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RESEARCH

Bariatric Surgery Outcomes in an Italian Single-Center Study: Does Chronotype Matter?

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Abstract

Background Chronotype reflects an individual's intrinsic circadian preference for the timing of daily behaviors, including sleep, eating, and physical activity. It influences not only biological rhythms but also lifestyle patterns that may impact metabolic health. In the context of bariatric surgery, numerous factors may affect postoperative outcomes such as weight loss and the risk of weight regain. Given the growing interest in chronobiology and its relevance to obesity management, this study aimed to explore whether chronotype is significantly associated with key weight loss outcomes following bariatric surgery at 6 and 12 months post-intervention.

Methods A total of 263 patients underwent bariatric surgery at a single center. Baseline assessments included anthropometric, biochemical, and behavioral evaluations, including chronotype categorization. Postoperative outcomes at 6 and 12 months included absolute weight, BMI, percentage of initial body weight loss (%IBWL), and percentage of excess body weight loss (%EBWL).

Results There was no significant difference among the three different chronotypes (evening, intermediate, and morning chronotype) in terms of absolute weight, BMI, %EWL and %IBWL at 6 and 12 months after surgery.

Conclusions Our results suggest that chronotype does not seem to play a critical role in weight loss outcomes in bariatric surgery patients, characterized by severe obesity. Further studies are needed to more thoroughly assess the impact of chronotype on bariatric surgery outcomes and a more detailed characterization of chronotype itself in these patients could be decisive.

Key points

1.Chronotype is not associated with weight loss outcomes after bariatric surgery at 6 and 12 months postoperatively.
2.No significant differences in BMI, %EWL, or %IBWL were found among morning, intermediate, and evening chronotypes.
3.Further research is needed to clarify the role of circadian preferences in long-term bariatric surgery outcomes and improve chronotype categorization.

Keywords Chronotype · Bariatric surgery · Weight loss

Introduction

Bariatric surgery is a cornerstone in the treatment of severe obesity, yet patient outcomes are highly variable. Its success, measured by weight loss and long-term control of comorbidities, is influenced by a wide range of factors, from lifestyle habits to eating behaviors. A growing body of research in chrono-nutrition highlights that the timing of food intake can significantly impact weight loss, a particularly relevant outcome in bariatric surgery follow-up.

Chronotype is an individual's innate preference for activity and sleep timing, a key biological trait that governs these behavioral rhythms [1]. It can be broadly categorized into morning, intermediate, and evening types, based on an organism's circadian preference for biological rhythm and behavioral traits, with a favored daytime for main activities

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such as sleep, food intake, or exercise [2]. Three categories of chronotypes can be identified according to circadian behavioral variants: morning, evening, and intermediate chronotypes, with the latter's habits falling between morning and evening chronotypes. These traits are strongly linked to food intake patterns and nutritional status; for instance, individuals with an evening chronotype tend to consume more calories in the last part of the day, eating a higher amount of saturated fats and lower quantities of fruits and vegetables compared to morning types [3]. This behavior may be linked to a different biological rhythm, including delayed release of appetite-regulating hormones like ghrelin and leptin [4]. Accordingly, previous literature has often associated the evening chronotype and long sleep duration with a higher prevalence of excess weight and related comorbidities than those with morning chronotype and sufficient sleep hours amount [5–7].

The current treatments for obesity include lifestyle interventions and pharmacological and surgical approaches [8].

The influence of chronotype on response to different treatments for obesity is still a matter of debate. Particularly, some studies have been conducted on response to dietary interventions, concluding that prescribing chronotype-adjusted diets is more effective in terms of total weight loss, BMI, and waist circumference [9]. To date, there are no studies investigating the response to glucagon-like peptide-1 (GLP1)- receptor agonists according to chronotype, except for one study observing that evening chronotype individuals have lower plasmatic levels of endogenous GLP-1 than morning chronotype subjects [10].

