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REVIEW ARTICLE

Relative Energy Expenditure Decreases during the First Year after Bariatric Surgery: A Systematic Review and Meta-Analysis

Fernando Lamarca[1] · Mariana Silva Melendez-Araújo[1] · Isabela Porto de Toledo[2] · Eliane Said Dutra[1] · Kênia Mara Baiocchi de Carvalho[1,3]

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Abstract
The effect of bariatric surgery on resting energy expenditure (REE) remains unclear, particularly in terms of the REE/fat-free mass (FFM) ratio. We performed a systematic review with a meta-analysis on Roux-en-Y gastric bypass (RYGB) studies to investigate the effect of bariatric surgery on the REE/FFM ratio 6 and 12 months postoperatively. Five of the 13 records of 6-month data ($n = 406$) showed a reduction in the REE/FFM ratio without significant summary effects. As regards 12-month data (10 records, $n = 713$), there was a significant relative REE mean reduction of 1.95 kcal/kg in FFM (CI: −2.82 to −1.09; $I^2 = 28\%$; $p < 0.00001$). These findings suggest that bariatric surgery, specifically RYGB, leads to a decrease in the REE/FFM ratio during the first postoperative year, which may compromise long-term treatment outcomes.

Keywords Bariatric surgery · Calorimetry · Energy metabolism · Body composition · Resting energy expenditure · Systematic review

Introduction

The treatment of obesity is generally based on promoting a negative energy balance by reducing energy intake and increasing daily energy expenditure. In humans, energy utilization consists of resting energy expenditure (REE), the thermic effect of food consumed, and the energy expended in physical activity [1]. REE is proportional to body mass, particularly the amount of fat-free mass (FFM) [2]. In general, the process of weight loss leads to FFM reduction, and based on the adaptive thermogenesis theory, the reduction in REE per kilogram of FFM explains the low success rate of most weight loss interventions [3, 4].

The metabolic mechanisms involved in energy balance are not fully understood; however, an extensive body of data on clinical interventions shows that weight loss is accompanied by persistent endocrine adaptations that increase appetite and decrease satiety, thereby resisting continued weight loss or conspiring against long-term weight maintenance [5, 6]. With regard to bariatric surgery, different techniques and procedures, specifically Roux-en-Y gastric bypass (RYGB) and sleeve gastrectomy, have been reported to influence both energy intake and energy expenditure [7, 8], mostly during the first postoperative year [9] by endocrine adaptations. For instance, the increased release of gut hormones such as glucagon-like peptide-1 and peptide YY, which possess anorectic properties, could contribute to better appetite control [10–12]. Some studies have found an increase in REE related to total body mass postoperatively [13–15], whereas others have found no changes [16] or reductions [17, 18] during the different postoperative periods.

✉ Kênia Mara Baiocchi de Carvalho
kenia@unb.br

Fernando Lamarca
lamarcapardo@gmail.com

Mariana Silva Melendez-Araújo
nutmelendez@gmail.com

Isabela Porto de Toledo
pt.isabela@gmail.com

Eliane Said Dutra
elidutra@unb.br

1 Graduate Program of Human Nutrition, University of Brasília, Brasília, Brazil

2 Candidate for the Health Science Graduate Program, University of Brasília, Brasília, Brazil

3 Faculty of Health Sciences, Graduate Program in Human Nutrition, University of Brasilia, Zip Code 70910-900, Asa Norte, Brasília, Federal District, Brazil

The most appropriate way to evaluate changes in REE has not yet been fully established. The REE/FFM ratio may be useful for investigating the repercussions of bariatric surgery on energy balance. Although both FFM and fat mass (FM) add to the variance in REE, the former contributes three to seven times as much to the energy expenditure [19, 20]. Therefore, the REE/FFM ratio remains a significant method of evaluating energy expenditure, since it reinforces the effect of the most metabolically active body compartment. A narrative review also pointed out increases and decreases when REE is expressed per kilogram of body weight and per kilogram of FFM, respectively [21]; however, the data search was not conducted systematically and no meta-analysis was performed in that study, thereby reducing the level of evidence. Considering all these aspects and the importance of systematically organizing available data related to bariatric surgery, this systematic review aimed to analyze the effect of bariatric surgery on the REE/FFM ratio during the first year after surgery.

Methods

Protocol and Registration

This systematic review is based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [22]. The protocol of this systematic review was registered in the International Prospective Register of Systematic Reviews (PROSPERO) (No. CRD42017073768).

Eligibility Criteria

Inclusion Criteria

This review included only observational studies involving adults who had undergone any type of bariatric surgery. Only studies that analyzed the body composition and REE during the preoperative and 6- or 12-month postoperative periods were considered for inclusion. Indirect calorimetry was required, and its outcomes in terms of resting or basal energy expenditure were considered as synonymous. In order to reduce publication and retrieval bias, the search was not restricted by language, publication date, or publication status.

Exclusion Criteria

The exclusion criteria were as follows: (1) patients under 18 years old; (2) procedures for weight loss other than bariatric surgery; (3) measurement of energy expenditure other than indirect calorimetry; (4) follow-up period of less than 6 months; (5) reviews, letters, conference abstract, personal opinions, books, cross-checking information, case report, experimental studies in vivo (animals) and in vitro, research protocols, and clinical trials; (6) studies without REE/FFM ratio data available, even after at least two attempts to contact the authors by email.

Information Sources and Search Strategies

The search strategy was developed in accordance with the criteria established by the Peer Review of Electronic Search Strategies (PRESS checklist) [23]. Subsequently, two researchers, who conducted a systematic review, evaluated and contributed to its adequacy.

The search was conducted using the following databases: PubMed, Embase, LILACS, Web of Science, Scopus, and LIVIVO. A partial search in the gray literature was also performed using ProQuest Dissertations & Theses Global and Google Scholar (limited to the first 200 most relevant articles). The search was conducted on April 12, 2018, and it was updated on November 12, 2018. In addition, manual searches were performed using selected articles in the references.

