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ORIGINAL ARTICLE

Clinical Trials and Investigations

Changes in hedonic hunger and food reward after a similar weight loss induced by a very low-energy diet or bariatric surgery

Marthe Isaksen Aukan[1,2] | Ingrid Øfsti Brandsæter[1] | Silje Skårvold[1] | Graham Finlayson[3] | Siren Nymo[1,2,4] | Silvia Coutinho[1,5] | Catia Martins[1,2,6]

[1]Obesity Research Group, Department of Clinical and Molecular Medicine, Faculty of Medicine, Norwegian University of Science and Technology, Trondheim, Norway

[2]Centre of Obesity and Innovation (ObeCe), Clinic of Surgery, St. Olav University Hospital, Trondheim, Norway

[3]School of Psychology, University of Leeds, Leeds, UK

[4]Nord-Trøndelag Hospital Trust, Clinic of Surgery, Namsos Hospital, Namsos, Norway

[5]Department of Public Health Nutrition at the Institute of Basic Medical Sciences, Faculty of Medicine, University of Oslo, Oslo, Norway

[6]Department of Nutrition Sciences, University of Alabama at Birmingham, Birmingham, Alabama, USA

Correspondence

Marthe Isaksen Aukan, Department of Clinical and Molecular Medicine, Norwegian University of Science and Technology, Forsyningssenteret, Prinsesse Kristinas gate 5, 7030 Trondheim, Norway.
Email: marthe.i.aukan@ntnu.no

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Abstract

Objective: The aim of this study was to compare changes in hedonic hunger and food reward in individuals with severe obesity achieving 10% to 15% weight loss with a very low-energy diet (VLED) alone or VLED and bariatric surgery.

Methods: Patients scheduled for sleeve gastrectomy (SG) or Roux-en-Y gastric bypass (RYGB) initiated a VLED 2 weeks prior to surgery and continued the diet for 8 weeks postoperatively. BMI-matched controls underwent a VLED for 10 weeks. Hedonic hunger was assessed with the Power of Food Scale, and food reward with the Leeds Food Preference Questionnaire, pre and post intervention.

Results: A total of 44 participants completed the study: 15 SG, 14 RYGB, and 15 controls (61%, 79% and 69% females, respectively; BMI: 40.5 ± 0.5 kg/m^2; age: 43.9 ± 1.4 years). Average weight loss was 18.3 ± 0.6 kg (16%), comprising 13.5 ± 0.5 kg fat mass, with no significant differences between groups. Similar reductions in hedonic hunger were observed in all groups. Overall, food reward was similarly reduced in SG and RYGB groups, whereas controls showed little or no change.

Conclusions: Independent of modality, weight loss seems to reduce hedonic hunger, but bariatric surgery leads to several additional favorable changes in food reward and preferences.

INTRODUCTION

Lifestyle treatments of obesity have had limited success. Even though most individuals with obesity can achieve a clinically significant weight loss (5%–10% of initial body weight), the majority experience weight regain and some relapse to or above baseline weight [1]. To date, bariatric surgery is the most effective treatment, leading to sustained lower body weight in the long term, which is not yet achievable with conservative approaches [2]. The mechanisms behind the long-term weight loss success after bariatric surgery are still not clearly understood, but beneficial changes in appetite behavior are seen [3].

Appetite behavior is highly complex, and the brain plays a key role controlling energy intake. Homeostatic brain regions, mainly the hypothalamus, receive information from the periphery regarding both acute and chronic nutritional status and adjust appetite accordingly in order to maintain homeostasis [4]. However, advances in research have led to the integration of hedonic brain regions in appetite control [5]. Hedonic hunger refers to appetite for palatable foods and is driven by external sensory information, feelings, and emotions [6]. Food reward can be characterized by "liking" (pleasurable response to food) and "wanting" (motivation to eat palatable foods that provided pleasure in the past) [7]. Exposure to palatable foods trigger dopamine release and is associated with wanting for food [8]. Thus, the hedonic system can operate independently of homeostatic signals when food is highly palatable and easily available [9]. Moreover, individuals with obesity have shown greater food reinforcement [10] and hedonic hunger [11], stronger liking for sweetness [12], and higher wanting for food [13], compared with individuals without obesity. Higher sensitivity to food reward and food reinforcement has also been associated with greater energy intake [14]. This might compromise adherence to dietary interventions.

Even though an increased drive to eat is commonly seen following diet-induced weight loss [15,16], food reward has been described to decrease following different lifestyle interventions [17]. Following sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB), patients experience decreases in measures of hedonic eating, lower preference for energy dense foods [11,18–24], development of an aversion to sweetness [25,26], lower frequency of food cravings, and decreased influence of emotions and external food cues on food intake [22,25]. However, knowledge on the effect of dietary restriction alone on hedonic hunger is limited, and no studies have compared diet alone with bariatric surgery. Moreover, it remains to be elucidated whether the beneficial effects of bariatric surgery on hedonic hunger and food reward are mediated by the bariatric procedure, weight loss, the inherent changes in the diet, or a combination of those.

Therefore, we aimed to compare how a similar weight loss achieved by a very low-energy diet (VLED) alone or VLED in combination with one of the two most performed bariatric procedures (SG and RYGB) impacts hedonic hunger and food reward in individuals with severe obesity.

