Obesity

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Key Determinants of Weight Loss Trajectory Across Different Periods of a Behavioral Weight Loss Intervention

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ABSTRACT

Objective: This longitudinal study aims to identify the key factors influencing the weight loss trajectory during a 24-week intervention and their relevance at different stages of the treatment.

Methods: We studied 1252 participants (age 18–65 years) of a cognitive behavioral program to lose weight. Body weight was measured weekly, and a range of variables at baseline and throughout the treatment period were assessed. Linear regression analyses were conducted to understand the factors involved in the weight loss trajectory across three treatment periods (0–6, 7–12, 13–24 weeks).

Results: The rate of weight loss progressively decreased from the 1st to the 3rd period (770–198 g/week). During the 1st period, the recent history of the individual, including baseline metabolic status, dietary habits, and motivation, was the highest-ranked determinant. In the 2nd period, the sole predictor was the long-term personal history of obesity, that is, the duration of the individual's lifetime spent with overweight/obesity. In the 3rd period, emotional eating behaviors and related barriers emerged as the two highest-ranked determinants of reduced rate of weight loss.

Conclusions: Findings suggest targeted interventions that address the specific challenges of each period of weight loss interventions. As treatment progresses, strategies focused on emotional-related behaviors may be crucial for sustaining weight loss.

Trial Registration: ClinicalTrials.gov identifier NCT02829619

1 | Introduction

The continuous global rise in obesity [1] suggests that current efforts have been insufficient and remain ineffective [2]. Well-established factors associated with effective body weight loss during dietary and behavioral interventions include diet adherence, physical activity [3], and, more recently, sleep habits [4, 5]. However, even after accounting for these factors, interindividual differences in total weight loss during the treatments persist [6, 7].

Study Importance

- What is already known?
  - Interindividual variability in weight loss outcomes persists despite controlling for established factors such as diet adherence, physical activity, and sleep.
- What does this study add?
  - Determinants of weight loss vary across a 24-week intervention. They shift from recent metabolic status and dietary habits at the beginning to long-term obesity history during the intermediate phase and to emotional eating and behavioral factors at the end of the intervention.
  - Lack of motivation emerged as the primary factor influencing the overall rate of weight loss for this study.
- How might these results change the direction of research or the focus of clinical practice?
  - Our results emphasize the importance of tailoring weight loss interventions to address different determinants across treatment stages.
  - Incorporating emotional and behavioral support in later phases may enhance the effectiveness of weight loss treatments.

Previous research by our group has shown that genetic predisposition to BMI is not significantly associated with the magnitude of weight loss, whether expressed in absolute (g) or relative (%) terms [8]. However, social, behavioral, cognitive, and motivational challenges—known as barriers to weight loss—may significantly impact weight loss and maintenance [9]. Individuals with emotional eating behavior, who overeat in response to negative emotions, face greater difficulties adhering to weight loss treatments [10, 11].

Additionally, pretreatment lifestyle and dietary habits—such as whether individuals typically consume healthy foods or tend to favor processed and unhealthy options [12]—along with personal history of obesity (e.g., the age at which overweight first developed, body weight at various life stages) [13] and the individual's metabolic status [14], have been proposed as factors that may influence the rate of weight loss during treatment and the likelihood of weight regain.

Despite these insights, several limitations persist in the literature on dietary obesity treatment. Most studies are conducted over relatively short durations (commonly 12 weeks) or within highly controlled environments, limiting their generalizability to real-world settings. Additionally, many investigations rely solely on pre- and posttreatment weight measurements, failing to capture continuous weight changes and the patterns of weight loss dynamics throughout the intervention period [15, 16]. Furthermore, existing literature primarily focuses on physiological and metabolic determinants [6], overlooking psychological and emotional factors [15, 16].

Critically important, to our knowledge, no study has systematically evaluated how these factors influence the trajectory and rate of weight loss at different stages of a structured weight loss program. Addressing these knowledge gaps could enable clinicians to develop personalized nutritional interventions that strategically target the most influential factors at each stage of treatment, thereby enhancing the effectiveness of weight management programs. Weight loss, like many voluntary behavior changes, often unfolds in distinct phases on the path to sustained results [17]. We hypothesize that the determinants of weight loss success may shift throughout treatment, with different factors exerting varying degrees of influence at different stages. Accordingly, to advance the field of personalized obesity management, we examined weight loss progression in individuals participating in a 24-week obesity treatment program. We identified distinct periods within the intervention, each characterized by a different rate of weight loss, and aimed to determine the key factors associated with weight loss during these phases. This knowledge may inform the development of tailored interventions and provide critical insights into optimizing weight loss outcomes for diverse patient populations.

2 | Methods

2.1 | Study Participants

This analysis is based on the ONTIME study (Obesity, Nutrigenetics, Timing, and Mediterranean Diet), a prospective longitudinal study including adults with overweight or obesity, recruited from six weight loss clinics across Spain. Data were collected weekly in real time over the 24-week intervention. Data from this prospective cohort were retrospectively analyzed for the present study. Full study details are available on ClinicalTrials.gov (NCT02829619). The protocol adhered to good clinical practice and received approval from the Research Ethics Committee of the University of Murcia (ID:632/2017) prior to recruitment. The participants were volunteers and signed an informed consent form before any study procedures were conducted.

The original ONTIME sample consisted of 5426 participants. Participants were excluded based on the following criteria: (1) age outside the range of 18–65 years, (2) BMI greater than 35 kg/m^2 at baseline (as they followed a different intervention protocol), (3) lack of data on energy intake and physical activity. Because the weekly rate of weight loss is closely linked to treatment progression and the overall rate of treatment duration, participants completing the program in less than 6 weeks or more than 24 weeks were excluded. Thus, the final sample consisted of 1252 adults (Figure 1). All analyses were conducted on this final dataset, and no imputation of missing data was performed.

2.2 | Weight Loss Intervention Program

Participants engaged in a comprehensive cognitive behavioral weight loss program that combined nutrition education, physical activity, and behavioral therapy [18] and included 60-min weekly group sessions led by nutritionists. Cognitive behavioral techniques, such as stimulus control, positive reinforcement, and self-monitoring of eating, activity, weight, and meal factors, were included in the group therapy and follow-up sessions [18]. The duration of the intervention was tailored to individual weight loss goals (average length of 13.73 ± 5.5 weeks).