For each database search, adapted combinations of terms and words were applied. For example, in the search on the PubMed database, the following search terms were used: [obesity OR "morbid obesity" OR "severe obesity" OR overweight OR "weight loss" OR obese] AND ["bariatric surgery" OR gastroplasty OR "metabolic surgeries" OR "bariatric surgeries" OR "stomach stapling" OR "bariatric surgical procedure" OR bariatric OR "metabolic surgery" OR "gastric bypass" OR "sleeve gastrectomy" OR "obesity surgery" OR "obesity surgeries" OR "surgery for obesity" OR "gastric banding" OR "gastric band" OR "vertical banded gastroplasty" OR "banded gastroplasty" OR "Roux-en-Y" OR "Roux-en-Y gastric bypass" OR "RYGB"] AND ["energy metabolism" OR "energy expenditure" OR "resting energy expenditure" OR "energy expenditures" OR "basal metabolic rate" OR "resting metabolic rate" OR calorimetry OR "indirect calorimetry" OR "resting metabolism" OR "basal metabolism"]. Further information on search strategies is presented in the Appendix. For the elimination of duplicate references and screening, which is performed independently, Covidence software (Cochrane Collaboration Software®, Melbourne, Australia) was used [24].

Study Selection

Two authors (F.L. and M.S.M.A.) independently conducted the study selection process in two phases. The first phase consisted of screening the articles through their titles and abstracts and eliminating studies that did not meet the eligibility criteria. In the second phase, the remaining articles were read in full and those eligible were selected for review. In the absence of consensus on the inclusion of a study by the two authors, a third author (I.P.T.) contributed in the final decision-making. The lists of references of the included articles were analyzed by the two authors (F.L. and M.S.M.A.).

Data Collection

The data were extracted by one author (F.L.), and the cross-checking of all information was performed by a second author (M.S.M.A.). The records were divided into 6- and 12-month follow-up periods, and the following information details were collected from all selected studies: authors, publication year, country of study, aim of study, sample size, age and sex of the sample, method of body composition assessment, type of surgery, preoperative REE, postoperative REE, preoperative REE adjusted by FFM, postoperative REE adjusted by FFM, and changes in REE adjusted by FFM over time.

Risk of Bias in Individual Studies

For the assessment of the risk of bias, the critical appraisal tool was used for cohort studies as recommended by the Joanna Briggs Institute [25]. The quality assessment of each study was performed independently by two authors (F.L. and M.S.M.A.). The disparities were resolved by a third reviewer (I.P.T.). The critical appraisal tool consists of a checklist containing 11 questions answerable by "yes," "no," "unclear," or "not applicable." The higher the number of "yes" answers obtained, the greater the methodological rigor of the study and the lower the risk of bias. Thus, the studies were classified as having a high risk of bias if the number of "yes" answers corresponded to less than 49% of the questions, moderate risk of bias if it corresponded to 50–69% of the questions, and low risk of bias if it corresponded to more than 70% of the questions. The results were expressed as the frequency of each classification with consideration of the 11 evaluation parameters.

Data Synthesis

The main outcome was a change in the REE in relation to FFM (REE/kg of FFM). A mean difference meta-analysis was performed using the data from at least two studies, with the aid of Review Manager (RevMan) version 5.3 software (The Cochrane Collaboration 2014) [26]. The analysis was performed using the data from the preoperative and 6- and 12-month postoperative periods, in relation to the RYGB procedure. The heterogeneity was calculated using the inconsistency index (I^2), where a value greater than 50% was considered substantial heterogeneity [27]. When there was high heterogeneity, a random-effects model was chosen.

Results

Literature Search

A total of 1862 records were obtained from the database search. After eliminating duplicates, 1165 records were screened through their titles and abstracts. Fifty-six articles were selected for full-text reading, of which 38 were excluded from the analysis. An additional record was identified from the manual search of the reference list of the fully read articles. Nineteen original articles were included for qualitative synthesis, and of these, 12 were included for quantitative synthesis (meta-analysis), as described in the study flowchart (Fig. 1).

Study Characteristics

In this review, 406 and 713 patients were evaluated 6 and 12 months after surgery, respectively. All the studies had an observational design, and were conducted in Brazil [28–31], Chile [32, 33], Finland [34], France [15, 35, 36], Italy [37–40], the USA [14, 41, 42], Switzerland [43], and Iran [44]. Only the study by Carrasco et al. (2008) is published in Spanish; the others are available in English. In terms of surgical techniques, four different procedures were identified: RYGB [14, 28–34, 36, 41–44], adjustable gastric banding [14, 15, 35, 37, 41, 42], biliopancreatic diversion [38, 39], and laparoscopic sleeve gastrectomy [40, 44]. In four studies, more than one surgical technique had been performed [14, 41, 42, 44]. All included studies were published between 1995 and 2018, and nine of these had samples comprising only women [15, 28, 30, 33, 35–37, 39, 41].

Twelve studies involved assessment of body composition by bioelectrical impedance [15, 28, 30, 31, 34, 36–38, 40, 41, 43, 44], whereas five studies involved assessment of body composition by dual-energy X-ray absorptiometry (DXA) [14, 29, 33, 35, 39]. Carey et al. (2006) [42] assessed body composition by hydrostatic weighing and Carrasco et al. (2007) [32] by doubly labeled water (DLW). Of all the studies, four showed results of REE at both 6 and 12 months after bariatric surgery [28, 33, 39, 42], while the rest presented results from either 6 [14, 15, 29–32, 37, 41, 44] or 12 months after bariatric surgery [34–36, 38, 40, 43].

A summary of the characteristics of the included studies is presented in Table 1.

Risk of Bias within Individual Studies

A critical evaluation of the studies showed that they are heterogeneous with respect to methodological quality. Six studies had a low risk of bias [28–30, 36, 43, 44], meeting four of the 11 parameters: (1) exposures measured similarly to assign people to both exposed and unexposed groups, (2) exposure measured in a valid and reliable way, (3) outcomes measured in a valid and reliable way, and (4) follow-up time reported and sufficient to be long enough for outcomes to occur. Of the studies, 26.3% were considered as having a moderate risk of bias [14, 15, 32, 35, 42] and 42.1% as having a high risk of bias [31, 33, 34, 37–41]. The parameters related to loss of follow-up presented a critical performance among the studies (Fig. 2).