With regards to bariatric surgery, a multitude of factors are involved in response to surgical intervention in terms of weight loss, eventual weight regain, and long-term comorbidities control, from lifestyle habits to eating behavior [9, 11]. The strict dietary and lifestyle changes required after surgery may be easier for some chronotypes to adapt to than others [12, 13]. However, the existing evidence on this topic is limited and not conclusive. Some studies on dietary interventions suggest that chronotype-adjusted diets are more effective [13], while a systematic review noted that eating in the last hours of the day, a habit typical of evening types, is associated with lower weight loss after bariatric surgery [12]. Conversely, it has also been proposed that bariatric surgery itself might modify a patient's chronotype profile, restoring circadian rhythms that were previously disrupted by obesity [14].

To date, we have no conclusive data on whether bariatric surgery success may be strongly influenced by chronotype of an individual or if, vice versa, bariatric interventions may modify circadian rhythm of subjects undergoing these procedures. Therefore, our aim is to investigate if there is a significant association between chronotype and biochemical and anthropometric parameters at basal patients' evaluation and between chronotype and main bariatric surgery outcomes at 6 and 12 months after intervention.

Materials and Methods

Study Structure

This prospective cohort study involved 638 patients who attended the bariatric surgery outpatient clinic at our institute between June 2021 and November 2024. All participants underwent a comprehensive, structured medical, nutritional and psychological examination. Eligibility for bariatric surgery was determined according to the 2023 consensus guidelines of the Italian Society of Bariatric Surgery and Metabolic Diseases (SICOB) [15]. Baseline data collection included detailed medical history, laboratory tests and instrumental examinations required for preoperative assessment.

Anthropometric measurements were performed according to internationally standardized protocols [16]. Body weight was measured to the nearest 100 g using a calibrated column scale (Wunder RB column scale, Wunder, Milan, Italy), with patients wearing only light underwear. Height was measured to the nearest 0.1 cm using a vertical stadiometer. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Waist circumference was measured at the midpoint between the lower costal margin and the upper anterior iliac spine with a non-stretchable tape held horizontally.

Laboratory parameters collected for descriptive purposes included fasting blood glucose, total cholesterol, HDL cholesterol, triglycerides, aspartate aminotransferase (AST), alanine aminotransferase (ALT), thyroid stimulating hormone (TSH) and 25-hydroxyvitamin D.

During the multidisciplinary assessment, patients completed several psychometric instruments, including the reduced Morningness - Eveningness Questionnaire (rMEQ) [17], a validated 5-item chronotype classification instrument. Based on the rMEQ scores, participants were categorized as evening type (score < 12), intermediate type (score between 12 and 17), or morning type (score > 17). RMEQ questions and answers are presented in Supplementary Table 1.

Our only inclusion criteria were the availability of the rMEQ score and a minimum follow-up of 12 months; therefore, we included only patients with an rMEQ result and at least 12 months of follow-up, excluding all those with a shorter follow-up period. After applying these eligibility

criteria, the final study cohort comprised 263 patients. Written informed consent was obtained from all participants. The study protocol complied with the principles of the Declaration of Helsinki (1964) and was approved by the Ethics Committee of the University of Milan.