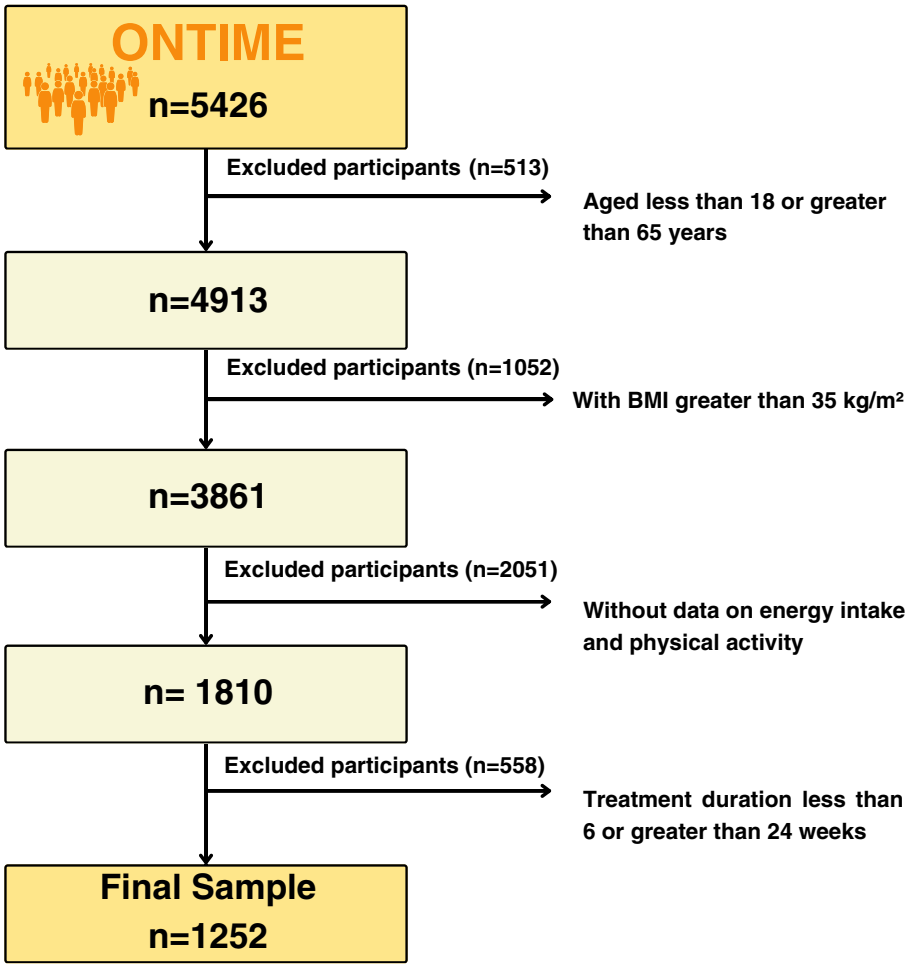

FIGURE 1 | Flowchart illustrating the subject selection process from ONTIME. [Color figure can be viewed at wileyonlinelibrary.com]

Resting energy expenditure was estimated using the Harris–Benedict formula, and total energy expenditure was calculated based on the type and duration of physical activity. To promote a weight loss of 0.5–1 kg/week, patients followed a diet with a daily 620 kcal deficit, resulting in 1200–1800 kcal for women and 1500–2000 kcal for men [19]. The diet recommendations followed the principles of the Mediterranean diet, with macronutrient distribution in line with the Spanish Society of Community Nutrition [20] guidelines. Nutritional education during group sessions empowered participants to create healthy daily meal plans.

Lastly, during group therapy sessions, participants were encouraged to engage in at least 15–30 min of moderate-intensity activity two to three times per week. They were also advised to use a pedometer to reach a daily goal of 10,000 steps.

2.3 | Rate of Weight Loss

Participants were weighed weekly at the clinical center throughout the intervention, using a digital scale with 0.1 kg precision while barefoot and wearing light clothing.

The rate of weight loss was defined as the average percentage of body weight lost per week throughout the intervention period. We included only participants who completed the program within 6 to 24 weeks to prevent the rate of weight loss from being influenced by excessively short or long treatment durations. The weight loss trajectory was analyzed in three distinct periods, reflecting the progression of the treatment. The 1st period ranged from 0 to 6 weeks, the 2nd period from 7 to 12 weeks, and the 3rd period from 13 to 24 weeks. The division into these three periods was chosen a priori based on clinical and behavioral weight loss patterns observed in our previous studies [11, 18, 21, 22]. The 1st period (0–6 weeks) typically represents the rapid weight loss phase, driven by initial motivation and lifestyle changes. The 2nd period (7–12 weeks) marks the transitional phase, where early adaptation can influence ongoing adherence. The 3rd period (13–24 weeks) reflects the plateau phase, where motivational challenges often emerge.

2.4 | Lifestyle Habits and Metabolic Status at Baseline

- *Physical activity* was evaluated using the International Physical Activity Questionnaire (IPAQ) completed by the participants [23].
- *Sleep habits* were assessed with questions about usual bedtimes and wake times on weekdays and weekends. Sleep

duration was calculated as the difference between bed and wake times. Weekly sleep duration and sleep onset timing were determined using the formula: ([weekday value ×5] + [weekend value ×2])/7. Participants were also asked about nap frequency and nocturnal awakenings.

- *Dietary habits* were assessed using 24-h dietary recalls, from which energy, macronutrient, and micronutrient intake and meal timing patterns were derived. Analyses were conducted using the GRUNUMUR 2.0 software developed for research and practice in human nutrition [24]. Also, the Mediterranean Diet Score was calculated based on nine food groups (vegetables, legumes, fruits, dairy, cereals and potatoes, meat and eggs, fish, fat quality index, and alcohol), ranging from 0 (low-quality diet) to 9 (high-quality diet) [9, 25]. Finally, midpoint of meal intake was the midpoint between the weekly averages for breakfast and dinner times.
- *Personal history of overweight or obesity* score was calculated based on participants' reported body weight and size during childhood, adolescence, and adulthood. Each life stage was assigned a value: "0" for underweight or normal weight, "0.8" for overweight, and "1" for obesity. The score was then determined as the proportion of life periods in which the participant had overweight or obesity, ranging from 0 to 1. A higher score reflects a more extended time spent with overweight or obesity throughout the participant's life. Participants younger than 20 years (1.9% of the sample) were not assigned a value for adulthood overweight or obesity.
- *Family history of overweight or obesity* score was based on the obesity status of participants' family members (we calculated the number of family members with overweight or obesity relative to the total members, including parents, grandparents, and, if applicable, siblings, partners, and children). Each family member was assigned a value: "0" for underweight or normal weight, "0.8" for overweight, and "1" for obesity. The final score was calculated by summing the individual scores for each family member, ranging from 0 to 8. A higher score indicated a greater number of family members with overweight or obesity.
- *Metabolic status* was assessed by measuring plasma concentrations of glucose, insulin, cholesterol, triglycerides, and lipoproteins during the first visit under fasting conditions. Insulin was measured through a solid-phase, two-site chemiluminescent immunometric assay (IMMULITE 2000 Insulin). The QUICKI index (quantitative insulin sensitivity check index, 1/[log (fasting insulin μU/mL) + log (fasting glucose mmol/L)]), an inverse measure of insulin resistance, was used to assess insulin sensitivity [3]. The eight metabolic measures (QUICKI index, glucose, insulin, LDL, HDL, VLDL, triglycerides, and cholesterol) were reduced to three components using principal component analysis: PC1, negatively correlated with the QUICKI index and positively correlated with insulin, triglycerides, and VLDL; PC2, associated with total cholesterol and LDL; and PC3, combining QUICKI index, triglycerides, and HDL. In summary, PC1 and PC2 represent poorer metabolic status, while PC3 reflects better metabolic health [9].
- *Emotional eating behaviors* were assessed using the Emotional Eater Questionnaire [10], which comprises 10 questions that evaluate three key aspects of emotional eating: "Disinhibition," reflecting overeating in response to emotional stimuli; "Type of food cravings," referring to intense desire for specific foods, and "Sense of guilt," referring to the feelings of regret or self-blame experienced after eating, especially when individuals perceive that they have lost control or chosen unhealthy foods. The responses to the questionnaire were scored as follows: "0" = Never; "1" = Sometimes; "2" = Usually; "3" = Always. The total score ranged from 0 to 30, with higher scores indicating stronger emotional eating tendencies. The general characteristics of the validated Emotional Eater Questionnaire study population (age [39 ± 12 years], sex [84% women], and BMI [31.6 ± 5.4 kg/m^2]) were very similar to those of the current study population, and both populations belong to a Mediterranean region from southeast Spain.