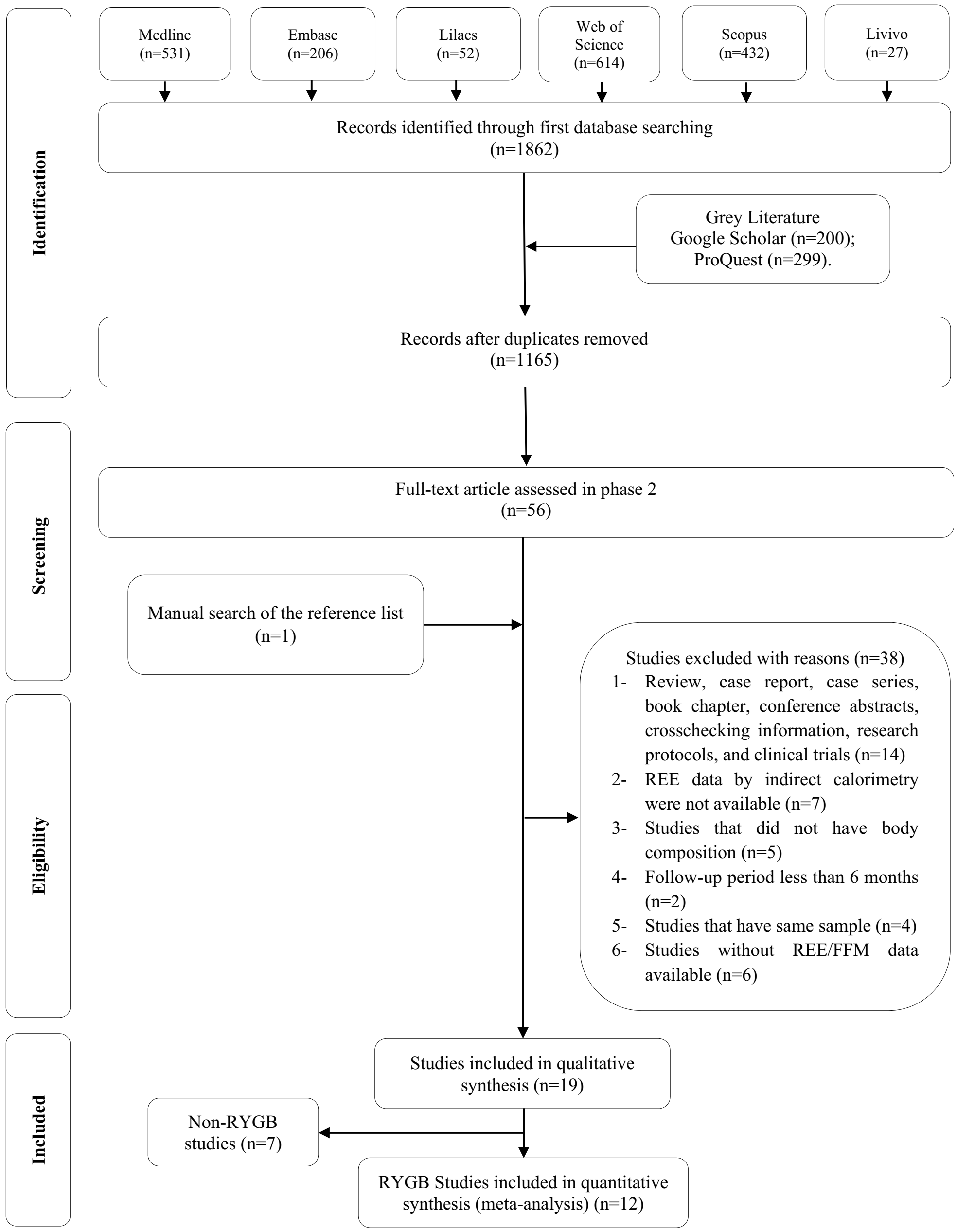


Fig. 1 Flowchart of literature search and selection criteria

Results of Individual Studies

Among the included studies, 17 presented data in absolute values of REE regardless of the postoperative time. Except for the study by Adami et al. [38], all studies showed a significant reduction in REE between the pre- and postoperative periods. From the 13 included studies that assessed the 6-month postoperative period, five studies showed a reduction in the REE/FFM ratio [15, 32, 39, 41, 44], and in the remaining eight studies [14, 28–31, 33, 37, 42], there was no significant difference in the REE relative to the FFM between the two periods studied, despite the reduction in the REE in absolute terms. Based on the studies, after the 6-month postoperative period, the mean REE/FFM ratio ranged from 24.2 kcal/kg of FFM in patients who underwent adjustable gastric banding [37] to 37.3 kcal/kg of FFM in those who underwent RYGB [30]. In the 12th postoperative month, of the 10 studies evaluated, six presented a decrease in the REE/FFM ratio in relation to the baseline [34–36, 39, 40, 43]. Twelve months after the RYGB procedure, the mean REE/FFM ratio ranged from 23.9 kcal/kg of FFM in patients who underwent sleeve gastrectomy [40] to 32.7 kcal/kg of FFM in those who underwent RYGB [33]. No study showed an increase in the REE/FFM ratio 6 and 12 months after bariatric surgery.

Table 1 Summary of study characteristics and main results of included studies ($n = 19$)