Table 1 Patients' characteristics

	Total (*N*=263)	Evening chronotype (*N*=31)	Intermediate chronotype (*N*=135)	Morning chronotype (*N*=97)	*P* value
	N (%)	*N* (%)	*N* (%)	*N* (%)	
Sex (women)	199 (75.7)	23 (8.7)	107 (40.7)	69 (26.3)	0.356
Type of surgery					0.519
Sleeve gastrectomy	178 (67.7)	18 (6.8)	93 (35.3)	67 (25.6)	
BIB	66 (25.1)	11	34	21	
Other interventions	19 (7.2)	2	8	9	
	Median (IQR)	**Median (IQR)**	**Median (IQR)**	**Median (IQR)**	
Age (years)	44 (36, 51)	37 (24, 48)	44 (35, 52)	46 (38, 51)	0.0108
BMI (kg/m^2)	41.1(37.7, 44.9)	40.1 (35.6, 45.2)	41.4(38.4, 45.7)	41 (37.5, 44)	0.175
Waist circumference (cm)	120 (112, 131)	115.5(107, 127)	120.3(112, 132)	120 (112, 131)	0.416
Glycemia (mg/dL)	97 (90, 105)	91.5 (87, 111)	98 (91, 106)	98 (90, 104.5)	0.241
Total cholesterol (mg/dL)	188(167, 213)	178.5 (164, 209)	190.5(167, 221)	187 (171, 205)	0.543
HDL cholesterol (mg/dL)	49 (40, 56)	47 (39, 54)	49 (42, 55)	50 (39, 59)	0.639
Triglycerides (mg/dL)	116.5 (87, 151)	120 (92, 130)	119 (86.5, 163)	112 (84, 146)	0.412
Insulin (mU/L)	16.9 (12, 28)	15.4 (9.8, 31.3)	17.5(12.6, 29.7)	16.4(12, 24.6)	0.657
AST (U/L)	20 (17, 26)	20 (17, 24)	20 (17, 26)	20 (17, 27)	0.749
ALT (U/L)	26 (17, 37)	26 (17, 36)	25 (17, 37)	26 (17, 37)	0.997
TSH (mU/L)	2.2 (1.49, 3.32)	2.55 (1.6, 3.4)	2.38(1.52, 3.57)	2.05(1.4, 2.6)	0.031
25OHvitaminD (ng/mL)	18.3(12.5, 25.1)	17.1 (11.9, 24.5)	19.1 (12.3, 26)	19 (13.4, 25.2)	0.872

IQR Interquartile range, *BIB* BioEnterics Intragastric Balloon, *BMI* Body Mass Index, *HDL* High Density Lipoprotein, *AST* Aspartate Aminotransferase, *ALT* Alanine Aminotransferase, *TSH* Thyroid Stimulating Hormone

Evaluation of the Results

Primary outcomes included anthropometric parameters — body weight, BMI and waist circumference — measured at baseline (before surgery) and 6 and 12 months after surgery. In addition, percentage excess weight loss (%EWL) and percentage initial body weight loss (%IBWL) were calculated at 6 and 12 months.

- %IBWL was calculated as:

$[(Initial\ Weight - Current\ Weight)\ /Initial\ Weight] * 100.\ \%EWL\ was\ calculated\ with\ the\ formula:\ (Weight\ Loss/Excess\ Weight) * 100).$

Statistical Analysis

Continuous variables are presented as medians with interquartile ranges (IQR) due to their non-normal distribution. Categorical variables are summarized as frequencies and percentages. Chronotype was treated as a categorical variable, classified into morning, intermediate, and evening types based on scores from the reduced version of the Morningness-Eveningness Questionnaire (rMEQ) [18]. Descriptive analyses were performed for the overall sample and stratified by chronotype. Given the non-normal distribution of the variables, comparisons between chronotype groups were performed using the Kruskal-Wallis test for continuous variables. To assess the effect of chronotype on absolute weight and BMI over time, linear mixed-effects models were used that included fixed effects for chronotype (coded as 0 = evening, 1 = medium, 2 = morning), time (baseline, 6 months, 12 months), and their interaction with random intercepts for subjects to account for repeated measures. The models were adjusted for potential confounders such as gender (0 = female, 1 = male) and age (continuous). To corroborate the results, quantile regression analyses adjusted for sex, age and baseline BMI were performed to assess the impact of chronotype on %EWL and %IBWL at 6 and 12 months and to account for the non-normal distribution of these outcomes. Statistical significance was set at a two-sided p-value < 0.05. All analyses were performed using Stata version 18.0 (StataCorp, University Station, TX, USA).

Results

A total of 263 patients, 64 men and 199 women (median age: 44 years, IQR 36; 51 years; median BMI: 41.1 kg/m^2, IQR 37.7; 44.9 kg/m^2), were involved in the study, and their anthropometric characteristics and biochemical parameters are reported in Table 1. The patients did not differ in anthropometric and baseline biochemical parameters between the

different chronotypes nor in the choice of the type of surgery, except for age and TSH levels, since evening chronotype patients were younger and had higher TSH levels compared to intermediate and morning chronotype patients.

Linear mixed-effects models were fitted to evaluate changes over time (baseline, 6 and 12 months after surgery) across the three chronotype groups (evening-type, intermediate, morning-type) for absolute weight and BMI. Results are reported in Table 2. The evening chronotype was used as the reference category in all linear mixed-effects models; therefore, the estimates reported in both Tables 2 and 3 represent the difference in outcomes for intermediate and morning types relative to evening types over time.