2.5 | Barriers to Weight Loss During the Treatment

Barriers to weight loss were assessed using a Barriers to Weight Loss Questionnaire [26]. This questionnaire was implemented during the first 6 weeks of the intervention, when participants were adapting to the program, to capture early motivational and behavioral obstacles.

The questionnaire consists of 37 components grouped into seven categories: the first three categories assess behaviors during the treatment: "self-monitoring of eating," "weighing and weekly interviews," and "eating habits during treatment."

The remaining categories focus on habitual lifestyle behaviors (Table S1). The total Barriers to Weight Loss Score ranged from −20 (indicating the lowest barriers) to +50 (indicating the highest barriers).

2.6 | Statistical Analysis

A total of 38 variables were examined as potential determinants of overall rate of weight loss across three treatment periods. These variables included participants' characteristics, clinical history, metabolic status, dietary intake, physical activity, sleep habits, chronotype, emotional eating, and social and environmental barriers to weight loss (Table 1). The selection of these variables was informed by our previous study, where we began with 138 variables from the ONTIME database and reduced them to 38 through different variable-reduction methods [9].

To identify the significant contributing factors in the rate of weight loss, we used traditional regression models for $Y = \text{age} + \text{BMI} + \text{sex} + X_i$, where X_i is one of the 38 independent variables, and Y is the rate of weight loss. We further included the total number of treatment weeks as a covariate. We calculated the F statistics for X_i by calculating the additional variance it explained when comparing with the null model $Y = \text{age} + \text{BMI} + \text{sex}$ and tested the significance of X_i. We also

TABLE 1 | Variables included in the study.

Final variables ($n = 38$)	Variables in the raw data ($n = 138$)
BMI, kg/m^2	BMI, kg/m^2
Age, years	Age, years
Female, %	Female, %
Treatment duration, *n* weeks	Treatment duration, *n* weeks
Energy intake, kcal/day	Energy intake, kcal/day[a]
Physical activity, METs[b] min/week	Physical activity, METs[b] min/week[a]
Metabolic status PC1	QUICKI index[c]
Metabolic status PC2	Insulin, mIU/L[a]
Metabolic status PC3	Glucose, mmol/L[a]
	Triglycerides, mmol/L[a]
	Cholesterol, mmol/L[a]
	VLDL, mmol/L[a]
	LDL, mmol/L[a]
	HDL, mmol/L[a]
Midpoint of meal intake, hh:mm	Midpoint of meal intake, h
Macronutrients intake PC2	Carbohydrates, kcal/day
Macronutrients intake PC3	Fiber, g/day
	Cholesterol, g/day
	Proteins, kcal/day
	Fat, kcal/day
	MUFA, kcal/day
	PUFA, kcal/day
	SFA, kcal/day
Mediterranean Diet Score[d]	Vegetables, g/day
	Legumes, g/day
	Fruits, g/day
	Dairy, g/day
	Cereals and potatoes, g/day
	Meat and eggs, g/day
	Fish, g/day
	Fat quality index
	Alcohol, g/day
Alcohol intake	Alcohol, g/day
Sleep timing, hh:mm	Sleep timing, h
Duration, h	Duration, h
Nap, yes, %	Nap, yes, %
Awakening at night, yes, %	Awakening at night, yes, %

(Continues)

TABLE 1 | (Continued)

Final variables ($n = 38$)	Variables in the raw data ($n = 138$)
Micronutrients intake PC1[a]	Iron, mg/day
Micronutrients intake PC2[a]	Magnesium, mg/day
Micronutrients intake PC3[a]	Niacin, mg/day
Micronutrients intake PC4[a]	Pyridoxine, mg/day
Micronutrients intake PC5[a]	Thiamin, mg/day
	Riboflavin, mg/day
	Vitamin A, μg/day
	Folic acid, μg/day
	Vitamin C, mg/day
	Vitamin D, μg/day
	Iodine, μg/day
	Calcium, mg/day
	Zinc, mg/day
	Cobalamin, μg/day
	Vitamin E, mg/day
Morningness Eveningness Score[e]	Morningness Eveningness Score[e]
Emotional Eater Score[f]	Emotional Eater Score[f]
Disinhibition	Do you have problems controlling the amount of certain types of food you eat?
	Do you eat when you are stressed, angry, or bored?
	Do you eat more of your favorite food and with less control when you are alone?
	Do you feel less control over your diet when you are tired after work at night?
	When you overeat while on a diet, do you give up and start eating without control, particularly food that you think is fattening?
	Often do you feel that food controls you, rather than you controlling food?
Type of food cravings	Do you crave specific foods?
	Is it difficult for you to stop eating sweet things, especially chocolate?
Sense of guilt	Do the weight scales have a great power over you? Can they change your mood?
	Do you feel guilty when eat "forbidden" foods, like sweets or snacks?
Barriers to Weight Loss Score[g]	Barriers to Weight Loss Score[g]
Self-monitoring of eating	Is absolutely everything you've eaten written down?
	Do you carefully calculate calories?
	Do you accurately measure your portions?
	Do you write down extra portions?
Weighing and weekly interviews	Do you get your weight checked at the clinic once a week?
	Do you check your weight at home as well?
	Are you attending weekly group therapy sessions?

