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ORIGINAL CONTRIBUTIONS

The Relationship Between Energy Intake and Weight Loss in Bariatric Patients

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Abstract

Introduction There is a huge variation in weight loss outcomes between bariatric patients, possibly due to differences in caloric intake and changes in the amount physical activity. However, the association between the change in energy intake and weight loss has not yet been the subject of an extensive investigation.

Objective To explore the relationship between total energy intake and % total body weight loss (%TBWL) over a period of 4 years post-surgery.

Methods Of the 466 patients who were asked to participate, a total 135 patients were included in this study. They all underwent bariatric surgery, 54 with primary Roux-en-Y Gastric Bypass, 43 redo Roux-en-Y gastric bypass after laparoscopic gastric banding and 38 laparoscopic sleeve gastrectomy. Pre- and post-operative dietary intake and physical activity were collected for both a weekday and a weekend day. The main analysis was performed using multiple regression analyses and was adjusted for age at surgery, BMI at baseline, obstructive sleep apnoea syndrome, type of eating behaviour, change in physical activity and protein intake (g/kg body weight).

Results %TBWL over time, post-operative energy intake and change in physical activity did not differ between the different procedure groups ($p = 0.312$, $p = 0.988$ and $p = 0.050$, respectively). Change in energy intake did differ between different procedure groups ($p = 0.031$) and linear regression showed that this was related to total body weight loss for the fully adjusted model ($\beta = -0.004$, $p = 0.014$).

Conclusion This study showed a higher decrease in energy intake to be related with a higher %TBWL.

Keywords Dietary intake · Bariatric surgery · Roux-en-Y gastric bypass · RYGB · Redo · Gastric sleeve · LSG · Weight loss · Macronutrients · Micronutrients

Introduction

The prevalence of obesity has risen explosively over the past decades according to the World Health Organization [1].

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Bariatric surgery is the most effective treatment for (morbid) obesity as well as improvement of its related comorbidities [2–4]. The most performed bariatric procedures are the Roux-en-Y gastric bypass (RYGB) and the laparoscopic sleeve gastrectomy (LSG). Both procedures have shown a significant long-term weight reduction with 76% (95%CI 65–88) excess weight loss (EWL) in RYGB patients and 59% (95%CI 48–71) EWL in LSG patients 3 years after surgery [3]. In general, both procedures seek to reduce the caloric intake of patients. The RYGB is a restrictive procedure by which the proximal part of the stomach is used to create a small pouch. This pouch is attached to a Roux limb of the proximal jejunum and thereby bypasses parts of the stomach and duodenum [5, 6]. There is also a malabsorptive component to the RYGB, influenced by the length of the biliopancreatic limb. This causes malabsorption, as the absorption starts in the jejunum instead of the duodenum, leading to additional weight loss [7]. The LSG is considered mainly a restrictive procedure that involves

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removal of a large part of the stomach and thereby decreases the volume of the stomach [8].

A decreased caloric intake due to a smaller stomach volume seems to be the most obvious cause for weight loss following bariatric surgery. However, reducing stomach volume is not the only cause for a decreased food intake, according to a study by Ionut and Bergman [9]. They suggest that changes in gut bacteria and (gastrointestinal) hormones also influence satiety, satiation and appetite suppression, resulting in reduced food intake. Besides physiological factors influencing weight loss, there are also several studies that show dietary habits and lifestyle factors as predictors of weight loss after bariatric surgery. Masood and colleagues [10] suggest that weight regain after bariatric surgery might be less due to excessive consumption and more to a poorer selection of healthy foods. Furthermore, Shilton et al. found pre-operative clinical attendance to be associated with poorer weight loss outcomes [11] and Karfopoulou and colleagues found habits such as eating at home, involvement in meal preparation, higher eating frequency and slower eating rate to be associated with weight maintenance following bariatric surgery [12].