Study Importance

What is already known?

- Hedonic appetite can easily override homeostatic signals.
- Individuals with obesity have a greater hedonic appetite compared with individuals without obesity.
- Following bariatric surgery, patients experience decreased hedonic eating behavior and improved appetite control, but the effect of weight loss induced by dietary restriction alone is unclear.

What does this study add?

- Hedonic hunger decreases regardless of weight loss modality when weight loss is matched.
- However, bariatric surgery is superior compared with dietary restriction alone on the effect of food reward.

How might these results change the direction of research or the focus of clinical practice?

- Comprehensive behavioral interventions might be needed to control hedonic hunger and food reward after weight loss with dietary restriction alone.
- Future research should investigate potential relationships between hedonic hunger and food reward and long-term weight loss maintenance after both lifestyle treatment and bariatric surgery.

METHODS

The effect of DIet-induced weight loss versus Sleeve gastrectomy and Gastric bypass on APpetite (DISGAP) study is a three-armed prospective nonrandomized controlled trial, comparing how a similar weight loss induced by diet or bariatric surgery impacts homeostatic and hedonic appetite markers and gut microbiota, both in the short and long term. The present paper reports the initial changes in hedonic hunger and food reward after a similar weight loss induced by diet alone, diet plus SG, or diet + RYGB. An outline of the present study can be seen in Figure 1.

Adults with severe obesity scheduled for SG or RYGB at two local hospitals in the Central Norway Health Region were recruited. The control group (VLED intervention alone) was composed of patients on a waiting list for bariatric surgery and patients who declined or were not eligible for surgery, as well as individuals from the local community (advertised at St. Olav's and the Norwegian University of Science and Technology [NTNU] intranet). The control group was matched for preoperative body mass index (BMI), age, and sex of the surgical groups. Recruitment and data collection took place between September 2019 and January 2022. A flowchart of the study can be seen in Figure 2. The study was approved by the regional ethics committee (REK 2019/252), registered in ClinicalTrials.gov (NCT04051190), and conducted according to the guidelines laid down in the Declaration of Helsinki. All participants provided written informed consent before enrollment in the study.

Participants had to be weight stable (self-reported) (< 2-kg body weight change over the last 3 months) and not enrolled in any other obesity treatment or behavioral program. Patients who had previously undergone bariatric surgery, who used medication known to affect energy metabolism or appetite, and who had a current cancer diagnosis or substance abuse, as well as those presenting with a psychiatric diagnosis that precluded bariatric surgery (such as eating disorders), were excluded from the study.

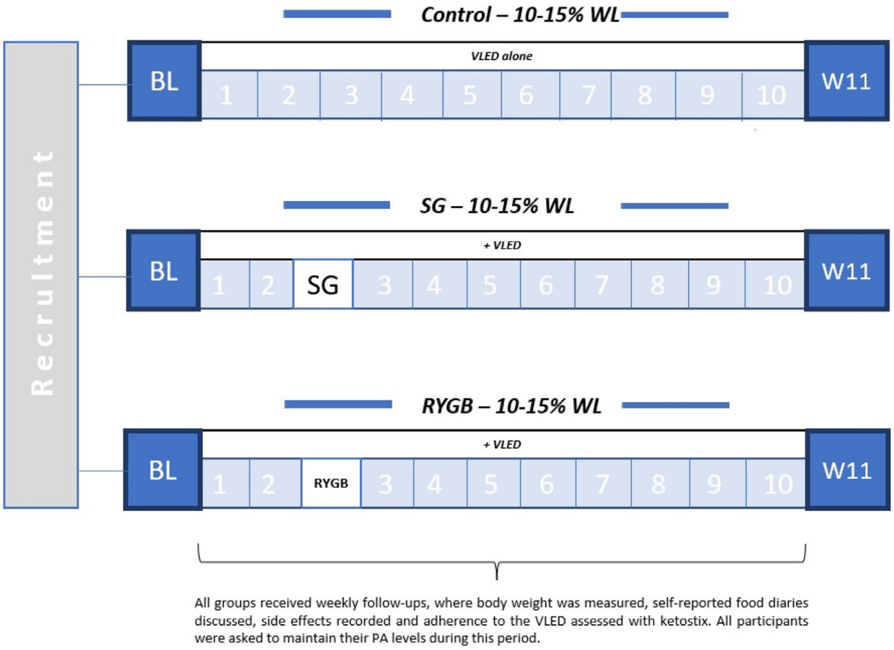

FIGURE 1 Study design. BL, baseline; PA, physical activity; RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy; VLED, very low-energy diet; W11, week 11; WL, weight loss [Color figure can be viewed at wileyonlinelibrary.com]

Bariatric surgeries were performed at St. Olav University Hospital in Trondheim and the Namsos Hospital, both in Norway, using standard laparoscopic procedures. The SG involved dividing the gastrocolic ligament, initiating the gastrectomy 4 cm proximal to the pylorus along the greater curvature, and creating the sleeve along the lesser curvature using a 36 French Bougie. The RYGB procedure involved creating a small (~20–30 mL) proximal gastric pouch and a stapled gastrojejunostomy. A 75– to 150-cm Roux-Y limb was constructed by transecting the jejunum 60 to 100 cm distal to the ligament of Treitz and performing a stapled jejunostomy at this site.