Follow-up time	Author, Year, Country	Aim of study	Sample size (number female)	Age (years; mean ± SD)	Body composition method	Type of surgery	Pre-REE (kcal) REE/FFM (kcal/kg)	Post-REE (kcal) REE/FFM (kcal/kg)	p value	Changes in REE/FFM over time
6 months	Algahin et al. 2010, USA [41]	To evaluate changes in BMI, waist circumference and hip circumference, fat mass, lean mass, and REE, and compare these changes with changes in left ventricular mass	13 (all female)	49.1 ± 2.1	BIA	RYGB = 9 AGB = 4	2068 ± 342 34.6 ± 4.7	1501 ± 206 28.8 ± 4.9	<0.001 0.001	Decreased
	Busetto et al. 1995, Italy [37]	To evaluate the relationship between visceral fat accumulation and REE in obese women and the effects of severe weight loss on energy expenditure and fat distribution	12 (all female)	35.8 ± 8.1	BIA	AGB	1903 ± 423 26.8 ± 7.2	1570 ± 165 24.2 ± 3.3	<0.01 0.668	Maintained
	Carey et al. 2006, USA [42]	To investigate changes in REE and BC after bariatric surgery and evaluate its association with BC	19 (female = 14)	40.5 ± 10.2	HW	RYGB = 18 AGB = 1	2091 ± 588 28.3	1651 ± 460 27.2	<0.05 NA	Maintained
	Carrasco et al. 2007, Chile [32]	To assess the changes in REE, BC, and other metabolic data and identify predictors of these changes in severely obese patients after bariatric surgery	31 (female = 27)	37.3 ± 11.1	DLW	RYGB	1845 ± 302 33.4 ± 4.1	1449 ± 215 30.1 ± 2.6	<0.001 <0.05	Decreased
	Carrasco et al. 2008, Chile [33]	To analyze metabolic changes and their association with BC in morbidly obese women after bariatric surgery	23 (all female)	36.4 ± 9.8	DXA	RYGB	1923 ± 289 32.3 ± 3.9	1631 ± 256 34.2 ± 4.7	<0.001 NA	Maintained
	deCleva et al. 2018, Brazil [31]	To describe changes in BC, REE, and weight loss after bariatric surgery and evaluate association between variables	45 (female = 33)	38.9 ± 9.4	BIA	RYGB	1779 ± 433 25.9 ± 4.0	1564 ± 277 29.4 ± 4.1	NA >0.05	Maintained
	Faria et al. 2012, Brazil [28]	To evaluate the clinical effects of RYGB on REE	16 (female = 15)	37.7 ± 9.1	BIA	RYGB	1745 ± 380 34.2 ± 5.6	1538 ± 319 33.8 ± 5.5	0.024 0.805	Maintained
	Galtier et al. 2006, France [15]	To evaluate the effect of expressive weight loss on REE and substrate oxidation and determine the metabolic predictive factors of weight loss after bariatric surgery	39 (all female)	39.1 ± 10.4	BIA	AGB	2007 ± 294 30.8 ± 3.1	1695 ± 259 29.4 ± 3.3	<0.001 0.001	Decreased
	Golzarand et al. 2018, Iran [44]	To compare the changes in BC, dietary intake, and substrate oxidation between LRYGB and LSG	43 (female = 42)	40.6 ± 6.8	BIA	RYGB = 22	2109 ± 268 39.0 ± 3.2	1662 ± 300 34.5 ± 4.6	<0.0001 0.002	Decreased
				40.3 ± 12.7		LSG = 21	1932 ± 238 37.2 ± 3.9	1454 ± 175 31.4 ± 4.2	<0.0001 <0.0001	
	Moehlecke et al. 2016, Brazil [29]	To investigate the effects of RYGB on REE and BC, and whether changes in REE affect weight loss after bariatric surgery	30 (female = 25)	43.0 ± 12.0	DXA	RYGB	2297 ± 182 34.2 ± 10.1	1892 ± 182 30.9 ± 6.4	<0.001 0.319	Maintained
	Oliveira et al. 2016, Brazil [30]	To describe the influence of UCP1 and UCP3 expression on substrate oxidation in bariatric patients and evaluate changes in BC in bariatric patients	13 (all female)	32.7 ± 9.1	BIA	RYGB	2094 ± 275 38.3 ± 4.1	1863 ± 210 37.3 ± 3.2	0.01 0.36	Maintained
			21 (NA)		DXA	RYGB = 14	2096 ± 298	1777 ± 270	<0.01	Maintained

Table 1 (continued)

Follow-up time	Author, Year, Country	Aim of study	Sample size (number female)	Age (years; mean ± SD)	Body composition method	Type of surgery	Pre-REE (kcal) REE/FFM (kcal/kg)	Post-REE (kcal) REE/FFM (kcal/kg)	*p* value	Changes in REE/FFM over time
	Rabl et al. 2014, USA [14]	To investigate associations between changes in REE, weight loss, and type of surgery		RYGB 47.4 ± 8-.7			30.9 ± 2.6	32.1 ± 4.0	0.25	
				AGB 49.0 ± 1-0.7		AGB = 7	1840 ± 202 31.3 ± 4.8	1684 ± 278 31.3 ± 3.7	0.05 0.95	
	Tacchino et al. 2003, Italy [39]	To identify associations between FFM and BF over a wide range of weight loss after bariatric surgery	101 (all female)	41.0 ± 8.0	DXA	BPD	2206 ± 18 37.9 ± 6.7	1647 ± 61 33.3 ± 4.9	<0.05 <0.05	Decreased
12 months	Adami et al. 1996, Italy [38]	To determine BC and REE in patients after BPD	69 (female = 50)	37.0	BIA	BPD	1715 ± 997 26.4 ± 10.8	1584 ± 307 28.9 ± 0.5	0.31 >0.05	Maintained
	Bettine et al. 2018, Italy [40]	To investigate changes in REE and the metabolic adaptation occurring after surgery	154 (female = 98)	45.1 ± 11.6	BIA	LSG	1980 ± 483 28.6 ± 4.7	1410 ± 312 23.9 ± 4.3	<0.001 <0.001	Decreased
	Carey et al. 2006, USA [42]	To investigate changes in REE and BC after bariatric surgery and evaluate their association with BC	17 (female = 14)	40.5 ± 10.2	HW	RYGB = 16 AGB = 1	2091 ± 588 28.3	1674 ± 342 27.4	<0.05 NA	Maintained
	Carrasco et al. 2008, Chile [33]	To analyze metabolic changes and their association with BC in morbidly obese women after bariatric surgery	23 (all female)	36.4 ± 9.8	DXA	RYGB	1923 ± 289 32.3 ± 3.9	1569 ± 221 32.7 ± 5.1	<0.001 NA	Maintained
	Coupaye et al. 2005, France [35]	To describe changes in REE and serum leptin adjusted for BC after bariatric surgery	36 (all female)	42.7 ± 8.7	DXA	AGB	2006 ± 362 36.3 ± 4.9	1707 ± 285 32.3 ± 4.5	<0.0001 <0.001	Decreased
	Faria et al. 2012, Brazil [28]	To evaluate the clinical effects of RYGB on REE	13 (all female)	40.6 ± 12.1	BIA	RYGB	1659 ± 355 31.3 ± 4.8	1431 ± 263 31.2 ± 3.0	0.016 0.900	Maintained
	Sans et al. 2017, France [36]	To analyze the association between preoperative factors and weight loss after bariatric surgery and to identify the postoperative factors associated with insufficient weight loss	103 (all female)	40.6 ± 11.2	BIA	RYGB	1746 ± 370 31.3 ± 6.2	1346 ± 224 28.7 ± 4.3	<0.0001 <0.0001	Decreased
	Simonen et al. 2012, Finland [34]	To assess the effect of RYGB on serum bile acid levels and their relation to clinical outcomes	30 (female = 27)	45.2 ± 7.9	BIA	RYGB	NA 32.1 ± 3.6	NA 29.7 ± 3.1	NA 0.001	Decreased
	Tacchino et al. 2003, Italy [39]	To identify associations between FFM and BF over a wide range of weight loss after bariatric surgery	101 (all female)	41.0 ± 8.0	DXA	BPD	2206 ± 18 37.9 ± 6.7	1623 ± 72 NA	<0.05 <0.05	Decreased
	Wilms et al. 2017, Switzerland [43]	To identify changes in REE after RYGB and how REE could predict weight loss	167 (NA)	40.3 ± 11.1	BIA	RYGB	2129 ± 420 31.9 ± 4.5	1691 ± 290 29.6 ± 3.8	<0.001 <0.001	Decreased