Whether caused by a reduced stomach volume or a change in gut bacteria and (gastrointestinal) hormones, a decreased caloric intake is most likely the main cause for weight loss following bariatric surgery. Several studies have examined dietary intake in bariatric patients. However, most of these studies only studied energy intake and macronutrient distribution, but not its relationship with weight loss [13, 14]. Other studies examined dietary habits and eating behaviour rather than actual energy and macronutrient intake [15–19], focussed on just one bariatric procedure, did not assess dietary changes within persons [20] or had a relatively short follow-up time [21, 22]. In addition to this, physical activity was often not accounted for, although it is an important factor associated with long-term weight loss [23–25].

To our knowledge, there are only a few studies that have assessed the actual relationship between (change in) dietary intake and weight loss [26, 27]. The aim of this study is therefore to explore the relationship between total energy intake and % total body weight loss (%TBWL) over a period of 4 years post-surgery. Furthermore, we aim to assess if there are differences in energy intake between individuals with external, emotional and restrained eating behaviour.

Methods

This longitudinal observational study used data collected prospectively from patients who were participants in the ELEGANCE-study (clinical trial: NCT01686997) and the VITAAL I-study (clinical trial: NCT01609387). Both studies were conducted at the Rijnstate Hospital in Arnhem, the Netherlands. In addition, data was retrieved from the Dutch Obesity Clinic. Inclusion criteria were adults who underwent a primary RYGB, redo RYGB (RYGB after laparoscopic adjustable gastric banding) or LSG between 2011 and 2013 in the Rijnstate Hospital. To be eligible for bariatric surgery, the Fried guidelines were applied, which states that patients should be between 18 and 65 and have a BMI > 40 kg/m^2 or BMI > 35 kg/m^2 with a comorbidity related to obesity [28]. Exclusion criteria for this study were absence of data on dietary intake either pre- or post-operative, absence of data on weight loss and suffering from conditions that influenced either post-operative weight or dietary intake such as pregnancy.

Surgical Procedure RYGB

All patients underwent their respective operations using a standardized operation technique. A laparoscopic antecolic antegastric RYGB procedure was performed. A small gastric pouch of 40–50 mL was constructed. An alimentary limb and a biliopancreatic limb of 75–150 were constructed.

Surgical Procedure LSG

Transection of the stomach was performed using staplers along the greater curvature, progressing upwards from 4 cm proximal from the pylorus. The staple line was aimed towards the angle of His, taking care not to narrow the incisura angularis.

Dietary Intake and Physical Activity Measurements

Pre-operative data on dietary intake, eating behaviour and physical activity were collected. Dietary intake was assessed using a 2-day food diary (one week day and one weekend day). Diet composition was analysed with EVRY version 6.3.1.1 (EVRY B.V.), a nutrition calculation software based on The Dutch Food Composition Database (NEVO-table 2013) [29]. Change in energy intake was calculated by subtracting pre-operative dietary intake from post-operative dietary intake. Pre-operative eating behaviour was assessed using the Dutch Eating Behaviour Questionnaire. The questionnaire is comprised of 33 questions which can be answered with a 5-point Likert scale to score the extent to which people show external, emotional or restrained eating behaviour [30]. Pre-operative physical activity was measured using the Baecke questionnaire which indicates the score of work activity, leisure activity and sports activity. The total physical activity score was obtained by accumulating these three scores [31]. Before surgery, patients were advised to lose weight and had to attend regular structured (group) meetings to learn how to adapt to a healthy lifestyle after surgery.

Post-operative dietary intake and physical activity data were collected. Post-operative dietary intake was assessed using a semi-structured food questionnaire which was also filled in for both a weekday and a weekend day and analysed with EVRY. Post-operative physical activity was again measured using the Baecke questionnaire.

Anthropometric Measurements

Participants were pre-operatively weighed to the nearest 0.1 kg, using a Tanita BC-420MA scale. Height was determined using a Seca 222 height rod. Body mass index (BMI) was calculated by dividing weight (kg) by height (m^2) and % total body weight loss (%TWBL) was calculated by dividing weight loss (kg) by pre-operative weight multiplied by 100.

