s11883-022-00996-x
16. Muscogiuri G, Tuccinardi D, Nicastro V, Barrea L, Colao A, Savastano S (2020) Sleep disturbances: one of the culprits of obesity-related cardiovascular risk? Int J Obes Suppl 10:62–72. https://doi.org/10.1038/s41367-020-0019-z
17. Pugliese G, Barrea L, Laudisio D, Salzano C, Aprano S, Colao A et al (2020) Sleep apnea, obesity, and disturbed glucose homeostasis: epidemiologic evidence, biologic insights, and therapeutic strategies. Curr Obes Rep 9:30–38. https://doi.org/10.1007/s13679-020-00369-y
18. Muscogiuri G, Barrea L, Scannapieco M, Di Somma C, Scacchi M, Aimaretti G et al (2019) The lullaby of the sun: the role of vitamin D in sleep disturbance. Sleep Med 54:262–265. https://doi.org/10.1016/j.sleep.2018.10.033
19. Romano F, Muscogiuri G, Di Benedetto E, Zhukouskaya VV, Barrea L, Savastano S et al (2020) Vitamin D and sleep regulation: is there a role for vitamin D? Curr Pharm Des 26(21):2492–2496. https://doi.org/10.2174/1381612826666200310145935
20. Ikonte CJ, Mun JG, Reider CA, Grant RW, Mitmesser SH (2019) Micronutrient inadequacy in short sleep: analysis of the NHANES 2005–2016. Nutrients 11(10):2335. https://doi.org/10.3390/nu11102335
21. Eyles DW (2020) Vitamin D: brain and behavior. JBMR Plus 5(1):e10419. https://doi.org/10.1002/jbm4.10419

22. Jonasson TH, Costa TMDRL, Petterle RR, Moreira CA, Borba VZC (2020) Body composition in nonobese individuals according to vitamin D level. PLoS ONE 15(11):e0241858. https://doi.org/10.1371/journal.pone.0241858
23. Muscogiuri G, Sorice GP, Prioletta A, Policola C, Della Casa S, Pontecorvi A, Giaccari A (2010) 25-Hydroxyvitamin D concentration correlates with insulin-sensitivity and BMI in obesity. Obesity (Silver Spring) 18(10):1906–1910. https://doi.org/10.1038/oby.2010.11
24. Corica D, Zusi C, Olivieri F, Marigliano M, Piona C, Fornari E, Morandi A, Corradi M, Miraglia Del Giudice E, Gatti D, Rossini M, Bonadonna RC, Maffeis C (2019) Vitamin D affects insulin sensitivity and β-cell function in obese non-diabetic youths. Eur J Endocrinol 181(4):439–450. https://doi.org/10.1530/EJE-19-0369
25. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, STROBE Initiative (2007) The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet 370(9596):1453–1457. https://doi.org/10.1016/S0140-6736(07)61602-X
26. Barrea L, Vetrani C, Verde L, Napolitano B, Savastano S, Colao A et al (2021) "Forever young at the table": metabolic effects of eating speed in obesity. J Transl Med 19(1):530. https://doi.org/10.1186/s12967-021-03199-1
27. World Health Organization. Body mass index—BMI. https://www.euro.who.int/en/health-topics/disease-prevention/nutrition/a-healthy-lifestyle/body-mass-index-bmi. Accessed 15 Sept 2022
28. National Center for Health Statistics. https://www.cdc.gov/nchs/data/nhanes/nhanes_11_12/Anthropometry_Procedures_Manual.pdf. Accessed 15 Sept 2022
29. Horne JA, Ostberg O (1976) A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. Int J Chronobiol 4(2):97–110
30. Ruiz-Lozano T, Vidal J, de Hollanda A, Canteras M, Garaulet M, Izquierdo-Pulido M (2016) Evening chronotype associates with obesity in severely obese subjects: interaction with CLOCK 3111T/C. Int J Obes (Lond) 40(10):1550–1557. https://doi.org/10.1038/ijo.2016.116
31. Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC (1985) Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia 28(7):412–419. https://doi.org/10.1007/BF00280883
32. American Diabetes Association Professional Practice C (2022) 2. Classification and Diagnosis of Diabetes: Standards of Medical Care in Diabetes-2022. Diabetes Care 45(Suppl 1):S17–S38. https://doi.org/10.2337/dc22-S002
33. Holick MF, Binkley NC, Bischoff-Ferrari HA, Gordon CM, Hanley DA, Heaney RP et al (2012) Guidelines for preventing and treating vitamin D deficiency and insufficiency revisited. J Clin Endocrinol Metab 97(4):1153–1158. https://doi.org/10.1210/jc.2011-2601
34. De Amicis R, Galasso L, Leone A, Vignati L, De Carlo G, Foppiani A et al (2020) Is abdominal fat distribution associated with chronotype in adults independently of lifestyle factors? Nutrients. https://doi.org/10.3390/nu12030592
35. Muscogiuri G, Barrea L, Laudisio D, Pugliese G, Aprano S, Framondi L et al (2021) The opera prevention project. Int J Food Sci Nutr 72(1):1–3. https://doi.org/10.1080/09637486.2020.1765152
36. Engeland WC, Massman L, Mishra S, Yoder JM, Leng S, Pignatti E et al (2018) The Adrenal clock prevents aberrant light-induced alterations in circadian glucocorticoid rhythms. Endocrinology 159(12):3950–3964. https://doi.org/10.1210/en.2018-00769
37. Dockray S, Steptoe A (2011) Chronotype and diurnal cortisol profile in working women: differences between work and leisure days. Psychoneuroendocrinology 36(5):649–655. https://doi.org/10.1016/j.psyneuen.2010.09.008
38. Kudielka BM, Federenko IS, Hellhammer DH, Wust S (2006) Morningness and eveningness: the free cortisol rise after awakening in "early birds" and "night owls." Biol Psychol 72(2):141–146. https://doi.org/10.1016/j.biopsycho.2005.08.003
39. Toda M, Kawai T, Takeo K, Rokutan K, Morimoto K (2013) Associations between chronotype and salivary endocrinological stress markers. Endocr Res 38(1):1–7. https://doi.org/10.3109/07435800.2012.683225
40. Rafiq S, Jeppesen PB (2021) Vitamin D deficiency is inversely associated with homeostatic model assessment of insulin resistance. Nutrients. https://doi.org/10.3390/nu13124358
41. Hawkins M, Elsworth GR, Osborne RH (2018) Application of validity theory and methodology to patient-reported outcome measures (PROMs): building an argument for validity. Qual Life Res 27(7):1695–1710. https://doi.org/10.1007/s11136-018-1815-6