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REVIEW: Long-Term Impact of Bariatric Surgery on Body Weight, Comorbidities, and Nutritional Status

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Context: The number of patients who undergo Roux-en-Y gastric bypass (RYGB) and gastric banding (GB) surgeries has increased dramatically over the past decade, yet the long-term impact of these surgeries on body weight, comorbidities, and nutritional status remains unclear, as do the mechanisms of weight regain.

Evidence Acquisition: The articles were found via PubMed searches. To review the impact of bariatric surgery on weight maintenance and comorbidities, only articles with a postoperative follow-up of 3 yr or longer were included. The articles on nutritional status had a follow-up of 12 months or longer.

Conclusions: RYGB and GB surgeries lead to substantial weight loss in individuals with morbid obesity. However, significant weight regain occurs over the long term, and according to the only well-designed prospective controlled study, the improvement in comorbidities associated with weight loss mitigates in the long term on weight regain. There is some evidence from a retrospective study that RYGB surgery is associated with a modest decrease in long-term mortality. These results remain to be substantiated by well-designed, long-term, randomized and prospective controlled studies. The mechanisms that lead to weight regain need to be further examined and may include increase in energy intake due to enlargement of stoma and adaptive changes in the levels of gut and adipocyte hormones such as ghrelin and leptin, which regulate energy intake; decrease in physical activity; changes in energy expenditure; and other factors. In addition to weight regain, RYGB surgery is associated with frequent incidence of iron, vitamin B12, folate, calcium, and vitamin D deficiency, which requires regular supplementation and monitoring. ***(J Clin Endocrinol Metab* 91: 4223–4231, 2006)**

ACCORDING TO THE National Health and Nutrition Examination Survey conducted in 2003–2004, a staggering proportion (66.3%) of the U.S. adults are overweight or obese [body mass index (BMI) $\geq$ 25 kg/m^2], 32.2% are obese (BMI $\geq$ 30 kg/m^2), and 4.8% are morbidly or severely obese (BMI $\geq$ 40 kg/m^2) (1). In addition, according to another survey, the Behavioral Risk Factor Surveillance System, conducted from 1986 to 2000, the prevalence of severe obesity has increased twice as fast as the prevalence of obesity (2).

Obesity is associated with a number of comorbidities including type 2 diabetes, coronary heart disease, hyperlipidemia, hypertension, sleep apnea, pulmonary dysfunction, ischemic stroke, knee osteoarthritis, gallbladder disease, nonalcoholic steatohepatitis, and certain types of cancer (3, 4). In addition, obesity, specifically severe obesity, markedly lessens life expectancy, especially among younger adults (5).

Diet, exercise, and medical therapy have not been shown to be effective in treating severe obesity in the long term (6, 7). This and the steep rise in prevalence of severe obesity and the introduction of laparoscopic procedures may explain the exponential increase in the number of bariatric surgeries from 13,365 in 1998 to 72,177 in 2002 (8). The various types of bariatric procedures include Roux-en-Y gastric bypass (RYGB), gastric banding (GB), vertical banded gastroplasty (VBG), duodenal switch, biliopancreatic diversion, isolated intestinal bypass, and gastrectomy. Of these, RYGB and GB surgeries are the most commonly performed (9) and will be the focus of this review.

According to a recent metaanalysis on bariatric surgery outcomes (10), the patients who undergo RYGB and GB surgeries lose 61.6 and 47.5% of their excess body weight (actual body weight − expected body weight based on height and gender) respectively, and a majority of patients with diabetes, hyperlipidemia, hypertension, and obstructive sleep apnea experience complete resolution or improvement of these comorbidities. However, most of the studies included in the metaanalysis were uncontrolled case series, and patients were followed up for no more than 2 yr. Emerging data, however, suggest some gradual weight regain and return of comorbidities during the long term (11). Therefore, we review the literature on the impact of RYGB and GB surgeries on long-term maintenance of weight loss and improvement in comorbidities and the factors that may lead to weight regain in these patients. We also review the effect of these surgeries on nutritional status and intolerance.

The articles in this review were found via PubMed search engines. Only studies with a postoperative follow-up period of at least 3 yr and in which the patients had achieved their maximum weight loss were considered in the review of the impact of bariatric surgery on weight maintenance and improvement in comorbidities. To assess the impact of bariatric surgery on nutritional status, only studies that followed up patients for at least 12 months postoperatively were included. Because of limited research, we did not apply any entrance criteria on the articles on mechanisms of weight regain in bariatric surgery patients.

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Abbreviations: BMI, Body mass index; GB, gastric banding; GLP, glucagon-like-peptide; HDL, high-density lipoprotein; PYY, peptide YY; RYGB, Roux-en-Y gastric bypass; VBG, vertical banded gastroplasty.