(Continues)

TABLE 1 | (Continued)

Final variables ($n = 38$)	Variables in the raw data ($n = 138$)
Eating habits during treatment	Do you eat legumes three times a week?
	Do you eat fish once a week?
	Do you have a complete breakfast?
	Do you skip any meals?
	Do you tend to snack between meals?
	Are there any particular times of the day when you tend to overeat (morning, evening, night)?
	When do they occur?
	Do you have "binges" (big or small)?
Portion size when you are not dieting	Are your portion sizes on the large side?
	Do you buy food in large packages?
	Do you eat second servings?
	Do you eat leftovers?
Choice in foods and beverages when not dieting	Are you prone to eating energy-rich (i.e., high-fat) foods?
	Do you eat sweets?
	Do you drink alcohol?
	Are you actively avoiding any foods?
"How do you eat?"	Are you someone who eats very fast?
	Do you eat in places other than the kitchen or dining room?
	Do you eat while watching television?
	Do you eat while driving or engaged in other activities?
	Is your eating planned in advance?
	Do you eat directly from packets or containers?
Lack of motivation and other obstacles to weight loss	Have you lost your motivation to lose weight?
	Are you prone to stress-related eating?
	Are you prone to stress when you are on a diet?
	Are you liable to eat when bored?
	Does thinking in black-and-white terms undermine your attempts to lose weight?
	Are you facing other obstacles to losing weight?
Personal history of obesity score[h]	Infancy obesity
	Childhood obesity
	Adolescent obesity
	Obesity grade from 20 to 30 years old
	Obesity grade from 30 to 40 years old

(Continues)

TABLE 1 | (Continued)

Final variables ($n = 38$)	Variables in the raw data ($n = 138$)
Family history of obesity score[i]	Father obesity grade
	Mother obesity grade
	Number of brothers
	Number of brothers with obesity
	Partner obesity grade
	Paternal grandfather obesity grade
	Paternal grandmother obesity grade
	Maternal grandfather obesity grade
	Maternal grandmother obesity grade
	Number of sons
	Number of sons with obesity

[a]Trait log transformed in analytical model.
[b]METs: metabolic equivalents.
[c]QUICKI, quantitative insulin sensitivity check index (inverse measure of insulin resistance): 1/(log, fasting insulin μU/mL + log, fasting glucose mg/dL).
[d]*Mediterranean Diet Score*: The diet score varied from 0 (low-quality diet) to 9 (high-quality diet). For the different components such as total fatty acids, fruits, vegetables, legumes, fish, and cereals and potatoes, a value of 1 was assigned to participants whose consumption was equal to or higher than the sex-specific median value and 0 to the others. For meat and eggs and dairy products, a value of 1 was assigned to participants whose consumption was less than the sex-specific median and 0 to the others.
[e]*Morning Eveningness Score*: The score ranged from 17 to 86. Lower score indicated more eveningness and higher score more morningness. More specifically, score between 17 and 30: Definitely evening type; score between 31 and 41: Moderately evening type; score between 42 and 48: Intermediate (neither type); score between 59 and 69: Moderately morning type; score between 70 and 86: Definitely morning type.
[f]*Emotional Eater Score*: The answers to the questionnaire were "0" = Never; "1" = Sometimes; "2" = Usually; "3" = Always. The total score ranged from 0 to 30. A total emotional eating score between 0 and 5 means that the participant is a non-emotional eater. Emotions have little or nothing to do with the participant's eating behavior. This is a person with great stability with respect to feeding behavior. The participant eats when feeling hungry, regardless of external factors or emotions. Scores between 6 and 10 indicate that the participant is a low emotional eater. It is rare for the participant to solve the problems related to eating. However, he/she feels that certain foods affect willpower. Scores between 11 and 20 indicate that the participant is an emotional eater. Responses indicate that to some extent emotions influence dietary intake. Feelings and mood at some moments in life determine how much and how the participant eats. Scores between 21 and 30 indicate that the participant is a very emotional eater. If he/she is not careful, food will control the participant. The participant's feelings and emotions constantly rotate around food.
[g]*Barriers to Weight Loss Score*: The answers to the questionnaire were "0" = Never; "1" or "-1" = Sometimes; "2" or "-2" = Generally; "3" or "-3" = Always. A positive sign indicated the presence of a barrier and the negative sign indicated the absence of a weight loss barrier, and the total score ranged from −20 (lowest barriers) to +50 (highest barriers). A higher cumulative score reflects more barriers to weight loss.
[h]*Personal history of obesity score*: Participants reported their body weight and size in childhood and the level of obesity in their adolescence and adulthood. Each period in life had a value: "0" for underweight or normal weight; "0.8" for overweight; and "1" for obesity. Then the score was calculated as the "proportion of periods in life" staying in overweight or obesity status, ranging from 0 to 1. A higher score reflects a longer period in life for the participant spent in overweight or obesity status.
[i]*Family history of obesity score*: Participants reported the obesity level of their family members including parents, grandparents, siblings (if any), partners, and children (if any). Each family member had a score, with "0" for underweight or normal weight; "0.8" for overweight; and "1" for obesity. Then the score was calculated by the summation of scores for family members, ranging from 0 to 8. A higher cumulative score reflected a higher number of family members with overweight or obesity.

determined the partial R^2 of X_i by the increase in R^2 from the null model to the testing model. To minimize false-positive results due to multiple comparisons, all p values derived from the same outcome were adjusted using the false discovery rate (Benjamini–Hochberg FDR) method. The importance of each predictor was defined by the F statistics and compared among variables.

When any of the 38 variables was found to be associated with the dependent variable, the same statistical method was applied to explore further the components with the strongest influence within each variable. For example, if the Mediterranean Diet Score was associated with the rate of weight loss during a specific period, we explored the association with all the underlying components of this variable, such as vegetables, legumes, fruits, dairy, cereals and potatoes, meat and eggs, fish, fat quality index, and alcohol. Variables and their respective components can be found in Table 1. All statistical analyses were performed using R (version 4.1.2).

3 | Results

The general characteristics of the individuals included in the study are presented in Table 2. At baseline, 36.4% of the study population had obesity (BMI ≥ 30 kg/m^2). During the weight loss treatment, a progressive reduction in the rate of weight loss was observed throughout the treatment, with the highest average rate of weight loss of 767 g/week in the 1st period (0–6 weeks), followed by 357 g/week in the 2nd (7–12 weeks), and 198 g/week in the 3rd period (13–24 weeks) (Figure 2A).