Table 2 Chronotype effect on absolute weight and BMI at baseline, 6 months and 12 months after surgery

	Weight loss	BMI
Chronotype		
Evening (baseline - ref)	-	-
Intermediate	−0.51 (−4.32, 3.30)	0.82 (−1.43, 3.08)
Morning	−2.58 (−6.54, 1.37)	0.06 (−2.28, 2.41)
Time		
6 months	4.80×10^{-15} (-1.52×10^{-9}, 1.52×10^{-9})	−8.76 (−11.80, −5.72)***
12 months	4.80×10^{-15} (-1.52×10^{-9}, 1.52×10^{-9})	−11.88 (−15.38, −8.39)***
Chronotype#time interaction		
Intermediate#6months	-7.52×10^{-16} (-1.70×10^{-9}, 1.70×10^{-9})	0.51 (−2.88, 3.91)
Intermediate#12months	-7.52×10^{-16} (-1.70×10^{-9}, 1.70×10^{-9})	−0.27 (−4.20, 3.66)
Morning#6months	-7.00×10^{-16} (-1.77×10^{-9}, 1.77×10^{-9})	−0.01 (−3.57, 3.55)
Morning#12months	-7.00×10^{-16} (-1.77×10^{-9}, 1.77×10^{-9})	0.27 (−3.87, 4.41)
Intercept		
Constant	114.5 (111.12, 117.91)***	40.8 (38.82, 42.86)***

Values are regression coefficients and 95% confidence intervals (in brackets) obtained from mixed-effects linear regression model. The reference group is participants with an evening chronotype at baseline. All other effects represent deviations from this reference group. Interaction terms represent additional differences at 6 and 12 months. Values represent differences in absolute weight in evening chronotype patients compared with intermediate and morning chronotype patients at baseline (effect of chronotype), changes between a time point and baseline (effect of time), and differences in changes between a time point and baseline in evening chronotype compared with intermediate and morning chronotype (effect of chronotype # time interaction). Abbreviations: $*p < 0.05$ $**p < 0.01$ $***p < 0.001$; *BMI* Body Mass Index

According to our results, there were no significant differences among the three chronotypes in terms of absolute weight and BMI at baseline, as well as at 6 and 12 months after surgery (chronotype#time interaction).

The models were then re-estimated adjusting for potential confounding factors, i.e. age and sex (0 = female, 1 = male) (Table 3).

Table 3 Chronotype effect on absolute weight and BMI at baseline, 6 months and 12 months after surgery adjusted for confounding factors (age, sex, BMI)

	Weight loss	BMI
Chronotype		
Evening baseline (ref)	-	-
Intermediate	1.63 (−1.77, 5.04)	1.05 (−1.22, 3.33)
Morning	−0.95 (−4.53, 2.62)	0.37 (−2.01, 2.75)
Time		
6 months	4.92×10^{-15} (-1.34×10^{-9}, 1.34×10^{-9})	−8.76 (−11.79, −5.73)***
12 months	4.92×10^{-15} (-1.34×10^{-9}, 1.34×10^{-9})	−11.87 (−15.37, −8.38)***
Chronotype#time interaction		
Intermediate#6 months	-1.88×10^{-16} (-1.51×10^{-9}, 1.51×10^{-9})	0.60 (−2.79, 3.99)
Intermediate#12 months	-1.88×10^{-16} (-1.51×10^{-9}, 1.51×10^{-9})	−0.16 (−4.09, 3.76)
Morning#6 months	-2.03×10^{-16} (-1.57×10^{-9}, 1.57×10^{-9})	−0.01 (−3.55, 3.55)
Morning#12 months	-2.03×10^{-16} (-1.57×10^{-9}, 1.57×10^{-9})	0.29 (−3.84, 4.44)
Confounding factors		
Age	−0.26 (−0.36, −0.17)***	−0.04 (−0.09, 0.02)
Sex	20.57 (17.97, 23.17)***	0.63 (−0.87, 2.14)
Intercept		
Constant	119.75 (114.94, 124.56)***	42.29 (39.32, 45.25)***