Participants from all groups were asked to follow a formula-based VLED using a variety of commercial food packs (Lighter Life) composed of different soups, shakes, pasta dishes, bars, and porridge for 10 weeks under the guidance of a registered dietitian. The average daily nutritional composition of the VLED used in this study was 750 kcal; energy percentages (E%) were 26 E% fat, 36 E% carbohydrates, 5 E% fiber, and 33 E% protein. In addition, participants were encouraged to consume a maximum of 100 g of low-starch vegetables per day, as well as 2.5 L of water daily. Alcohol consumption was not allowed during the 10-week intervention. Noncaloric beverages were allowed, and a maximum of 500 mL of low-energy drinks (<3 kcal/100 mL) and four sugar–/calorie-free chewing gum, artificial sweeteners, or mints per day. Patients scheduled for bariatric surgery initiated the diet 2 weeks prior to surgery as standard procedure and continued the VLED for another 8 weeks postoperatively. The first weeks after surgery, SG and RYGB patients were instructed to consume only fluids (food packs in liquid form as soups and shakes) and then gradually increase the texture of the commercial food packs provided. All participants were asked to fill out a self-reported food diary. At weekly follow-ups, food diaries were discussed, side effects recorded, body weight monitored, and ketone bodies (acetoacetate) measured in urine with ketostix (Bayer Ketostix 2880 Urine Reagent Test Strip, Ascensia Diabetes Care), as a measure of dietary compliance. The plasma concentration of beta-hydroxybutyric acid (ßHB), another ketone body, was also measured pre and post intervention as an additional measure of compliance (MAK134, Sigma-Aldrich). Because of COVID-19 restrictions, most participants were followed up by phone.

Participants were asked to maintain their physical activity (PA) level during the 10-week intervention. Compliance with this recommendation was assessed by asking participants to wear SenseWear armbands (BodyMedia) for 7 days prior to baseline (BL) and at week 10. The data were considered valid if participants wore the device for ≥ 4 days, including at least one weekend day, for more than 95% (22.8 h/d) of the time [27]. The following variables were analyzed: average daily steps, PA level, metabolic equivalents (METs), and total PA duration.

After an overnight fast (at least 10 hours) at BL and week 11 (W11), air-displacement plethysmography (BodPod, COSMED) was used to measure body weight, fat mass, and fat-free mass. The test meal consisted of a 200-mL commercial low-glycemic drink (Diben Drink, Fresenius Kabi Norge AS) (300 kcal, 42 E% fat, 35 E% carbohydrates, 3 E% fiber, and 20 E% protein), which was consumed slowly over a 15-minute period, to avoid dumping syndrome.

Hedonic hunger was assessed by the Power of Food Scale (PFS) [28]. This questionnaire consists of 15 questions, comprising an aggregated score and divided into three subcategories: "food available," readily attainable food, but not physically present; "food present," the food both available and physically present, but not tasted; and "food tasted," food physically present and tasted or about to be tasted. A

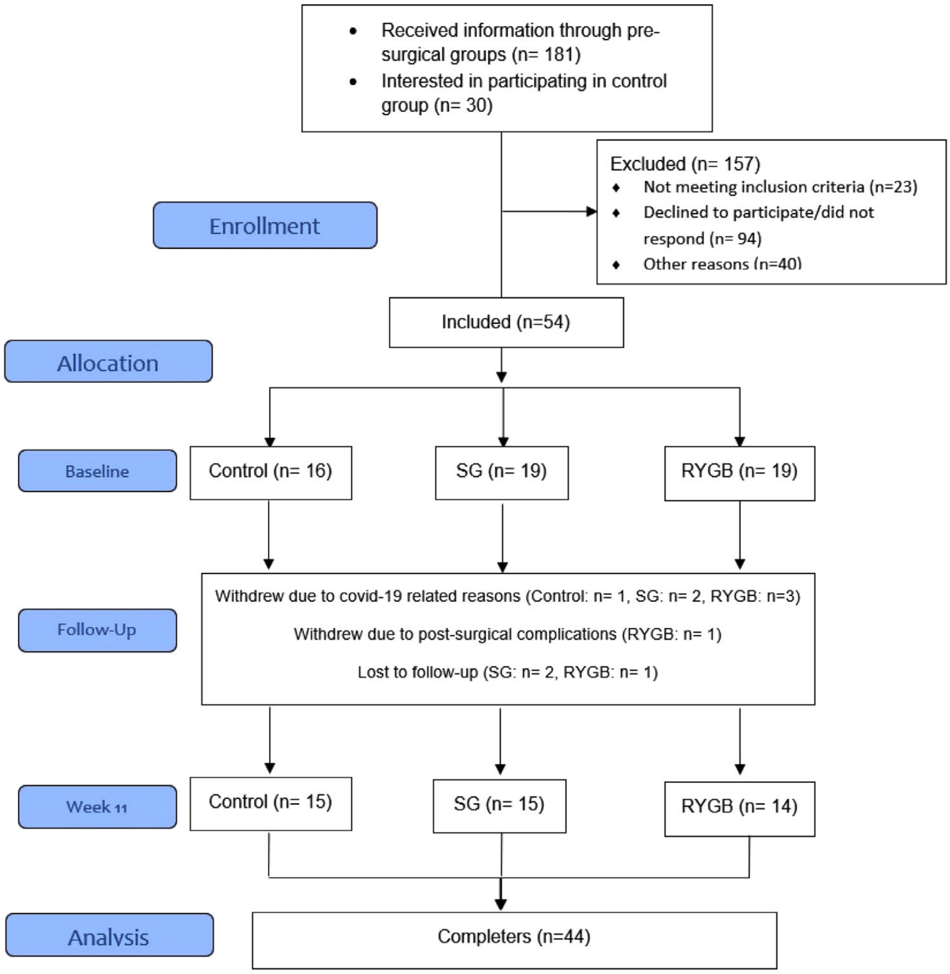

FIGURE 2 Flow diagram of the study. RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Mean characteristics of the participants at baseline and week 11