NA not available, *BC* body composition, *Pre* preoperative, *FM* fat mass, *Post* postoperative, *BF* body fat, *FFM* fat-free mass, *REE* resting energy expenditure, *BPD* biliopancreatic diversion, *AGB* adjustable gastric banding, *LSG* laparoscopic sleeve gastrectomy, *RYGB* Roux-en-Y gastric bypass, *BIA* bioelectrical impedance, *HW* hydrostatic weighing, *DLW* doubly labeled water, *DXA* dual-energy X-ray absorptiometry

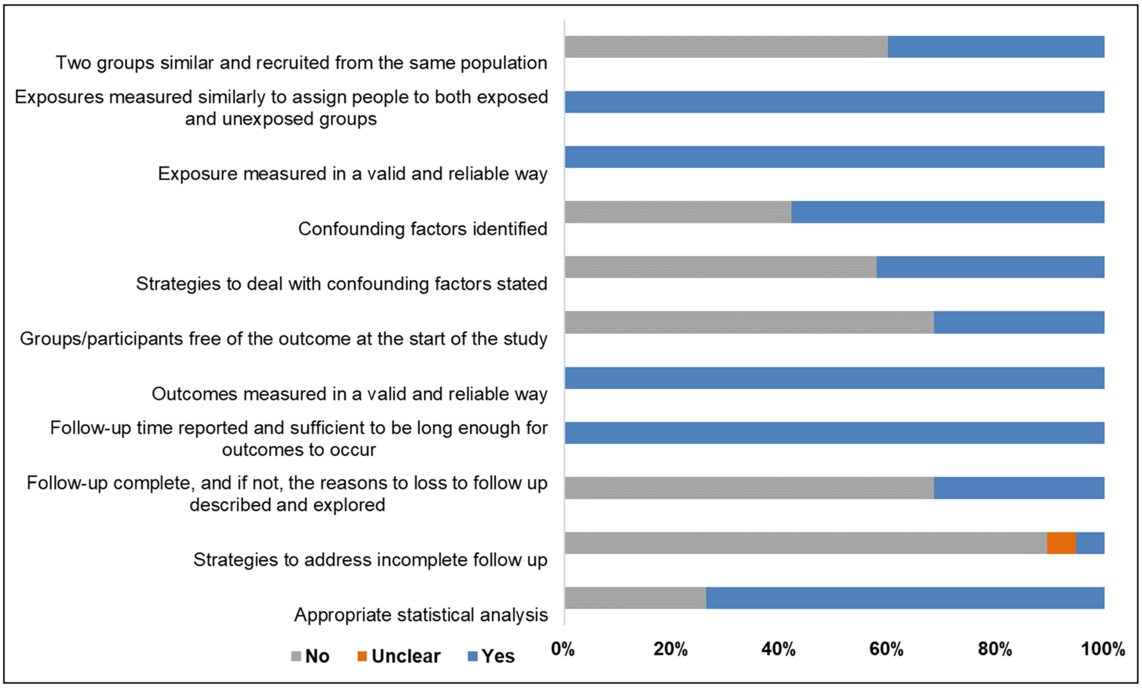


Fig. 2 Risk of bias in the included studies according The Joanna Briggs Institute Critical Appraisal Checklist for Cohort Studies [25]

Synthesis of Results

Considering only the studies wherein RYGB was performed as a bariatric procedure, Fig. 3 shows the changes in the REE/FFM ratio over the 6- and 12-month postoperative periods. In the 6-month postoperative period (Fig. 3a), this difference was not statistically significant (total sample = 203; mean reduction = −1.18; CI: −3.48 to 1.11; I^2 = 86%; $p = 0.31$). However, in the 12-month postoperative period, we found a reduction of 1.95 kcal/kg in FFM (total sample = 336; CI: −2.82 to −1.09; I^2 = 28%; $p < 0.00001$) in comparison to the baseline (Fig. 3b).

A subgroup analysis of those with similar characteristics in terms of low risk of bias and rigorous methods of body composition assessment (DLW and DXA) was performed for the 6-month postoperative period because of the high heterogeneity observed. No significant reduction in heterogeneity measures was found (Fig. 4).

Discussion

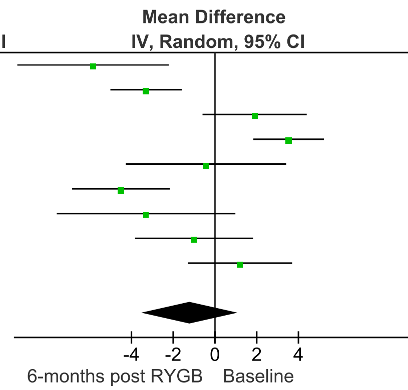
To our knowledge, this is the first systematized review with a meta-analysis that examines the effects of bariatric surgery on the REE/FFM ratio during the first year after surgery. The reduction in REE in relation to FFM occurred during the period when the highest rate of weight loss was achieved, which may influence the long-term outcomes of surgery. This fact suggests that these findings need to be carefully assessed.