Multiple linear regression models, adjusted for age, sex, baseline BMI, and treatment weeks, were used to evaluate determinants of the overall rate of weight loss in each treatment period. The variables associated with the outcome (rate of weight loss) at any treatment period are presented in Table 3, along with their respective effect directions (coefficients), F values, p values, and partial R^2. Figure 2B illustrates the most important variables, ranked by their average contribution to predicting the rate of

TABLE 2 | Baseline characteristics and lifestyle traits of participants ($n = 1252$).

Variables	Mean ± SD
Rate of weight loss, g/week	543 ± 296
BMI, kg/m^2	28.80 ± 3.26
Age, years	39.89 ± 11.27
Female, %[a]	83.8
Obesity, %	36.4
Treatment duration, *n* weeks	13.73 ± 5.50
Energy intake, kcal/day[b]	1978.53 ± 746.10
Physical activity, METs[c]	4091.17 ± 7156
QUICKI index[d]	0.38 ± 0.04
Glucose, mmol/L[b]	4.77 ± 0.84
Insulin, mIU/L[b]	6.23 ± 4.79
LDL, mmol/L[b]	2.94 ± 0.86
HDL, mmol/L[b]	1.54 ± 0.39
VLDL, mmol/L[b]	0.48 ± 0.26
Triglycerides, mmol/L[b]	1.07 ± 0.56
Cholesterol, mmol/L[b]	4.98 ± 0.97
Midpoint of meal intake, hh:mm	14:52 ± 0:36
Carbohydrates, kcal/day	809.07 ± 370.19
Proteins, kcal/day	333.04 ± 131.12
Fat, kcal/day	876.14 ± 414.18
Fiber, g/day	17.11 ± 10.75
MUFA, kcal/day[e]	398.5 ± 246.28
PUFA, kcal/day[f]	100 ± 61.56
SFA, kcal/day[g]	218.67 ± 135.12
Mediterranean Diet Score	3.59 ± 1.53
Alcohol intake, g/day	12.90 ± 14.09
Sleep onset, hh:mm	23:52 ± 0:53
Sleep duration, h	7.60 ± 1.02
Emotional Eater Score	11.87 ± 6.08
"Disinhibition"	6.66 ± 4.01
"Type of food cravings"	2.37 ± 1.70
"Sense of guilt"	2.77 ± 1.83
Barriers to Weight Loss Score	1.31 ± 7.89
"Self-monitoring of eating"	−1.50 ± 0.55
"Weighing and weekly interviews"	−0.84 ± 0.41
"Eating habits during treatment"	−0.14 ± 0.30
"Portion size when you are not dieting"	0.64 ± 0.49
"Choice in foods and beverages when not dieting"	0.93 ± 0.40
"How do you eat?"	0.35 ± 0.35
"Lack of motivation and other obstacles for losing weight"	0.47 ± 0.40
Personal history of obesity score	0.46 ± 0.33
Family history of obesity score	2.13 ± 1.51

[a]Values in the percentage of the total population.
[b]Trait log transformed in analytical model.
[c]METs: metabolic equivalents.
[d]QUICKI, quantitative insulin sensitivity check index: 1/(log, fasting insulin μU/mL + log, fasting glucose mg/dL).
[e]MUFA: monounsaturated fatty acids.
[f]PUFA: polyunsaturated fatty acids.
[g]SFA: saturated fatty acids.

weight loss in each of the three treatment periods (0–6, 7–12, and 13–24 weeks), as determined by comparing the *F* values from the multiple linear regression models. Figure 2C presents the most significant variables within the Barriers to Weight Loss Questionnaire that contributed in each period.

The primary factor influencing the overall rate of weight loss was the "lack of motivation and other obstacles for losing weight," which contains questions like "Have you lost your motivation to lose weight?" and "Are you prone to stress-related eating?" (Table 1). In addition, distinct variables emerged as the most significant determinants for the rate of weight loss in the different treatment periods (Table 3 and Figure 2B).

During the first period (*weeks 0–6*), lack of motivation and other obstacles to weight loss also emerged as the primary determinant of a lower rate of weight loss, followed by the recent history of the individual, including the metabolic status and the dietary habits just before starting the intervention. The metabolic status was represented by a principal component variable (PC1), which included the insulin sensitivity index (QUICKI), serum levels of insulin, total triglycerides, and VLDL. A worse metabolic status just before starting the program was significantly associated with a lower rate of weight loss during this 1st period of 6 weeks. In addition, the dietary habits at baseline had the strongest influence on the rate of weight loss during the 1st period: higher daily alcohol consumption was associated with a lower rate of weight loss, while higher energy intake at baseline was associated with a higher rate of weight loss. Finally, "eating habits during treatment" (derived from eating habits questions of the Barriers to Weight Loss Questionnaire) were also associated with a lower rate of weight loss ($\beta = -0.11$, $F = 0.7191$, $p = 0.02$) (Table 3 and Figure 2B)—specifically, a lower frequency of "legume consumption" (less than three times per week) was associated with a reduced rate of weight loss ($\beta = -0.04$, $F = 14.23$, $p = 0.003$) (Figure 2C).

During the second period (*weeks 7 to 12*), the long-term personal history of obesity score was the only factor significantly associated with weight loss. This score, reflecting the age at which

overweight first developed and the cumulative duration of an individual's history of having overweight or obesity, was associated with a slower rate of weight loss (Table 3 and Figure 2B,C).

During the third period (*weeks 13 to 24*), emotional eating behaviors and related barriers were the main contributors negatively associated with the rate of weight loss (Table 3 and Figure 2). The most relevant factors, in order of importance, were: lack of motivation and other obstacles for losing weight ($\beta = -0.14$, $F = 16.91$, $p = 0.0015$) (Table 3 and Figure 2B), among which "thinking in black-and-white terms," which measures the extent to which dichotomous thinking negatively influences weight management behaviors ($\beta = -0.05$, $F = 12.62$, $p = 0.01$), was the most significant item (Figure 2C). The second important variable