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TABLE 1. Long-term effect of bariatric surgery on weight loss maintenance, comorbidities, and major end points

Study	Study design	Sample size	Weight loss maintenance		Comorbidities and major end points	
			Excess weight loss (%)	Weight change (%)	Patients	Controls
Balsiger *et al.* (15)	Case series	39 RYGB patients	2 yr: 72 4 yr: 63	2 yr: −38 4 yr: −35	–	–
Christou *et al.* (21)	Observational 2-cohort	841 RYGB and 194 VBG patients	2 yr: 78 10 yr: 65 16 yr: 60	– – –	*Relative risk over 5 yr* Mortality: 0.11 CV & circ: 0.18 Endocrinol: 0.35 Cancer: 0.24	 1.0 1.0 1.0 1.0
		5,746 matching controls	–	–		
Flum and Dellinger (23)	Retrospective controlled	3,328 RYGB	–	–	*Mortality over 15 yr* 11.8%	 16.3%
		62,781 matching controls	–	–		
MacDonald *et al.* (22)	Retrospective controlled	154 RYGB patients	1 yr: 62 14 yr: 50	– –	Mortality over 9 yr 9%	Mortality over 6 yr 28%
		78 controls	–	–	*Medication use for DM (baseline to last observation)* 32 to 9%	 56 to 88%
Martikainen *et al.* (17)	Case series	120 GB patients	1 yr: 36 9 yr: 21	–	–	–
O'Brien *et al.* (20)	Case series	709 GB patients	2 yr: 53 6 yr: 57	– –	–	–
Pories *et al.* (19)	Case series	608 RYGB patients	2 yr: 70 10 yr: 55 14 yr: 49	– – –	*Recovery of DM in 83% of patients with adequate follow-up*	
Sjostrom *et al.* (11)	Prospective-controlled	34 RYGB patients	– –	1 yr: −38 10 yr: −25	*Recovery at 2 and 10 yr, respectively* HTG: 62, 46% Low HDLC: 76, 73%	 22, 24% 39, 53%
		156 GB patients	– –	1 yr: −21 10 yr: −13	DM: 72, 36% HTN: 34, 19% HUA: 71, 48%	21, 13% 21, 11% 31, 27%
		627 matching controls	– –	1 yr: +0.1 10 yr: +1.6		
Sugerman *et al.* (12)	Case series	1,025 RYGB patients	1 yr: 66 5–7 yr: 59 10–12 yr: 52	1 yr: −35 5–7 yr: −31 10–12 yr: −28	*Recovery at 1, 5–7, and 10–12 yr, respectively* HTN: 69, 66, 51% DM: 83, 86%, –	
van de Weijgert *et al.* (14)	Case series	100 RYGB patients	1 yr: 78 7 yr: 67	–	–	–
Waters *et al.* (13)	Case series	157 RYGB patients	–	1 yr: −36 3 yr: −30	–	–
Wittgrove and Clark (18)	Case series	500 RYGB patients	1 yr: 77 5 yr: ~80	–	–	–
Yale (16)	Case series	251 RYGB patients	2 yr: 69 5 yr: 60	2 yr: −36 5 yr: −31	–	–

DM, Type 2 diabetes mellitus; HTN, hypertension; HTG, hypertriglyceridemia; HDLC, HDL cholesterol; HUA, hyperuricemia; CV & circ, cardiovascular and circulatory conditions including hypertension; endocrinol, endocrinological conditions including type 2 diabetes; –, data not available.

Long-Term Effect of RYGB and GB Surgeries on Body Weight and Comorbidities

The majority of the studies were uncontrolled case series (12–20), two were prospective controlled studies (11, 21), and two were retrospective controlled studies (22, 23) (Table 1). The studies usually presented the data on weight loss as percent excess weight loss or percent weight change.

In the 10-yr, prospective, controlled study by Sjostrom *et* *al.* (11), percent weight loss decreased from 38% at yr 1 to 25% at yr 10 in RYGB patients and from 21 to 13%, respectively in GB patients (Fig. 1). Body weight increased slightly in the matched controls (Fig. 1). The rate of recovery from hypercholesterolemia was not different between the surgery (RYGB, GB, and VBG) and control groups at either 2 or 10 yr, whereas the rate of recovery from hypertriglyceridemia, low levels of high-density lipoprotein (HDL) cholesterol, type 2 diabetes, hypertension, and hyperuricemia was more frequent in the surgery groups than in the control group at both 2 and 10 yr. The rate of recovery from comorbidities in the surgery group was, however, much less impressive at 10 yr than 2 yr (Table 1), possibly due to the weight regain over time. The authors also reported a significantly better improvement from baseline in serum insulin, triglycerides, total cholesterol, and HDL cholesterol levels in the RYGB group than the GB group at 10 yr, probably because the RYGB patients had a higher percent weight loss than the GB group (10 yr: 25 *vs.* 13%, respectively).