Values are regression coefficients and 95% confidence intervals (in brackets) obtained from mixed-effects linear regression model. The reference group is participants with an evening chronotype at baseline. All other effects represent deviations from this reference group. Interaction terms represent additional differences at 6 and 12 months. Values represent differences in absolute weight and BMI in evening chronotype patients compared with intermediate and morning chronotype patients at baseline (effect of chronotype), changes between a time point and baseline (effect of time), and differences in changes between a time point and baseline in evening chronotype compared with intermediate and morning chronotype (effect of chronotype # time interaction). All estimates are adjusted for age, sex (0 = female, 1 = male), and BMI. Abbreviations: $*p < 0.05$ $**p < 0.01$ $***p < 0.001$; *BMI* Body Mass Index

After adjustment, association between absolute body weight and BMI with chronotype remained statistically not significant, with a statistically significant impact of both age and sex on absolute weight (age: −0.26, 95% CI [−0.36, −0.17], $p<0.001$; sex: 20.57, 95% CI [17.97, 23.17], $p=0.001$), with male and younger patients having a higher weight than women and older patients at baseline, respectively. This statistical significance is lost when analyzing chronotype effect on BMI.

To corroborate our results, we also performed quantile regression analyses adjusted for sex, age, and BMI for two bariatric surgery outcomes, i.e. percentage of excess weight loss (%EWL) and percentage of initial body weight loss (%IBWL), calculated at 6 and 12 months after surgery.

In the quantile regression analysis of %EWL at 6 months, adjusted for age, sex, and BMI, neither intermediate nor morning chronotypes showed significant differences compared to evening types. Specifically, intermediate chronotypes had a β coefficient of −11.19 (p = 0.748), while morning types had a β coefficient of −2.24 (p = 0.951). Similarly, at 12 months after surgery, chronotype was not associated with variations in %EWL, with intermediate chronotypes showing a β coefficient of −27.55 (p = 0.372) and morning types a β coefficient of 0.57 (p = 0.986)."

The same result was found in the quantile regression analysis of %IBWL at 6 months and 12 months, adjusted for age, sex, and BMI, where neither intermediate nor morning chronotypes showed significant differences compared to evening types. Particularly, intermediate chronotypes had a β coefficient of 1.84 (p = 0.935), while morning types had a β coefficient of 0.41 (p = 0.986). Equivalently, at 12 months after surgery, chronotype was not associated with variations in %IBWL, with intermediate chronotypes showing a β coefficient of −0.52 (p = 0.975) and morning types a β coefficient of −8.04 (p = 0.651)."

To summarize, these analyses showed a non-significant association between %EWL and %IBWL at 6 and 12 months after surgery, considering age, sex, and BMI as confounding factors.

Discussion

In this large, single-center cohort study, we investigated whether an individual's chronotype influenced weight loss outcomes at 6 and 12 months after bariatric surgery. Our central finding is that there was no statistically significant association between chronotype and the main surgical outcomes, including changes in absolute weight, BMI, %EWL, and %IBWL. This result is noteworthy as it contrasts with a significant body of previous literature that links the evening chronotype with adverse health outcomes, such as higher insulin resistance [19], an increased risk of type 2 diabetes [20], a tendency toward a higher BMI [5, 21], and less success in long-term weight control [21, 22]. Specifically concerning bariatric surgery, a previous study found that patients with an evening chronotype had less weight loss compared to morning types [21], and a systematic review associated late-night eating—a typical trait of evening chronotypes—with poorer weight-loss outcomes after surgery [12]. Additionally, another study analyzing chrono-nutritional profiles in patients undergoing bariatric surgery found a minor weight loss at 36 ± 11 months of follow-up in patients with irregular eating patterns [23].