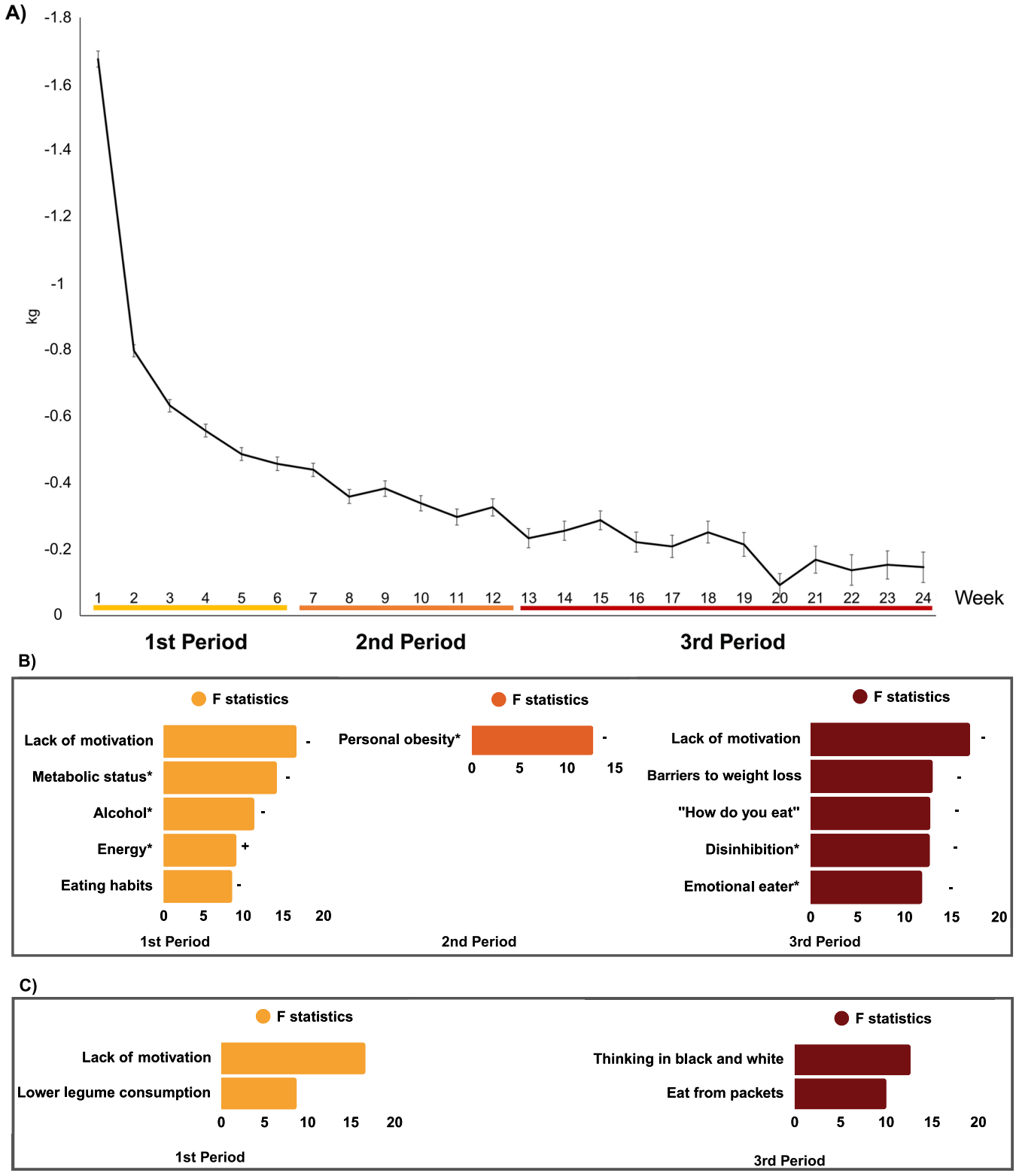

FIGURE 2 | Legend on next page.

FIGURE 2 | Weight loss trajectory during three treatment periods and top average variable importance in predicting rate of weight loss. (A) Weight loss trajectory during three periods of treatment. 1st period: 0–6 weeks, 2nd period: 7–12 weeks, 3rd period: 13 to 24 weeks. (B) Top 5 average variable importance as determinants of rate of weight loss. 1st period: "Lack of motivation" = Lack of motivation and other obstacles for losing weight from Barriers to Weight Loss Questionnaire, "Metabolic status" = Metabolic status PC1 from QUICKI index, insulin, triglycerides, very low-density lipoprotein (VLDL) data, "Alcohol" = Alcohol intake, "Energy" = Energy intake, and "Eating habits" = Eating habits during treatment from Barriers to Weight Loss Questionnaire. 2nd period: "Personal obesity"= Personal history of obesity score includes infancy obesity, childhood obesity, adolescent obesity, obesity grade from 20 to 30 years old, obesity grade from 30 to 40 years old. 3rd period: "Lack of motivation" = Lack of motivation and other obstacles for losing weight from Barriers to Weight Loss Questionnaire, "Barriers to weight loss"=Barriers to Weight Loss Score, "How do you eat?"=How do you eat? from Barriers to Weight Loss Questionnaire, "Disinhibition" = Disinhibition from Emotional Eater Questionnaire, and "Emotional eater" = Emotional Eater Score. The sign (–) or (+) represents the direction of the effect. *Indicates the variables measured at baseline. (C) Most contributing variable in the Barriers to Weight Loss Questionnaire during the treatment: In the 1st period for "Lack of motivation" was "Have you lost your motivation to lose weight?" and for "Eating habits" was "Do you eat legumes three times a week?" (Lower legume consumption). In the 3rd period for "Lack of motivation" was "Does thinking in black-and-white terms undermine your attempts to lose weight?" (Thinking in black and white) and for "How do you eat?" was "Do you eat directly from packets or containers?" (Eat from packets). [Color figure can be viewed at wileyonlinelibrary.com]

during this period was the global Barriers to Weight Loss Score ($\beta = -0.01$, $F = 12.95$, $p = 0.0035$), where a higher score indicated more obstacles to weight loss. The third important factor was "How do you eat?" ($\beta = -0.03$, $F = 12.70$, $p = 0.0035$) (Table 3 and Figure 2B), where "eating directly from packets or containers" (measured by the question, "Do you eat directly from packets or containers?") ($\beta = -0.04$, $F = 9.98$, $p = 0.01$) was the most significant item (Figure 2C). Additional factors included "disinhibition" ($\beta = -0.07$, $F = 12.64$, p = 0.0035), which refers to the tendency to overeat in response to stimuli or emotional cues, and the global Emotional Eater Score ($\beta = -0.01$, $F = 11.83$, $p = 0.0042$), which assessed food disinhibition, cravings, and guilt, with higher scores reflecting greater emotional eating (Table 3 and Figure 2B).

Furthermore, multiple comparison analyses were performed to determine if the rate of weight loss and total weight loss differ between age groups in the different periods of the program, toward a lower rate of weight loss in younger individuals. For rate of weight loss significant differences ($p = 0.004$) emerged during the 1st period (0–6 weeks). Particularly, the rate of weight loss for individuals from age 31 to 40 years was lower than for individuals from age 41 to 50 years. Moreover, there was also a tendency ($p = 0.076$) in the same period for individuals from age 31 to 40 years as compared to those from age 51 to 60 years in which the former showed a lower rate of weight loss than the latter. In contrast, when considering total weight loss (kg) no significant differences were found among the different age groups.

4 | Discussion

This study investigated the key factors associated with the rate of weight loss across distinct periods of a 24-week obesity treatment program. By examining a broad range of variables—including pretreatment metabolic status, lifestyle characteristics, emotional eating behaviors, and social and environmental barriers encountered during treatment—we aimed to capture how these determinants evolve throughout the treatment period.