Acquisition of Blood Parameters

Serum vitamin D total was determined with a chemiluminescence immunoassay on the DiaSorin Liason (DiaSorin, Saluggia, Italy) until July 2013. An electrochemiluminescence immunoassay on the Roche Diagnostics Modular E170 was used to determine serum vitamin D from July 2013 onwards, as well as to determine vitamin B_{12}, folic acid and ferritin. Calcium and albumin were determined with a colorimetric assay on the Roche Diagnostics Modular P800 (Roche Holding AG, Basel, Switzerland).

Statistical Analysis

The statistical analysis was carried out using the statistical software programs IBM SPSS Statistics version 24.0 for Windows. Graphs were created using Microsoft Excel 2016 for Windows. A p value < 0.05 was considered significant. Normally distributed variables were presented using means and standard deviations (SD). If data were not normally distributed, the median and interquartile range (IQR) were displayed and extreme outliers were excluded for analysis. The main analysis was performed using multiple regression analyses and was adjusted for age at surgery, BMI at baseline, obstructive sleep apnoea syndrome, type of eating behaviour, change in physical activity and protein intake (g/kg body weight). Repeated measures analysis of variance (ANOVA) was used to assess difference in %TBWL over the time between the different procedure groups. Differences between pre-operative and post-operative dietary intake and physical activity were assessed with one-way ANOVA. This also applied to differences in long-term calorie intake between individuals with different eating behaviour. Finally, multiple regression analyses were used to analyse the association between dietary intake and %TBWL over time.

Results

A total of 466 patients were asked to participate in this study including the extensive post-operative food questionnaire. Of these 466 patients, 205 patients returned their food questionnaire within the period of data collection (Fig. 1). Eventually, 135 participants were included in this study.

Of the 135 participants eligible for analysis, approximately 84% was female and the mean age was 46.5 ± 9.5 years (Table 1). Median follow-up time was 4.8 (4.4–5.0) years. Mean BMI at baseline of the total study population was 44.5 ± 6.7 kg/m^2 and mean excessive weight (EW) was 56.8 ± 20.4 kg. BMI and EW differed significantly among participants who underwent a primary RYGB, redo RYGB and LSG (respectively $p = 0.017$ and $p = 0.012$), whereas comorbidities did not. Lifestyle factors such as smoking, alcohol use and drug use did not differ significantly among different surgical procedures. Median blood levels of vitamin B_{12}, folic acid, ferritin, calcium and albumin were all within reference values and did not differ significantly among the three procedure groups. However, the median vitamin D values were below the cut-off value of 50 nmol/L and differed between the three procedures ($p = 0.024$).

Total Body Weight Loss and Change in Dietary Intake

Mean %TBWL at ≥ 4 years was highest in the redo RYGB group (29%), followed by the LSG group (28%). The primary RYGB group had the lowest total body weight loss (27%), although differences were minimal on the whole. Repeated measures ANOVA showed that change in %TBWL from 12 months until at least 48 months did not significantly differ between the three procedure groups ($p = 0.312$) (Fig. 2).

Regarding the change in energy intake over time (Fig. 3), there was a significant difference among the three groups (p = 0.031). Post hoc Bonferroni testing revealed that only the