All surgical techniques promote weight loss mainly during the first postoperative year, with RYGB and sleeve gastrectomy showing superior results [45, 46]. However, there is a lack of scientific evidence on changes in energy expenditure in relation to body composition in patients who undergo bariatric surgery. For instance, it is unclear whether weight loss is reinforced or prevented through effects on energy expenditure adaptation. Among the included studies, only those of Galtier et al. [15] and Carrasco et al. (2007) [32] investigated the REE/FFM ratio and magnitude of postoperative weight loss, reporting the lack of association between these two variables. On the other hand, some studies show that the greater the weight loss, the greater the reduction in the relative REE, which is strongly associated with FFM loss. This is particularly due to a decrease in the metabolic activity of organs with a high metabolic rate, including the heart, liver, kidneys, and brain [47, 48]. Remarkably, the muscle and skeletal bone are categorized as organs having a low metabolic rate [49], and possibly, after weight loss, the decrease in REE is less explained by the relative loss of these parts [19]. In a few studies, other methods of weight loss besides bariatric surgery were found to result in a reduction in the REE/FFM ratio, but only for a short period of exposure to caloric restriction, which compromises the comparison between studies [50, 51]. However, it is possible that the

a

Study or Subgroup	6-months post RYGB Mean	SD	Total	Baseline Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Algahin et al 2010	27.57	4.83	9	33.41	2.74	9	10.0%	-5.84 [-9.47, -2.21]
Carrasco et al 2007	30.1	2.6	31	33.4	4.1	31	12.5%	-3.30 [-5.01, -1.59]
Carrasco et al 2008	34.2	4.7	23	32.3	3.9	23	11.6%	1.90 [-0.60, 4.40]
de Cleva et al 2018	29.44	4.14	45	25.91	4.04	45	12.5%	3.53 [1.84, 5.22]
Faria et al 2012	33.8	5.51	16	34.23	5.58	16	9.8%	-0.43 [-4.27, 3.41]
Golzarand et al 2018	34.5	4.6	22	39	3.2	22	11.8%	-4.50 [-6.84, -2.16]
Moehlecke et al 2016	30.9	6.4	30	34.2	10.1	30	9.2%	-3.30 [-7.58, 0.98]
Oliveira et al 2016	37.3	3.2	13	38.3	4.1	13	11.1%	-1.00 [-3.83, 1.83]
Rabl et al 2014	32.1	4	14	30.9	2.6	14	11.6%	1.20 [-1.30, 3.70]
Total (95% CI)			**203**			**203**	**100.0%**	**-1.18 [-3.48, 1.11]**

Heterogeneity: Tau² = 10.25; Chi² = 58.64, df = 8 (P < 0.00001); I² = 86%
Test for overall effect: Z = 1.01 (P = 0.31)



b

Study or Subgroup	12 -months post RYGB Mean	SD	Total	Baseline Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Carrasco et al 2008	32.7	5.1	23	32.3	3.9	23	9.4%	0.40 [-2.22, 3.02]
Faria et al 2012	31.15	3	13	31.33	4.76	13	7.2%	-0.18 [-3.24, 2.88]
Sans et al 2017	28.74	4.33	103	31.25	6.15	103	23.7%	-2.51 [-3.96, -1.06]
Simonen et al 2012	29.7	3.1	30	32.1	3.6	30	19.0%	-2.40 [-4.10, -0.70]
Wilms et al 2017	29.57	3.75	167	31.85	4.47	167	40.7%	-2.28 [-3.16, -1.40]
Total (95% CI)			**336**			**336**	**100.0%**	**-1.95 [-2.82, -1.09]**

Heterogeneity: Tau² = 0.28; Chi² = 5.58, df = 4 (P = 0.23); I² = 28%
Test for overall effect: Z = 4.42 (P < 0.00001)

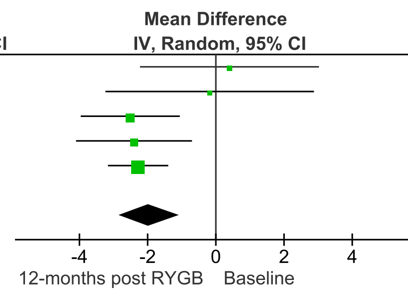


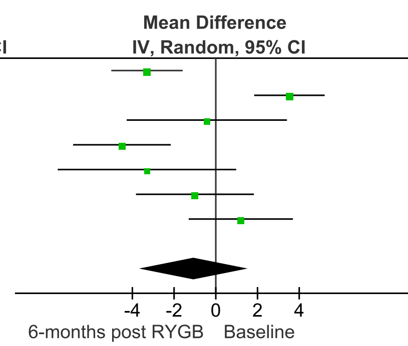
Fig. 3 Forest plot of changes in REE/FFM over (a) 6 months and (b) 12 months post-surgery by RYGB

reduction in the metabolic rate is a consequence of the reduction in the quantity of FFM and not necessarily its activity, since weight loss is accompanied by diminished FFM, and metabolic activity was not evaluated in studies included in this review. In addition, the REE is influenced by the FM reduction in patients with massive weight loss [52], although the magnitude of the relation between the REE and FM remains unclear.

a

Study or Subgroup	6-months post RYGB Mean	SD	Total	Baseline Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Carrasco et al 2007	30.1	2.6	31	33.4	4.1	31	15.9%	-3.30 [-5.01, -1.59]
de Cleva et al 2018	29.44	4.14	45	25.91	4.04	45	15.9%	3.53 [1.84, 5.22]
Faria et al 2012	33.8	5.51	16	34.23	5.58	16	12.4%	-0.43 [-4.27, 3.41]
Golzarand et al 2018	34.5	4.6	22	39	3.2	22	15.0%	-4.50 [-6.84, -2.16]
Moehlecke et al 2016	30.9	6.4	30	34.2	10.1	30	11.7%	-3.30 [-7.58, 0.98]
Oliveira et al 2016	37.3	3.2	13	38.3	4.1	13	14.2%	-1.00 [-3.83, 1.83]
Rabl et al 2014	32.1	4	14	30.9	2.6	14	14.8%	1.20 [-1.30, 3.70]
Total (95% CI)			**171**			**171**	**100.0%**	**-1.04 [-3.64, 1.56]**