	Baseline			Week 11		
	Control	SG	RYGB	Control	SG	RYGB
n	15	15	14			
Age	45.5 ± 2.6	39.6 ± 2.4	46.7 ± 2.5			
Females, %	69	79	61			
Body weight (kg)	115.4 ± 3.9^a	117.6 ± 3.6^b	120.4 ± 3.7^c	98.1 ± 3.9^a	98.6 ± 3.6^b	101.6 ± 3.7^c
Weight loss (kg)				−17.3 ± 1.0	−19.0 ± 1.0	−18.8 ± 1.0
BMI (kg/m^2)	39.7 ± 0.9^a	40.2 ± 0.7^b	41.6 ± 1.1^c	33.7 ± 0.9^a	34.1 ± 0.8^b	35.0 ± 1.3 ^{c}
FM (%)	46.6 ± 1.5^a	47.9 ± 1.4^b	47.0 ± 1.4^c	41.0 ± 1.5^a	43.0 ± 1.4^b	42.7 ± 1.4^c
FM (kg)	53.7 ± 2.6^a	56.5 ± 2.4^b	56.5 ± 2.4^c	40.4 ± 2.6^a	42.4 ± 2.4^b	43.6 ± 2.4^c
FFM (%)	53.0 ± 1.5^a	52.1 ± 1.4^b	53.0 ± 1.4^c	59.1 ± 1.5^a	57.0 ± 1.4^b	57.3 ± 1.4^c
FFM (kg)	61.7 ± 2.6^a	61.1 ± 2.4^b	63.8 ± 2.4^c	57.8 ± 2.5^a	56.2 ± 2.4^b	58.1 ± 2.4^c

Note: Data presented as estimated marginal mean ± SEM. Mean values sharing the same superscript letter denote significant changes over time ($p < 0.001$ for all).
Abbreviations: FFM, fat-free mass; FM, fat mass; RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy.

Likert scale with five levels was used (1 = "I don't agree at all" to 5 = "I strongly agree"). The higher the PFS score, the higher the hedonic hunger. The questionnaire was handed out 60 minutes after initiating the breakfast.