The discrepancy between our findings and this existing research may be explained by several factors. First, the profound physiological and behavioral impact of bariatric surgery may be powerful enough to come before the more subtle, pre-existing influence of chronotype, at least in the initial postoperative period. Furthermore, our results suggest that chronotype's influence may lose its impact after a certain BMI threshold is crossed, possibly being more determinant in milder cases of obesity rather than in severe obesity, typical of patients eligible for bariatric surgery. Second, strict adherence to standardized postoperative protocols and the structured and intensive follow-up protocol provided to our patients likely played a crucial mitigating role, promoting healthier behavioral patterns in all chronotype groups. Our cohort received comprehensive and periodic medical, nutritional, and psychological counseling, which is essential for increasing compliance and reducing complications. This high level of support may have effectively neutralized the negative behavioral tendencies sometimes associated with an evening chronotype, thereby leveling the playing field for all patients.

Importantly, the homogeneity of surgical technique and perioperative management in our center may have further minimized inter-individual variability, allowing a more accurate assessment of the role of chronotype on postoperative outcomes.

Beyond the primary outcomes, our baseline comparison of characteristics highlighted that patients with an evening chronotype were younger and had higher TSH levels than intermediate and morning chronotype patients. The association with age is in line with existing literature, which has observed that older age is associated with an earlier chronotype [24]. The finding of higher TSH levels in this specific subset of patients needs to be cautiously evaluated, especially concerning potential confounding factors not accounted for in this analysis.

Strengths of our study include the large number of included patients undergoing bariatric surgery with a chronotype classification available, an important tool in addition to comprehensive follow-up of these patients, following updated guidelines of national and international societies in line with clinical practice [25–27]. Their periodic evaluation in bariatric surgery outpatient clinic consists in a comprehensive assessment including medical examinations, dietitian consultations, and psychological counseling sessions at 1, 3, 6, and 12 months postoperatively. Ongoing medical, nutritional and psychological counseling and support in the form of a strict protocol were essential and strongly contributed to reducing postoperative complications' incidence, increasing their compliance with postoperative program, and maintaining a rigorous follow-up of these patients. Patients' follow-up is still ongoing, with yearly evaluations from 24 months onwards. Another important consideration is the possible influence of cultural and environmental factors, such as local dietary traditions and social routines, which may interact with chronotype and influence postoperative behavior and outcomes.

However, our study also has some limitations that point toward important directions for future research. The relatively small number of evening chronotype patients, while in line with population epidemiology [1], could have limited the statistical power of our analyses. Additionally, our definition of chronotype relied solely on the rMEQ questionnaire. Future studies should aim for a more thorough chronotype characterization by combining questionnaire results with objective measures like actigraphy, detailed meal timing analysis, the study of obesity risk genes linked to chronotype, such as the CLOCK 3111 T/C polymorphism [21], as well as an assessment of sleep duration, which could be strongly correlated with chronotype. Furthermore, we did not assess chronotype post-surgery, which prevented us from exploring the bidirectional relationship between bariatric surgery and circadian rhythms. As Solè et al. observed, sleeve gastrectomy can restore circadian rhythms and sleep patterns [14], and investigating this potential shift would have been a valuable addition. Ultimately, not all potential confounding variables were considered because some important factors that could have influenced the outcomes were not investigated - for example, a detailed stratification of patients' physical activity levels or more precise data on dietary adherence. More randomized clinical trials, like the one proposed by the ChronoWise Protocol [28], are needed to thoroughly examine this association.

Future multicenter studies involving different populations will be therefore essential to determine whether our findings are generalizable across different cultural contexts and healthcare settings.

Conclusion

In summary, our findings suggest that chronotype does not appear to be a determinant of weight loss outcomes within the first 12 months following bariatric surgery in patients with severe obesity. The powerful effects of surgery, combined with a rigorous follow-up program, may overshadow the influence of an individual's baseline chronotype. Additional studies with longer follow-up periods are needed to determine if chronotype plays a more significant role in long-term weight maintenance and to further characterize its role in this specific patient population.

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Author Contributions F.S. and S.C: writing - original draft (equally contributed). A.B., A.G., F.F., F.B., A.G., V.V. L.I., M.C., M.N., G.D.: investigation. A.B.: data curation. F.S.: formal analysis. G.D., R.C., A.B.: supervision. S.B.: conceptualization and methodology. A.B., A.L., R.D.A: writing – review & editing.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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