Heterogeneity: Tau² = 10.29; Chi² = 46.77, df = 6 (P < 0.00001); I² = 87%
Test for overall effect: Z = 0.79 (P = 0.43)



b

Study or Subgroup	6-months post RYGB Mean	SD	Total	Baseline Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Carrasco et al 2007	30.1	2.6	31	33.4	4.1	31	28.8%	-3.30 [-5.01, -1.59]
Carrasco et al 2008	34.2	4.7	23	32.3	3.9	23	26.0%	1.90 [-0.60, 4.40]
Moehlecke et al 2016	30.9	6.4	30	34.2	10.1	30	19.2%	-3.30 [-7.58, 0.98]
Rabl et al 2014	32.1	4	14	30.9	2.6	14	26.0%	1.20 [-1.30, 3.70]
Total (95% CI)			**98**			**98**	**100.0%**	**-0.78 [-3.74, 2.19]**

Heterogeneity: Tau² = 7.17; Chi² = 16.18, df = 3 (P = 0.001); I² = 81%
Test for overall effect: Z = 0.51 (P = 0.61)

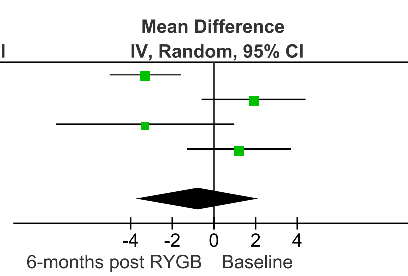


Fig. 4 Subgroup analysis of changes in REE/FFM over 6 months post-surgery by RYGB from (a) low risk of bias studies and (b) studies that applied DLW or DXA for body composition assessment

It is well established that multiple factors can contribute to the reduction in FFM including age, sedentary lifestyle, and reduced protein consumption [53, 54]. In the case of both young and old non-obese individuals, age-related decreases in REE are partially explained by decreases in FFM [55]. In our study, this factor was not assessed since all study sample populations were composed of adults with a small age range.

Engagement in physical exercise, through a combination of aerobic training and resistance, during the postoperative period after bariatric surgery was proven to be a fundamental factor not only in modifying a sedentary lifestyle, but also in achieving greater weight loss and maintaining better physical function [56]. Further studies, particularly randomized clinical trials, are necessary to assess whether programmed exercise during the period of greater post-bariatric weight loss attenuates the reduction in the REE/FFM ratio.

Of the included studies, only three evaluated dietary intake. As expected, Carrasco et al. (2007) [32], Carrasco et al. (2008) [33], and Golzarand et al. [44] demonstrated a significant reduction in energy and macronutrient intake 6 months postoperatively. Nevertheless, at 12 months postoperatively, Carrasco et al. (2008) [33] observed that such changes did not continue independently for lipid intake, and no correlation was found between energy or protein intake and REE. Studies that investigated the association between protein intake and FFM after bariatric surgery suggested that a protein intake of 60 g/day or more was positively associated with better lean mass preservation [57–59]. It is likely that, concomitant with the reduction in the REE/FFM ratio, protein intake was insufficient during the first postoperative year, although this factor was not evaluated in this study. One of the possible factors affecting protein consumption among patients who undergo bariatric surgery is the restriction of the global food intake imposed by surgery, especially the reduction in protein-rich foods such as dairy products, fish, and red meat [9, 60].

Strengths and Limitations

To our knowledge, this is the first systematic review with meta-analysis that organized data related to bariatric surgery and analyzed its effects on REE normalized by FFM during the first year after surgery. A systematic review protocol was carefully applied using current recommendations for the study method.

The limitations of this study are related to the heterogeneity found in studies with a 6-month postoperative follow-up period. It was not possible to apply the meta-regression method due to the small number of studies included in the meta-analysis. The fact that all the studies have an observational design limits the assessment of causality, and the different methods of body composition assessment undermine the interpretation of results in this review. Moreover, possibly due to cost constraints, many studies employ less accurate methods for body composition assessment, which may also compromise the interpretation of our results. Similarly, the use of different surgical techniques may confound the results with regard to the changes in energy expenditure during the postoperative period, since they can generate different results in terms of weight loss and body composition.

Conclusion

Qualitative synthesis data are consistent for absolute REE reduction regardless of the postoperative period studied and the type of surgery. For the majority of the studies, there was a reduction in the REE/FFM ratio mainly 12 months postoperatively for the different types of surgery. The meta-analysis performed with RYGB data showed that there was no change in the REE/FFM ratio 6 months after the procedure. However, during the 12-month postoperative period, there was a significant reduction in this parameter. These findings suggest the need for specific recommendations for management of these patients during the first year after surgery, and we speculate that protein supplementation and resistance exercise could be beneficial for patients.

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Author Contributions Fernando Lamarca, Eliane Said Dutra and Kênia Mara Baiocchi de Carvalho wrote the protocol and designed the study. Fernando Lamarca and Mariana Silva Melendez Araújo conducted literature searches, study selection, data collection, data analysis, and manuscript preparation. Isabela Porto de Toledo contributed to literature searches, data analysis, and figure and table conception. All authors reviewed the manuscript and approved the version to be submitted.

Compliance with Ethical Standards

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

Ethical Statement This article does not contain any studies with human participants or animals performed by any of the authors.

Informed Consent Statement Not applicable to this type of study.