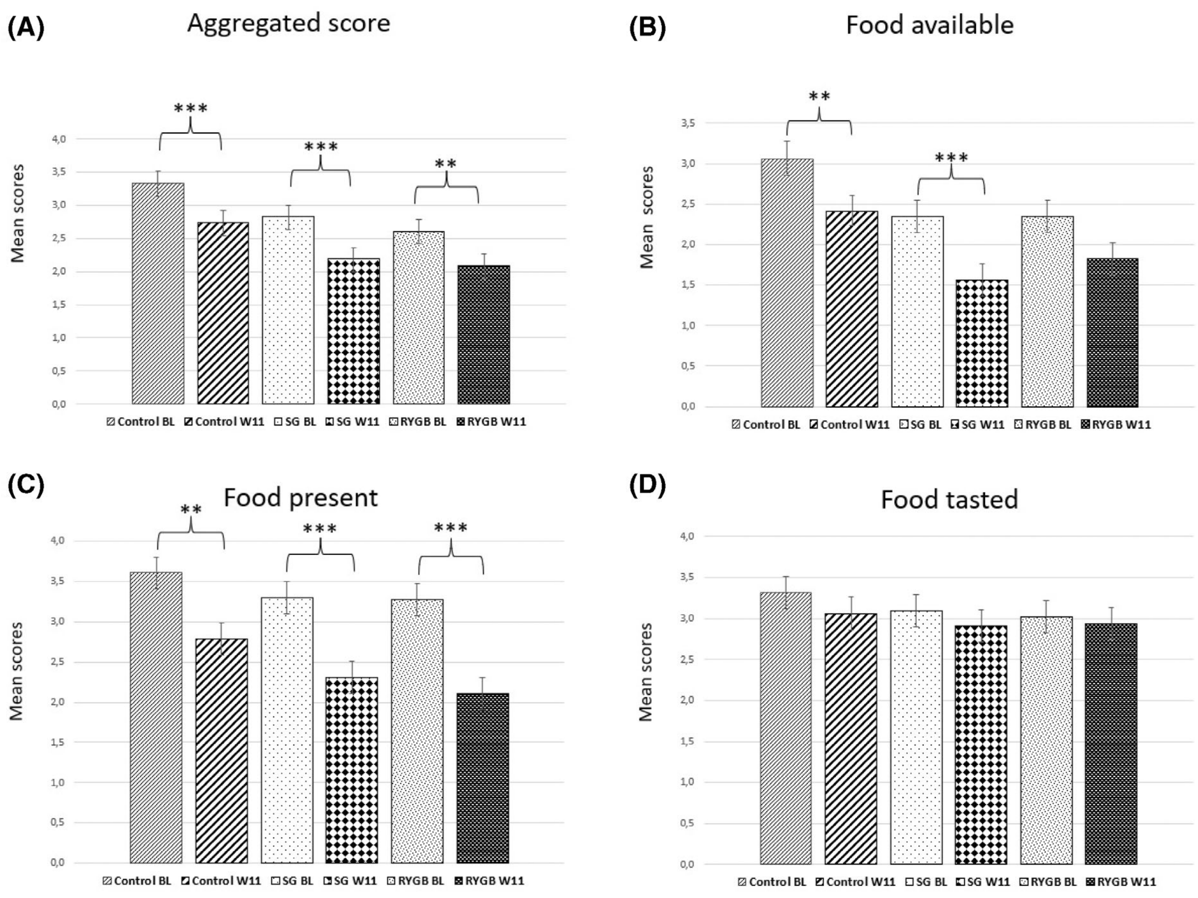

FIGURE 3 Power of Food Scale scores. Data presented as mean ± SE. Asterisks denote significant differences over time (***p < 0.001, **p < 0.01) BL, baseline; RYGB, Roux-en Y gastric bypass; SG, sleeve gastrectomy; W11, week 11

Food preferences and reward were assessed using the Leeds Food Preference Questionnaire (LFPQ) [29]. The LFPQ is a computerized behavioral task that provides measures of "explicit liking" and "explicit and implicit wanting" using images of food. The food pictures in the LFPQ are divided into four categories: high-fat and sweet (HFSW), low-fat and sweet (LFSW), high-fat and savory (HFSA), and low-fat and savory (LFSA). For this study, participants were presented with pictures of foods common in the Norwegian diet. Individual food images were randomly presented to the participants who were required to rate them according to "How pleasant would it be to taste some of this food now?" (explicit liking) and "How much do you want some of this food now?" (explicit wanting) with the scale ranging from "not at all" to "extremely." Next, a forced choice task presented participants with a series of food image pairs and the instruction "Which food do you most want to eat now?" A score was calculated according to how often a food category was chosen over another category, how often it was not selected, and the reaction time of the trial (implicit wanting). The LFPQ was performed in the fasted state and immediately after breakfast.

This paper reports a secondary analysis of the main study powered to detect differences in postprandial plasma concentrations of glucagon-like peptide-1 (GLP-1) between groups. Power calculation was performed assuming that bariatric surgery would induce a postprandial increase in GLP-1 that was two (SG) and three times (RYGB) larger compared with diet-induced weight loss. For a power of 80% and 0.05 significance level and assuming an SD of 1000 min*pmol/L and a within group variance of 640,000 min*pmol/L [30], 45 participants would be required (15 in each group).

Statistical analysis was carried out using SPSS Statistics version 27 (IBM Corp.). Data are presented as mean ± SEM, unless otherwise stated. Because of the large number of tests, the significance level was reduced to $p < 0.01$ to avoid type I errors. Residuals were checked and they did not deviate significantly from normality. All data were analyzed using a linear mixed-effects model with restricted maximum likelihood estimation, including fixed effects for group, time, and their interaction. Bonferroni correction was used for post hoc pairwise comparisons.

RESULTS

Table 1 shows anthropometrics at BL and W11. Forty-four participants completed BL and W11 assessments ($n = 15$ VLED, $n = 15$ SG, and $n = 14$ RYGB). There were no significant differences in any anthropometric variables between groups at either time point. Overall, participants lost 18.3 ± 0.6 kg (~16%) from BL to W11. BMI