In addition to demonstrating that weight loss progression over the 24-week intervention followed a distinct trajectory that allowed the identification of three phases—0–6 weeks, 7–12 weeks, and 13–24 weeks—with a 74% reduction in the rate of weight loss from 767 g/week in the 1st phase to 198 g/week in the 3rd, our findings provide valuable insights into the main factors associated with rate of weight loss at each period.

4.1 | Early Period of Treatment (1st Period, 0–6 Weeks)

Individual motivation emerged as the strongest determinant of both the rate of weight loss during the first 6 weeks of treatment and the total rate of weight loss over the entire treatment period. This finding aligns with previous research that recognizes motivation as a powerful factor empowering individuals with obesity throughout their weight management journey, which may positively affect adherence [16].

Since motivation is modifiable, fostering intrinsic motivation—driven by internal factors and activity satisfaction [27]—should be a key focus in the early stages of obesity treatment. Motivational interviews and interventions addressing barriers and motivators in the initial weeks could be a valuable strategy [28]. Encouraging weight loss in these early stages is likely to be critical, as greater initial weight loss has been shown to correlate with larger long-term weight reductions [29].

Before starting the program, the individual's lifestyle and health status also significantly affected the rate of weight loss during the initial treatment period. Notably, poor pretreatment metabolic health emerged as the second most influential predictor. Although a worse metabolic status may influence increased motivation for lifestyle changes [30], previous studies have demonstrated that metabolic status—particularly elevated fasting plasma glucose and type 2 diabetes at baseline—are key determinants of individual responsiveness to diets with varying carbohydrate and fat contents [31, 32].

We found that pretreatment eating habits influenced the early treatment phase, with higher daily alcohol consumption reducing rate of weight loss and higher energy intake increasing it. Regular alcohol consumption may add calories to daily intake, both directly through its own energy content and indirectly through its effects on appetite, leading to overeating episodes

TABLE 3 | Statistical data on weight loss trajectory during the overall treatment and the three periods of treatment.

	Overall rate of weight loss						0–6 weeks					
	Coefficient	***F***	***p***	**Partial R^2**	**Overall R^2**	***N***	**Coefficient**	***F***	***p***	**Partial R^2**	**Overall R^2**	***N***
"Lack of motivation and other obstacles for losing weight"	−0.0912	20.456	**0.0002**	0.015	0.2007	1099	−0.1135	16.635	**0.0017**	0.0103	0.0346	1567
Energy intake[a]	0.0901	18.379	**0.0002**	0.0119	0.1921	1252	0.092	9.107	**0.0226**	0.0049	0.0300	1810
Metabolic status PC1	−0.0218	18.778	**0.0002**	0.0142	0.1972	1070	−0.0273	14.173	**0.003**	0.0089	0.0358	1547
Barriers to Weight Loss Score	−0.0034	11.044	**0.0064**	0.0081	0.1939	1099	−0.0035	6.200	0.0644	0.0039	0.0282	1567
"How do you eat?"	−0.0348	2.242	0.2762	0.0017	0.1874	1099	−0.0038	0.013	0.9507	0.00001	0.0243	1567
Personal history of obesity score	−0.0489	3.781	0.1302	0.0026	0.1962	1168	−0.0384	1.063	0.5657	0.0006	0.0240	1677
"Disinhibition"	−0.0238	4.094	0.1262	0.0027	0.1859	1224	−0.0016	0.009	0.9507	0.00001	0.0229	1768
Micronutrients intake PC1[a]	0.0527	12.434	**0.0038**	0.0083	0.1985	1204	0.0511	5.338	0.0918	0.0030	0.0268	1721
Emotional Eater Score	−0.0029	4.719	0.106	0.0032	0.1861	1217	0.0000	0.000	0.9842	0.00001	0.0225	1760
Alcohol intake	−0.034	3.384	0.1542	0.0025	0.1808	1102	−0.0915	11.351	**0.009**	0.0070	0.0291	1576
"Eating habits during treatment"	−0.0762	8.274	**0.0239**	0.0061	0.1919	1099	−0.1082	8.571	**0.0243**	0.0053	0.0297	1567
Metabolic status PC3	−0.0082	1.229	0.4207	0.0009	0.1840	1070	−0.0291	7.191	**0.0432**	0.0045	0.0315	1547
	7–12 weeks						**13–24 weeks**					
"Lack of motivation and other obstacles for losing weight"	−0.0765	5.245	0.1939	0.0039	0.0051	1353	−0.1421	16.914	**0.0015**	0.0177	0.0416	921
Energy intake[a]	0.0404	1.210	0.6338	0.0008	0.0021	1519	0.0906	5.67	0.0699	0.0055	0.0272	1011
Metabolic status PC1	−0.0064	0.546	0.8131	0.0004	0.0020	1310	−0.0218	6.20	0.0699	0.0068	0.0310	892
Barriers to Weight Loss Score	−0.0048	8.002	0.083	0.0059	0.0072	1353	−0.0065	12.950	**0.0035**	0.0136	0.0375	921
"How do you eat?"	−0.0354	0.815	0.8022	0.0006	0.0019	1353	−0.1507	12.697	**0.0035**	0.0134	0.0372	921
Personal history of obesity score	−0.1561	12.688	**0.0133**	0.0089	0.0107	1411	−0.0328	0.535	0.7246	0.0006	0.0221	938
"Disinhibition"	−0.0413	4.164	0.2073	0.0028	0.0041	1490	−0.0735	12.643	**0.0035**	0.0124	0.0325	996
Micronutrients intake PC1[a]	0.0425	2.636	0.3054	0.0018	0.0038	1464	0.0646	5.617	0.0699	0.0056	0.0300	977
Emotional Eater Score	−0.0052	5.281	0.1939	0.0036	0.0053	1482	−0.0079	11.834	**0.0042**	0.0116	0.0320	991
Alcohol intake	−0.0684	4.329	0.2073	0.0033	0.0057	1300	0.0113	0.103	0.8788	0.0001	0.0236	833
"Eating habits during treatment"	−0.0848	3.629	0.2494	0.0027	0.0040	1353	−0.0869	3.287	0.2232	0.0035	0.0273	921
Metabolic status PC3	0.0044	0.116	0.886	0.0001	0.0017	1310	0.0107	0.617	0.7246	0.0007	0.0249	892

Note: Bold values indicate $p<0.05$. The importance of each predictor was assessed by comparing the *F* values obtained from the multiple linear regression models. *"Lack of motivation and other obstacles for losing weight"* from Barriers to Weight Loss Questionnaire, item The lack of motivation and other obstacles for losing weight. *Metabolic status PC1* from QUICKI index, insulin, triglyceride, very low-density lipoprotein (VLDL) data. "How do you eat?" from Barriers to Weight Loss Questionnaire, item How do you eat?. "*Disinhibition*" from Emotional Eater Questionnaire, item Disinhibition. *Micronutrients intake PC1* from iron, magnesium, niacin, pyridoxine data. "*Eating habits during treatment*" from Barriers to Weight Loss Questionnaire, item Eating habits during treatment. *Metabolic status PC3* from high-density lipoprotein (HDL), VLDL, triglyceride data.