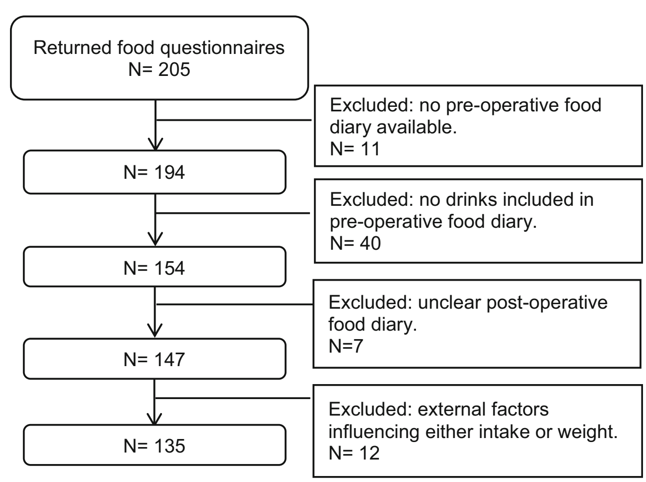


Fig. 1 Flowchart of included subjects for analysis

Table 1 Baseline characteristics by surgical procedure in Dutch patients who underwent bariatric surgery

	Total ($n = 135$)	Primary Roux-en-Y gastric bypass ($n = 54$)	Redo Roux-en-Y gastric bypass ($n = 43$)	Laparoscopic sleeve gastrectomy ($n = 38$)	p value
Age at surgery (years, ± 1 SD)	46.5 ± 9.5	46.8 ± 9.4	47.3 ± 8.2	45.2 ± 11.0	0.575
% women	83.7	88.9	83.7	76.3	0.275
BMI at baseline[a] (± 1 SD)	44.6 ± 6.7	44.6 ± 4.7	42.6 ± 4.3	46.8 ± 10.1	*0.017*
Excessive weight[b] (± 1 SD)	56.8 ± 20.4	56.9 ± 14.1	50.4 ± 12.9	63.8 ± 30.5	*0.012*
Comorbidities					
% diabetes mellitus	20.0	27.8	11.6	18.4	0.136
% hypertension	42.2	50.0	32.6	42.1	0.225
% dyslipidaemia	19.3	22.2	14.0	21.1	0.559
% obstructive sleep apnoea syndrome	8.9	9.3	7.0	10.5	0.848
% joint complaints	34.8	38.9	23.3	42.1	0.148
Smoking					
% current smokers	16.3	14.8	16.3	18.4	0.899
Alcohol use					
% not	48.1	44.4	44.2	57.9	0.222
% daily	10.4	7.4	9.3	15.8	
% weekly	14.8	13.0	16.3	15.8	
% monthly	26.7	35.2	30.2	10.5	
Drug use[c]					
% users	0.7	1.9	0.0	0.0	0.470
Blood levels					
Vitamin D (nmol/L)[d]	43 (30–58)	47 (34–58)	46 (33–59)	27.5 (22–52)	*0.024*
Vitamin B_{12} (pmol/L)[d]	291 (226–391)	274.5 (223–382)	285 (226–396)	313 (23–400)	0.445
Folic acid (nmol/L)[d]	14.8 (12.1–19.9)	14.5 (11.7–18.6)	16.5 (12.4–23.9)	14.2 (12.2–18.7)	0.670
Ferritin (μg/L)[d]	80.0 (49–131)	93.5 (55–140)	69.0 (42–95)	75.5 (40–131)	0.059
Calcium (mmol/L)[e]	2.33 (2.29–2.40)	2.33 (2.30–2.36)	2.40 (2.24–2.40)	2.36 (2.27–2.41)	0.533
Albumin (g/L)[e]	39 (37–40)	39 (37–40)	38 (33–38)	39 (37–41)	0.898

If normally distributed, continuous variables are shown as mean ± SD and if not normally distributed, median and (IQR) are shown. All categorical variables are displayed in percentages. Italic numbers are considered statistically significant ($p < 0.05$)

[a] kg/m^2

[b] Excessive weight = pre-operative body weight − body weight at a BMI of 25

[c] Drug use did not include the use of medication

[d] Ten participants missing data on baseline vitamin D, vitamin B_{12}, folic acid and ferritin

[e] 109 participants missing data on baseline calcium and albumin

difference between the redo RYGB group and the LSG group was significant ($p = 0.040$). Post-operative energy intake was almost exactly the same between the three procedures ($p = 0.988$).