TABLE 2 Mean scores from the Leeds Food Preference Questionnaire

		Baseline			Week 11		
		Control	SG	RYGB	Control	SG	RYGB
Explicit liking							
Fasting	HFSA	48.7 ± 5.7	39.4 ± 5.3	33.8 ± 5.4	43.9 ± 5.2	25.9 ± 5.2	28.1 ± 5.4
	LFSA	52.9 ± 5.6	43.6 ± 5.1	43.5 ± 5.3	57.9 ± 5.2	36.1 ± 5.2	41.4 ± 5.4
	HFSW	43.6 ± 5.8*	34.1 ± 5.3^{b}	17.4 ± 5.5*	32.9 ± 4.3	16.8 ± 4.3^{b}	12.7 ± 4.3
	LFSW	52.3 ± 5.5	47.4 ± 5.1	47.5 ± 5.2	51.8 ± 4.8	39.9 ± 4.8	45.0 ± 4.9
Postprandial	HFSA	43.5 ± 5.7	40.1 ± 5.3^{b}	23.4 ± 5.4^{c}	30.4 ± 5.2*	14.8 ± 5.2^{b}	2.3 ± 5.4^{c*}
	LFSA	43.5 ± 5.6	31.5 ± 5.1	28.5 ± 5.3^{c}	35.3 ± 5.2*	16.2 ± 5.2	5.7 ± 5.4^{c*}
	HFSW	35.9 ± 5.8	32.5 ± 5.3^{b}	17.6 ± 5.5^{c}	21.3 ± 4.3	7.7 ± 4.3^{b}	1.8 ± 4.3^{c}
	LFSW	48.1 ± 5.5	43.8 ± 5.1^{b}	38.2 ± 5.2^{c}	37.8 ± 4.8*	22.3 ± 4.8^{b}	7.2 ± 4.9^{c*}
Implicit wanting							
Fasting	HFSA	12.1 ± 5.8	1.0 ± 5.3	−0.5 ± 5.4	5.8 ± 4.8	1.2 ± 4.8	−1.5 ± 4.9
	LFSA	−5.1 ± 7.9^{a}	−5.5 ± 7.3	4.9 ± 7.5	16.5 ± 7.3^{a}	0.4 ± 7.2	15.7 ± 6.9
	HFSW	−11.0 ± 6.9^{a}	−11.4 ± 6.4	−23.9 ± 6.5	−34.0 ± 5.6^{a}	−24.5 ± 5.6	−38.6 ± 5.8
	LFSW	4.1 ± 4.5	15.9 ± 4.1	19.4 ± 4.2	11.7 ± 4.6	23.1 ± 4.6	24.4 ± 4.7
Postprandial	HFSA	9.6 ± 5.8	2.5 ± 5.3	0.7 ± 5.4	2.3 ± 4.8	7.2 ± 4.8	0.2 ± 4.9
	LFSA	−9.9 ± 7.9^{a}	−5.7 ± 7.3	−1.8 ± 7.5	8.2 ± 7.3^{a}	−2.8 ± 7.2	6.9 ± 7.5
	HFSW	−10.8 ± 6.9^{a}	−12.7 ± 6.3^{b}	−24.7 ± 6.5	−28.9 ± 5.6^{a}	−27.9 ± 5.6^{b}	−38.8 ± 5.8
	LFSW	11.2 ± 4.5	16.0 ± 4.1	25.8 ± 4.2	18.5 ± 4.6	23.6 ± 4.6	31.8 ± 4.8
Explicit wanting							
Fasting	HFSA	49.2 ± 5.6	38.7 ± 5.1^{b}	33.9 ± 5.3	44.8 ± 5.1	23.2 ± 5.1^{b}	23.7 ± 5.3
	LFSA	53.5 ± 5.4	42.4 ± 4.9	42.4 ± 5.1	56.4 ± 5.4	35.5 ± 5.4	40.7 ± 5.5
	HFSW	44.6 ± 5.4*	33.4 ± 4.9^{b}	17.4 ± 5.1*	32.0 ± 4.1	15.5 ± 4.1^{b}	12.1 ± 4.3
	LFSW	52.9 ± 5.4	47.9 ± 4.9	45.3 ± 5.1	52.6 ± 5.0	38.8 ± 5.0	44.1 ± 5.2
Postprandial	HFSA	42.6 ± 5.6	36.1 ± 5.1^{b}	22.7 ± 5.3^{c}	26.4 ± 5.1*	14.3 ± 5.1^{b}	2.7 ± 5.2^{c*}
	LFSA	44.2 ± 5.4	30.7 ± 4.9	30.6 ± 5.1^{c}	38.2 ± 5.4$^{*\#}$	16.5 ± 5.4*	5.7 ± 5.4$^{c\#}$
	HFSW	36.4 ± 5.4^{a*}	28.6 ± 4.9^{b}	15.5 ± 5.1^{c*}	19.9 ± 4.1^{a}	7.1 ± 4.1^{b}	1.7 ± 4.2^{c}
	LFSW	46.6 ± 5.4	40.1 ± 4.9^{b}	40.0 ± 5.1^{c}	35.9 ± 5.0*	22.2 ± 5.0^{b}	6.5 ± 5.2^{c*}

Note: Data presented as estimated marginal mean ± SEM. Averages sharing the same superscript letter denote a significant change over time ($p < 0.01$). Averages sharing the same superscript symbol denote significant differences between groups (*#, $p < 0.01$).
Abbreviations: HFSA, high-fat savory; HFSW, high-fat sweet; LFSA, low-fat savory; LFSW, low-fat sweet; RYGB, Roux-en Y gastric bypass; SG, sleeve gastrectomy.

dropped by 6.3 ± 0.8 kg/m^2, fat mass decreased by 13.5 ± 0.5 kg (24% change), and fat-free mass decreased by 4.8 ± 0.3 kg (8% change) ($p < 0.001$, for all). Participants were not ketotic at baseline (ßHB plasma concentration: 0.1 ± 0.07 mM), but all were in nutritional-induced ketosis at W11 (ßHB plasma concentration: 0.7 ± 0.07 mM), with no differences between groups. No significant differences between groups or changes over time were seen for any of the PA variables assessed (data not shown).

Hedonic hunger

Mean scores of the PFS can be seen in Figure 3A–D. At baseline, no differences were seen between groups, but there was a tendency for the control group to have a higher aggregated score compared with RYGB ($p = 0.024$). All groups experienced similar reductions in the aggregated score over time ($p = 0.001$, $p < 0.001$, and $p = 0.003$, for controls, SG, and RYGB, respectively). There was a decrease in the subcategory "food available" in controls and SG ($p = 0.003$ and $p < 0.001$, respectively) and a tendency toward a decrease in RYGB ($p = 0.013$). For the category "food present," all groups experienced similar reductions from baseline to W11 ($p = 0.002$, $p < 0.001$, and $p < 0.001$, for controls, SG and RYGB, respectively). There was an overall reduction in the category "food tasted" from baseline to W11 but this was not significant at group level.