[a]Log transformed.

during or after consumption [33]. A study of adults with overweight and obesity enrolled in a 1-year behavioral weight loss program found that, even excluding the calories from alcohol, alcohol intake was associated with total caloric intake [34].

The greater weight loss observed in participants with a higher energy intake at baseline, just before starting the treatment, may initially seem unexpected. However, possible explanations can be drawn from existing literature. While the treatment protocol prescribed the same caloric reduction for all participants, those with higher initial caloric intake may have found it easier to adhere to the diet, as the reduced portions may have still been perceived as relatively large [35].

Furthermore, reporting a lower frequency of legume consumption (lentils, chickpeas, and beans) during treatment—specifically, less than three times per week—was associated with a lower rate of weight loss. A lower intake of legumes may lead to higher overall energy intake due to the replacement with more energy-dense foods [36]. These results may also be explained by the high fiber and protein content of legumes, both related to increased satiety and satiation [36].

4.2 | Middle Period of Treatment (2nd Period, 7–12 Weeks)

During the 2nd period, the long-term personal history of obesity was the only factor significantly associated with the rate of weight loss. Participants who experienced excess weight at an early age (infancy, childhood, or adolescence) or who had obesity for a more extended period of their life exhibited a lower rate of weight loss during this period of the treatment. As we previously demonstrated [13], obesity during infancy and childhood negatively impacts the weight loss response to dietary treatments in adulthood.

It is understandable that, as treatment progresses, personal factors may come into play. Individuals with a long history of obesity may have developed both physiological and psychological mechanisms that complicate weight loss, such as hormonal changes, increased visceral fat accumulation, and emotional challenges related to chronic obesity [37]. Therefore, interventions that consider metabolic individuality, the patient's history, and additional risk factors or resistance to conventional treatments may be more effective for this population [16, 38].

4.3 | Final Period of Treatment (3rd Period, 13–24 Weeks)

In the final treatment period, emotional eating behaviors and related barriers were the primary determinants of reduced rate of weight loss.

Among the pro-obesity barriers, "thinking in black and white," a dichotomous thinking style, emerged as the most important determinant. Low psychological flexibility, a key aspect of this thinking pattern, is a recognized risk factor for poor weight management and disordered eating behaviors [39]. Behavioral weight loss interventions that specifically build skills to increase psychological flexibility may enhance the efficacy of behavioral weight loss by reducing binge eating [40].

Another identified emotional-related barrier was "eating directly from packets or containers," a behavior associated with mindless eating and poor portion control. Often driven by emotional factors, this habit contributes to excessive calorie intake. These findings highlight the need for interventions that promote mindful eating and portion control to support effective long-term weight management [41].

"Disinhibition" emerged as the fourth most influential factor in impairing the rate of weight loss during the final treatment period. At this stage, continued efforts are crucial to prevent overeating and manage the increased hunger and appetite often accompanying weight loss [42]. Additionally, disinhibition and overeating are common responses to prolonged food restriction, making emotional eating behavior more prevalent toward the end of the intervention [43].

Dedicating sufficient time during this treatment period to teaching strategies for managing eating in response to internal cues while addressing dichotomous thinking, low psychological flexibility, and disinhibition is crucial for strengthening mindful eating practices. This approach may enhance long-term weight loss outcomes and help prevent relapse.

4.4 | Strengths and Limitations

The main strength of our study lies in the use of weekly weight measurements, allowing for a detailed analysis of weight trajectories throughout the 24-week intervention. This approach provides a better understanding of implementing targeted interventions to address challenges as they arise. Incorporating psychological and behavioral constructs—often overlooked in weight loss interventions [16]—in addition to classical factors such as diet, physical activity, and sleep, enhances our understanding of the determinants of weight loss effectiveness.

Despite its strengths, using self-reported data for dietary intake and emotional eating behaviors may introduce response bias due to inherent inaccuracies. While evaluating a commercial weight management program in a real-world setting offers advantages, we recognize that the origin of a specific behavioral program may limit the generalization of results to other populations with different characteristics such as different sex distribution (the current population includes a low proportion of males), higher initial BMI (current excludes individuals with BMI $> 35\,kg/m^2$), or different behavioral styles (current is a Mediterranean population). Furthermore, although linear regression provides good interpretability, with coefficients indicating the scale and direction of variables and the R^2 value explaining the proportion of variation in the outcome, it does not allow us to infer causality. In addition, the barriers to weight loss were primarily assessed during the first six weeks of the program, a period of adaptation to new routines, that has been shown to predict later outcomes [44]. Nevertheless, these periods of assessment may partially reflect early experiences with weight loss and further studies should be done including this questionnaire in different periods of the treatment.

5 | Conclusion

Our findings highlight a dynamic progression in the factors influencing the rate of weight loss, revealing three distinct periods over 24 weeks in a cognitive behavioral weight loss program.

In the initial period, the *recent history of the individuals*, including the eating habits prior to treatment initiation together with metabolic status, is the highest-ranked determinant, alongside motivation to lose weight. As treatment progresses to the middle period, the individual's *long-term history* of excess weight and obesity—reflecting the cumulative duration of living with these conditions—becomes increasingly relevant. Finally, *emotional eating* behaviors and related barriers emerge as the most prominent factors toward the end of the program, potentially hindering success in weight loss. Recognizing these distinct periods is essential for adapting treatment strategies and providing comprehensive support to patients throughout their weight management journey. These findings suggest targeted intervention approaches that address each period's specific challenges, aiming to optimize weight loss.

Future interventional studies should explore these results further and evaluate the effectiveness of different interventions tailored to each period of the weight loss process.

Author Contributions

R.D.P.-A., G.L.-S., M.R.-M., H.-W.Y., and **M.G.:** conceptualization. **R.D.P.-A., H.-W.Y.,** and **M.G.:** formal analysis. **R.D.P.-A., H.-W.Y.,** and **M.G.:** investigation. **M.R.-M., M.G.:** data curation. **R.D.P.-A., G.L.-S.,** and **M.R.-M.:** writing – original draft. **M.G.:** visualization. **R.D.P.-A., G.L.-S., M.R.-M., H.-W.Y.,** and **M.G.:** writing – review and editing. **M.G.:** supervision.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Barriers to weight loss survey.