Physical Activity

In all three procedures groups, there were only small changes in physical activity (Fig. 4). In the primary RYGB group and the LSG group there was a small increase in physical activity, while in the redo RYGB group a small decrease in physical activity was found. Testing the difference in physical activity change over time using ANOVA, showed a minimal significant difference between the three procedure groups ($p = 0.050$). However, Bonferroni post hoc testing showed no significant difference between groups.

Relationship Between Change in Dietary Intake and Total Body Weight Loss

Linear regression showed change in energy intake was significantly related to %TBWL in the total study population ($\beta - 0.004$, $p = 0.039$). After adjustment for age, BMI at baseline, obstructive sleep apnoea syndrome, type of eating behaviour, change in physical activity and protein intake in g/kg, this relationship remained significant ($\beta - 0.004$, $p = 0.014$).

When performing subgroup analysis for gender, this significant relationship was only present in women (fully

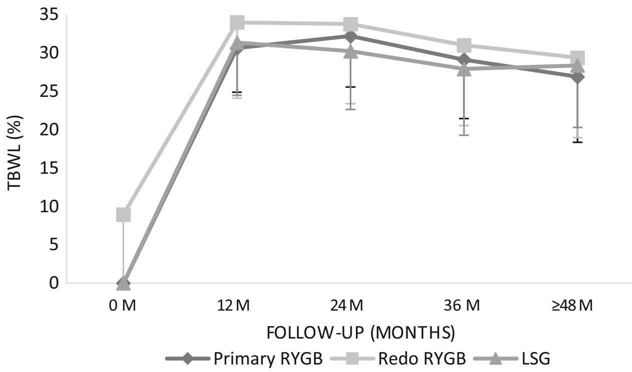


Fig. 2 Total body weight loss (%TBWL) over time (≥ 4 years follow-up) in Dutch patients who underwent bariatric surgery

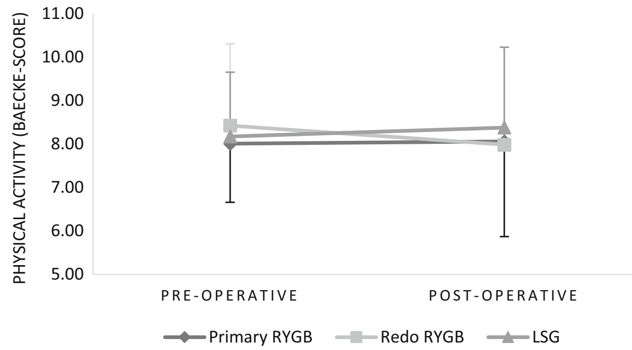


Fig. 4 Pre-operative and 4 years post-operative physical activity in Dutch patients who underwent bariatric surgery

adjusted model $\beta -0.004$, $p = 0.023$). Subgroup analyses were also performed for the three subgroups (primary RYGB, redo RYGB and LSG), protein intake (< 0.8 g/kg and ≥ 0.8 g/kg) and changes in energy intake (≤ − 600 kcal, − 200 to − 600 kcal and ≥ − 200 kcal).

In the subgroup analysis per different procedure, no significant relationship was found for any of the fully adjusted models. The same applied for the subgroup analysis in the different changes in energy intake groups. However, subgroup analysis for protein intake showed a significant relationship between change in energy intake and %TBWL for the fully adjusted model in the group that consumed ≥ 0.8 g/kg protein per day ($\beta -0.007$, $p = 0.027$), whereas the group that consumed < 0.8 g/kg protein per day did not show a significant relationship ($\beta -0.001$, $p = 0.746$).