Table 2 presents mean scores from the LFPQ.

Explicit liking

At BL, controls had greater fasting HFSW compared with RYGB ($p = 0.003$) (Table 2). SG experienced reductions in fasting for HFSW from BL to W11 ($p = 0.004$). Overall, there was a reduction over time for postprandial liking for all food categories but not at the group level. HFSA was reduced for SG and RYGB ($p < 0.001$ for both). At W11, controls had greater postprandial liking for HFSA compared with RYGB ($p = 0.001$). Postprandial LFSA decreased only for RYGB ($p = 0.001$), and scores were lower compared with controls ($p < 0.001$). Postprandial HFSW and LFSW were reduced for SG and RYGB ($p = 0.001$ and $p < 0.001$, respectively). At W11, RYGB had lower liking for LFSW compared with controls ($p < 0.001$).

Implicit wanting

For LFSA, there was an overall increase, but this was significant only for the control group ($p < 0.001$, both fasting and postprandially). Overall, implicit wanting for HFSW was reduced at W11 but this was significant only for controls ($p < 0.001$, both the fasted and fed state) and postprandially in SG ($p = 0.001$).

Explicit wanting

Controls had greater explicit wanting for HFSW in the fasting state compared with RYGB at BL ($p = 0.001$). At W11, SG showed reduced explicit wanting for HFSA and HFSW in the fasted state ($p = 0.008$ and $p = 0.001$, respectively). At BL, controls had higher postprandial explicit wanting for HFSW ($p = 0.002$) and for LFSA and LFSW at W11 compared with RYGB ($p = 0.001$ and $p = 0.004$, respectively). At W11, SG showed a postprandial reduction in explicit wanting for HFSA ($p = 0.001$), HFSW ($p = 0.001$), and LFSW ($p = 0.007$) and RYGB for HFSA ($p = 0.001$), LFSA ($p < 0.001$), HFSW ($p = 0.01$), and LFSW ($p < 0.001$), whereas the control group showed reductions only for HFSW ($p = 0.002$).

DISCUSSION

The aim of this study was to compare how a similar weight loss achieved by a VLED alone or VLED in combination with the two most common bariatric procedures (SG and RYGB) impacted hedonic hunger and food reward in individuals with severe obesity. Baseline characteristics and changes in body weight and composition were matched among groups and paralleled by similar reductions in hedonic hunger. However, weight loss induced by SG and RYGB yielded several additional and favorable changes in food reward.

Few studies have investigated the impact of diet-induced weight loss on hedonic hunger in individuals with obesity. Cameron and colleagues [31] reported that a 5% weight loss induced by a low-energy diet did not change the reinforcing value of palatable snacks, but food "liking" increased by 10%, independently of the magnitude of weight loss. However, this was a small study ($n = 15$), and liking was measured as a global evaluation of a meal. A much larger study ($n = 111$) by O'Neil et al. [32] found that a 4% weight loss induced by a 12-week commercial weight loss program, consisting of caloric restriction, encouragement of physical activity, and regular meetings, led to decreases in hedonic hunger. Similarly, a study by Ross et al. [33] reported that a 3-month behavioral weight loss program resulted in reduced food reward sensitivity and impulsivity after an average 6-kg (7%) weight loss. The two latter studies measured hedonic hunger with the PFS, and as such, results are similar and comparable with ours.

Ross et al. [33] reported that a greater food reward sensitivity (from PFS) was associated with greater body weight but not with weight loss. Contrarily, O'Neil and colleagues [32] showed that a decrease in the aggregated PFS score was associated with a greater percentage of weight loss and with improvements in reported weight control behaviors determined by the Eating Behavior Inventory.

To our knowledge, no studies have addressed the impact of SG on hedonic hunger. But several studies [11,18,34,35], including the present one, suggest that bariatric surgery in general leads to reductions in hedonic hunger. Moreover, significantly reduced hedonic hunger post RYGB was shown to be parallel with more favorable changes in dietary habits, such as increased intake of protein-rich foods and vegetables, as well as reduced consumption of sugary foods, snacks, and beverages [35]. Patients with severe obesity were shown to have higher hedonic hunger (aggregated score) compared with controls without obesity [11]. Furthermore, this difference was not seen between controls and patients who had already undergone RYGB ≥1 year ago [11]. Similarly, another study showed that hedonic hunger ("food available" and "food present") was not different in patients who had undergone gastric banding 7 years ago (with BMI between 25 and 52 kg/m^2) compared with individuals with a normal weight, and their scores were lower compared with individuals with severe obesity [18]. These two last studies suggest a "normalization" of hedonic hunger post bariatric surgery.