Appendix

Table 2 Search strategy and date search was performed in the chosen databases

Database	Search (November 12, 2018)
Medline	**#1** obesity[MeSH Terms] OR morbid obesity[MeSH Terms] OR "obesity" OR "morbid obesity" OR "severe obesity" OR overweight OR "weight loss" OR obese **#2** bariatric surgery[MeSH Terms] OR gastroplasty[MeSH Terms] OR "Metabolic Surgeries" OR "Bariatric Surgeries" OR "Stomach Stapling" OR "Bariatric Surgical Procedure" OR bariatric OR "bariatric surgery" OR "Metabolic Surgery" OR gastroplasty OR "gastric bypass" OR "sleeve gastrectomy" OR "obesity surgery" OR "obesity surgeries" OR "surgery for obesity" OR "gastric banding" OR "gastric band" OR "vertical banded gastroplasty" OR "banded gastroplasty" OR "Roux in Y" OR "Roux in Y gastric bypass" OR "RYGB" **#3** energy metabolism[MeSH Terms] OR "Energy Expenditure" OR "resting energy expenditure" OR "energy metabolism" OR "Energy Expenditures" OR "basal metabolic rate" OR "resting metabolic rate" OR calorimetry OR "indirect calorimetry" OR "resting metabolism" OR "basal metabolism" #4: #1 AND #2 AND #3
Embase	obesity:ab,ti OR 'morbid obesity':ab,ti OR 'severe obesity':ab,ti OR overweight:ab,ti OR 'weight loss':ab,ti OR obese:ab,ti AND ('metabolic surgeries':ab,ti OR 'bariatric surgeries':ab,ti OR 'stomach stapling':ab,ti OR 'bariatric surgical procedure':ab,ti OR bariatric:ab,ti OR 'bariatric surgery':ab,ti OR 'metabolic surgery':ab,ti OR gastroplasty:ab,ti OR 'gastric bypass':ab,ti OR 'sleeve gastrectomy':ab,ti OR 'obesity surgery':ab,ti OR 'obesity surgeries':ab,ti OR 'surgery for obesity':ab,ti OR 'gastric banding':ab,ti OR 'gastric band':ab,ti OR 'vertical banded gastroplasty':ab,ti OR 'banded gastroplasty':ab,ti OR 'roux in y':ab,ti OR 'roux in y gastric bypass':ab,ti OR 'rygb':ab,ti) AND ('energy expenditure':ab,ti OR 'resting energy expenditure':ab,ti OR 'energy metabolism':ab,ti OR 'basal metabolic rate':ab,ti OR 'resting metabolic rate':ab,ti OR calorimetry:ab,ti OR 'indirect calorimetry':ab,ti OR 'resting metabolism':ab,ti OR 'basal metabolism':ab,ti) AND ([article]/lim OR [article in press]/lim OR [short survey]/lim)
LILACS	(tw:("cirurgia bariátrica" OR "cirugía bariátrica" OR "derivação gástrica" OR "derivación gastrica")) AND (tw:(obesidade OR obesidad)) AND (tw:(metabolismo OR "gasto energético"))
Web of Science	#1 TS=(obesity OR "morbid obesity" OR "severe obesity" OR overweight OR "weight loss" OR obese) AND #2 TS=("Metabolic Surgeries" OR "Bariatric Surgeries" OR "Stomach Stapling" OR "Bariatric Surgical Procedure" OR bariatric OR "bariatric surgery" OR "Metabolic Surgery" OR gastroplasty OR "gastric bypass" OR "sleeve gastrectomy" OR "obesity surgery" OR "obesity surgeries" OR "surgery for obesity" OR "gastric banding" OR "gastric band" OR "vertical banded gastroplasty" OR "banded gastroplasty" OR "Roux in Y" OR "Roux in Y gastric bypass" OR "RYGB") AND #3 TS=("Energy Expenditure" OR "resting energy expenditure" OR "energy metabolism" OR "basal metabolic rate" OR "resting metabolic rate" OR calorimetry OR "indirect calorimetry" OR "resting metabolism" OR "basal metabolism")
Scopus	TITLE-ABS-KEY (obesity OR "morbid obesity" OR "severe obesity" OR overweight OR "weight loss" OR obese) AND TITLE-ABS-KEY ("Metabolic Surgeries" OR "Bariatric Surgeries" OR "Stomach Stapling" OR "Bariatric Surgical Procedure" OR bariatric OR "bariatric surgery" OR "Metabolic Surgery" OR gastroplasty OR "gastric bypass" OR "sleeve gastrectomy" OR "obesity surgery" OR "obesity surgeries" OR "surgery for obesity" OR "gastric banding" OR "gastric band" OR "vertical banded gastroplasty" OR "banded gastroplasty" OR "Roux in Y" OR "Roux in Y gastric bypass" OR "RYGB") AND TITLE-ABS-KEY ("Energy Expenditure" OR "resting energy expenditure" OR "energy metabolism" OR "basal metabolic rate" OR "resting metabolic rate" OR calorimetry OR "indirect calorimetry" OR "resting metabolism" OR "basal metabolism") AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "sh") OR LIMIT-TO (DOCTYPE , "ip"))
LIVIVO	TI=(obesity OR "morbid obesity" OR "severe obesity" OR overweight OR "weight loss" OR obese) AND TI= ("Metabolic Surgeries" OR "Bariatric Surgeries" OR "Stomach Stapling" OR "Bariatric Surgical Procedure" OR bariatric OR "bariatric surgery" OR "Metabolic Surgery" OR gastroplasty OR "gastric bypass" OR "sleeve gastrectomy" OR "obesity surgery" OR "obesity surgeries" OR "surgery for obesity" OR "gastric banding" OR "gastric band" OR "vertical banded gastroplasty" OR "banded gastroplasty" OR "Roux in Y" OR "Roux in Y gastric bypass" OR “RYGB”) AND TI=("Energy Expenditure" OR "resting energy expenditure" OR "energy metabolism" OR "basal metabolic rate" OR "resting metabolic rate" OR calorimetry OR "indirect calorimetry" OR "resting metabolism" OR "basal metabolism")
Google Scholar	"Bariatric surgery" OR "gastric bypass" AND obesity OR "morbid obesity" AND "energy expenditure" OR metabolism
ProQuest	TI,AB(obesity OR "morbid obesity" OR "severe obesity" OR overweight OR "weight loss" OR obese) AND TI,AB("Metabolic Surgeries" OR "Bariatric Surgeries" OR "Stomach Stapling" OR "Bariatric Surgical Procedure" OR bariatric OR "bariatric surgery" OR "Metabolic Surgery" OR gastroplasty OR "gastric bypass" OR "sleeve gastrectomy" OR "obesity surgery" OR "obesity surgeries" OR "surgery for obesity" OR "gastric banding" OR "gastric band" OR "vertical banded gastroplasty" OR "banded gastroplasty" OR "Roux in Y" OR "Roux in Y gastric bypass" OR “RYGB”) AND TI,AB("Energy Expenditure" OR "resting energy expenditure" OR "energy metabolism" OR "basal metabolic rate" OR "resting metabolic rate" OR calorimetry OR "indirect calorimetry" OR "resting metabolism" OR "basal metabolism")

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