Eating Behaviour

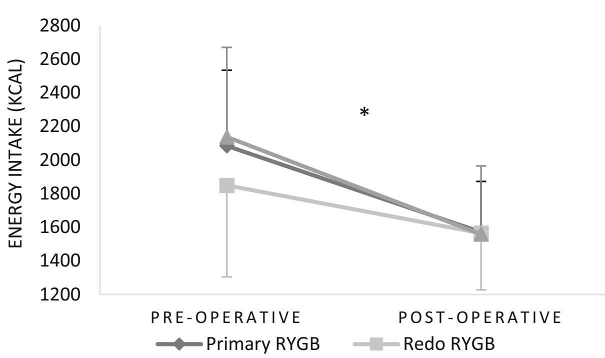
When investigating pre-operative energy intake between different types of eating behaviour, participants with external eating behaviour had the highest mean energy intake (Fig. 5). In contrast, participants with clear emotional eating behaviour tend to have to lowest mean energy intake. The change between pre- and post-operative energy intake was highest in the group that showed a combination of eating behaviours and smallest in the group with clear emotional eating behaviour. However, neither pre-operative energy intake nor the change between pre- and post-operative energy intake differed significantly among different eating behaviour styles.

Macronutrient Intake

Post-operative mean intake of carbohydrates, protein, fat and alcohol were respectively 43en%, 20en%, 32en% and 2en% (supplementary Table 1). Mean post-operative fibre intake was 16 g/day. Post-operative macronutrient distribution did not differ significantly between patients with primary RYGB, redo RYGB and LSG, except for fibre intake, which was significantly lower in the LSG group, compared to the primary RYGB group ($p = 0.039$).

Micronutrient Deficiencies

Post-operatively developed micronutrient deficiencies were also assessed. During the ≥ 48 months of follow-up, the most deficiencies occurred for vitamin B_{12} (32.6%), followed by ferritin (28.9%) and vitamin D (20.7%). For folic acid, 9.6%



*** p<0.05, significant difference over time between groups.**

Fig. 3 Pre-operative and 4 years post-operative energy intake in Dutch patients who underwent bariatric surgery. *$p < 0.05$, significant difference over time between groups

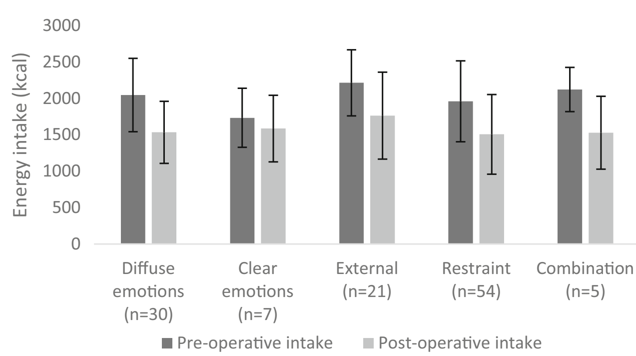


Fig. 5 Pre- and post-operative energy intake in different types of eating behaviour in Dutch patients who underwent bariatric surgery

developed a deficiency. Furthermore, albumin deficiencies occurred in 16.3% of the study population and calcium deficiencies in 8.1% of the study population.

Discussion

This study examined long-term change in energy intake and its relationship with %TBWL in Dutch individuals who underwent either primary RYGB, redo RYGB or LSG. Firstly, there were no significant differences between the three procedure groups neither for %TBWL nor for post-operative energy intake 4 years after surgery. Regarding macronutrient distribution, only fibre intake significantly differed and was significantly lower in the LSG group. Remarkably, there was only a small difference in physical activity level and even a small decrease of physical activity in the redo RYGB group.

In regard to the relationship between change in energy intake and %TBWL, a more positive delta energy intake was related to a significant decrease of %TBWL for the fully adjusted model in the total study population. However, this relationship was only present in women and in participants who ingested ≥ 0.8 g/kg protein per day. Comparable to other studies, participants developed several vitamin and mineral deficiencies, with vitamin B_{12}, ferritin and vitamin D being the most common [32–34].