An overall improvement in food reward after weight loss was seen in the present analysis, but the results are not completely in line with previous findings. A 5% weight loss, induced by continuous or intermittent energy restriction, was reported to improve dietary restraint, craving control, and susceptibility to hunger and binge eating in women with overweight or obesity, despite no changes in liking and wanting for high-fat foods relative to low-fat foods, as measured by the LFPQ [36]. However, a recent study from the same group comparing absolute changes for each food category showed that weight loss decreased liking across all foods [37]. In the present study, only the surgical groups experienced reductions in both liking and wanting for all food categories, whereas the control group showed an increase in wanting for LFSA and a decrease in wanting for HFSW. Even though the changes in controls were overall favorable, food reward was still greater in several food categories post weight loss compared with the surgical groups, especially RYGB. Several aspects may account for the inconsistencies seen among the previously discussed studies. In the present study, weight loss (%) was larger and energy intake significantly lower (almost half) compared with the Oustric et al. study [36].

Martin and colleagues showed in a long-term follow-up study that a low-carbohydrate diet decreased preferences for high-carbohydrate/sugary foods, whereas a low-fat diet decreased cravings for high-fat foods, despite no differences in weight loss at 24 months between diets [38]. In this study, participants from both groups received a comprehensive treatment program to foster daily adherence [38]. This is in contrast to the study by Oustric et al. [37], in which no contact was made until the 1-year follow-up, wherein participants regained half of the weight initially lost, and food reward was no longer different from baseline. Martin et al. (2011) also reported that greater weight loss was associated with larger reductions in cravings for sweets and high-fat foods, at 3 and 24 months, respectively, but in line with the present analysis, changes in food preferences did not correlate with weight loss [38].

Both SG [20,21] and RYGB [21] patients have shown positive alterations in food reward and appetite behaviors post bariatric surgery. Comparing the two procedures, one study [21] showed that SG led to more favorable changes, with decreased preference for high-sugar foods, whereas RYGB did not. Contrarily, we found RYGB to induce additional changes in liking and wanting for the different food categories but with no overall differences between the two. In line with this, a similar weight loss induced by either SG or RYGB was shown to lead to comparable changes on key factors involved in the regulation of eating behavior and hedonic components, such as frequency of food cravings, influence of emotions and external food cues, and favorable shifts in the pleasantness of sweets [25]. Dumping syndrome is a common side effect after bariatric surgery, especially post RYGB, and it was suggested to alter the pleasantness of foods, especially carbohydrate- and fat-rich foods [39]. This might explain some of the differences seen between bariatric surgery and diet-induced weight loss in the present and previously discussed studies. Moreover, individuals with obesity were reported to have decreased dopamine receptor availability [40], but bariatric surgery seemed to reverse this [41]. This could also serve as a possible mechanism for the additional improvements in food reward seen after bariatric surgery, compared with the control group.

Together with the current literature, the present findings have clinical implications for weight management. Overall, bariatric surgery seems to induce favorable (and sustained) changes in hedonic hunger, food reward, and weight control behavior toward a "normalization." To some extent, this appears to be possible to manipulate, which is especially important for those receiving conservative treatment, as comprehensive behavioral interventions seem to play a key role in ameliorating hedonic hunger and food reward after weight loss with dietary restriction. Moreover, adding pharmacotherapy, namely the recently approved GLP-1 receptor agonist [42], to lifestyle interventions might provide benefits on appetite behaviors and body weight, without the risks associated with bariatric surgery.

This study has several strengths. First, weight loss and diet were matched across groups, as well as sex distribution, age, and anthropometric variables, allowing for identification of the impact of SG and RYGB alone. Second, the significance level was adjusted for multicomparisons (Bonferroni) and for the large number of variables tested. This study also has some limitations. First, as the intervention period was 10 weeks, we could not ensure that measurements were taken in the same phase of the menstrual cycle, which is known to have an impact on appetite [43]. However, the distribution was likely to occur at random, so there is no strong indication that this constitutes an issue. Secondly, this was a secondary analysis of a trial powered to detect differences in postprandial GLP-1 secretion between groups, and therefore, this study might be underpowered to look at hedonic appetite and food reward. Additionally, the small number of participants in each group might have increased the possibility of type II error and prevented the detection of true differences among groups. Third, even though validated questionnaires were used to measure hedonic eating and food reward, only one instrument was used to measure each construct, and other instruments measuring different constructs, which might be differently impacted by bariatric surgery, might provide different results. Fourth, the strict significance level imposed might have affected the results and prevented the identification of significant findings. Fifth, even though the standardization of the diet across groups is a strength, we cannot rule out that some of the differences found among groups, especially bariatric groups versus controls, is due to transitory changes in postoperative physiology, including fluid shifts and changes in absorption and metabolism. Finally, stress is a potential mediator for appetite and food cravings [44], and given that this study was carried out under unusual circumstances (COVID-19 pandemic), stress could have affected our outcome variables.

CONCLUSION

Initial weight loss seems to reduce hedonic hunger, independent of modality. However, SG and RYGB led to several additional favorable changes in food reward. These preliminary findings need to be confirmed, and future research should also investigate the long-term impact of both diet-induced weight loss and bariatric surgery on hedonic hunger and food reward and how initial changes in these constructs might modulate long-term weight loss outcomes.O

AUTHOR CONTRIBUTIONS

CM and MIA formulated the research questions and designed the study. MIA, IØB, and SS carried out the study. GF analyzed data from the LFPQ. MIA analyzed the data. All authors were involved in the writing of the manuscript.

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

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ORCID

Marthe Isaksen Aukan https://orcid.org/0000-0002-0458-3640

Siren Nymo https://orcid.org/0000-0002-7217-5913

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