The results of the present study were in line with research by Moizé and colleagues. They found that energy intake independently predicted weight loss over time, as is the case with our study. Moreover, they reported no significant differences between RYGB and LSG in post-operative energy intake and weight changes over time [27]. Coupaye et al. also did not find a significant difference in post-operative energy intake between RYGB and LSG [21]. In addition, Kanerva et al. showed short-term (0.5 year) changes in dietary intake being associated with long-term weight loss [26]. Additionally, participants who favoured protein over carbohydrates achieved greater weight loss than participants who favoured carbohydrates or fat.

In our study, people who consumed ≥ 0.8 g/kg protein per day showed a significant relationship between dietary intake and %TBWL, whereas this relationship was not present in participants who ingested < 0.8 g/kg protein per day. Giusti et al. reported a major decrease in protein intake the first month following bariatric surgery, which was concomitant with major lean body mass loss [13]. This is in accordance with a systematic review and meta-analysis by Ito et al. in which they describe that a protein intake of 60 g/day or more was positively associated with better lean mass preservation [35]. In our study, the group that ingested < 0.8 g/kg protein per day may also have experienced more lean body mass loss, resulting in a lower basal metabolic rate and thus a lower energy expenditure. Furthermore, a study by Da Silva and colleagues showed that not food intake, but diet quality was associated with weight regain [16]. Similarly, a study by Freire et al. found that poor diet quality was higher among participants who regained weight [18]. These findings suggest that diet quality may play an important role in weight loss after bariatric surgery. Perhaps another interesting question would be if diet quality may not only play an important role in weight loss but also in nutritional status in bariatric patients?

Remarkably, in the present study, physical activity only slightly changed over time, with even a small decrease in the redo RYGB group. However, some other studies reported similar results [36, 37]. A study by Berglind et al. assessed changes in physical activity in women following RYGB. Physical activity decreased in the group that had the highest level of physical activity before surgery. This is comparable to our study, where the redo RYGB group also showed the highest level of pre-operative physical activity and a decrease in physical activity after surgery [38]. These results imply that in this study the majority of weight loss was caused by a decrease in calorie intake rather than a decrease in physical activity.

The strengths of our study were the relatively long follow-up period and the use of both pre- and post-operative data on total body weight loss, energy intake and physical activity. In this way, the relation between change in energy intake and total body weight loss could be assessed, instead of only taking into account post-operative intake. Furthermore, a distinction was made between surgical groups, which allowed us to compare different surgical procedures. An additional strength of our study is that all data entry was performed by just one researcher, limiting variability. Finally, analysis was adjusted for physical activity to independently assess the role of diet.

Limitations of this study were self-reported pre- and post-operative food intake. Other studies show underreporting is very common for energy intake, which makes our data more prone to reporting bias [39, 40]. Secondly, the group as a whole is heterogenous at the start and during the study. The differences in for example BMI and nutritional characteristics are however explained by the type of surgery used and represent a realistic clinical setting. Also, personal motivation and education were not taken into account, which are factors known to influence weight loss after bariatric surgery [41–43]. Another limitation is the fact that two different methods of assessing food intake were used, which may have caused differences in reporting dietary intake. Finally, there could be selection bias. People who participated and returned the food questionnaires might be more motivated, which could give a distorted view of reality and could have influenced our results.

In conclusion, our study contributes to the body of evidence that a higher decrease in energy intake is related with a higher %TBWL. For future research, it would be interesting to perform more intervention studies which will also take diet quality, body composition and basal metabolic rate into account.

Ideally, this could contribute to a more personalized post-operative dietary advice, further enhancing results of bariatric surgery in the future.

Authors' Contributions Louella A.H.M. Schoemacher: designed and conducted the research, collected and analysed the data and wrote the paper.

Abel B. Boerboom: conducted the research and provided essential materials.

Monique Thijsselink: collection of data and other (read and give feed-back on article).

Edo O. Aarts: designed the research, provided essential materials, wrote the paper and has the primary responsibility for the final content.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Statement of Human and Animal Rights All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration.

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