In a two-cohort study by Christou *et al.* (21), percent excess weight loss decreased by about 25% from yr 2 to yr 16 (<20% follow-up) in patients who underwent RYGB or VBG surgeries. Weight change in the matched control group was not reported. The relative risk reduction in mortality in the bariatric surgery group was 89% during the 5-yr follow-up period. Compared with the controls, the bariatric surgery patients also had significantly lower relative risk for cancer, cardiovascular disease, hypertension, and type 2 diabetes during that period. The controls, other than being severely obese, were not closely matched to the patients by BMI.

Flum and Dellinger (23), in a retrospective cohort study from Washington, reported a modestly lower mortality rate in morbidly obese subjects who underwent RYGB surgery, compared with a nonoperated cohort of patients with morbid obesity at 15-yr follow-up. This study had a number of limitations. RYGB patients were significantly younger (43 *vs.* 47 yr, respectively) and more likely to be female (81 *vs.* 64%, respectively) than the controls. This may have partly accounted for the difference in mortality between the two groups. Factors such as race/ethnicity and degree of obesity, which affect mortality, were not reported. In addition, there was a substantial dropout rate in both the groups. Because this study was retrospective and the data were derived from the Hospital Abstract Reporting System and Vital Statistics databases, the information may be subject to errors. The authors also could not separate patients who underwent the open surgery *vs.* laparoscopy. The RYGB laparoscopic procedure is associated with lower incidence of incisional hernia than the open procedure (24).

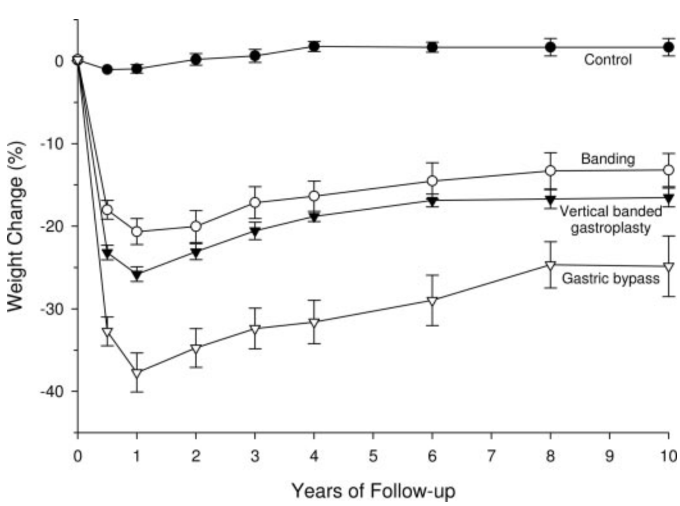

FIG. 1. Weight changes among subjects participating in the Swedish Obese Subjects study over a 10-yr period (11). There were 627 control subjects who did not undergo bariatric surgery, 156 who underwent banding, 451 who underwent vertical banded gastroplasty, and 34 who had gastric bypass.

In a retrospective cohort study, MacDonald *et al.* (22) compared morbidly obese type 2 diabetic patients who underwent RYGB surgery with type 2 diabetic controls who did not undergo surgery. The two groups were matched for age, weight, sex, BMI, and prevalence of hypertension. Percent excess weight loss was 62.4% at yr 1 and 50% at yr 14 in the surgery patients. Body weight of the matched patients with diabetes was not reported. The percent of diabetics requiring oral hypoglycemics or insulin decreased in the surgery group and increased in the control group. Mortality rate was lower in the surgery group than in the control group. The limitations of the study include a higher proportion of whites (76.6 *vs.* 50%, respectively) and a lower proportion of hypoglycemic medication use in patients undergoing surgery than in the controls (32 *vs.* 56%, respectively), which could have affected the results, retrospective cohort design, and limited sample size. In addition, information on the proportion of subjects who provided follow-up data were not provided.

Sugerman *et al.* (12) examined the database of patients who underwent RYGB surgery and reported a decrease in percent excess body weight loss from 66% at 1 yr (91% follow-up) to 52% at 10–12 yr (37% follow-up). Resolution of hypertension fell over that time, but resolution of diabetes was unchanged, although the value at yr 10–12 was not provided. These results are, however, difficult to interpret because of substantially different sample size at each follow-up and lack of a control group. Other uncontrolled case series studies (13–17, 19) have also reported a decrease in percent excess weight loss or percent weight loss over time after bariatric surgery but provided limited or no long-term data on comorbidities or major endpoints.

Two uncontrolled case series, on the other hand, reported successful long-term weight loss maintenance in RYGB (18) and GB (20) patients over 60 and 72 months, respectively. The validity of the results from these studies, however, may be questioned because the sample sizes decreased by more than 95% by the end of the studies.

In conclusion, RYGB and GB surgeries lead to substantial weight loss, but weight regain over the long term is not insignificant. According to the only well-designed, prospective, controlled study, the improvement in comorbidities seen initially mitigates in the long term possibly because of weight regain. There is also some evidence from a long-term retrospective study that RYGB surgery is associated with a modest reduction in mortality.

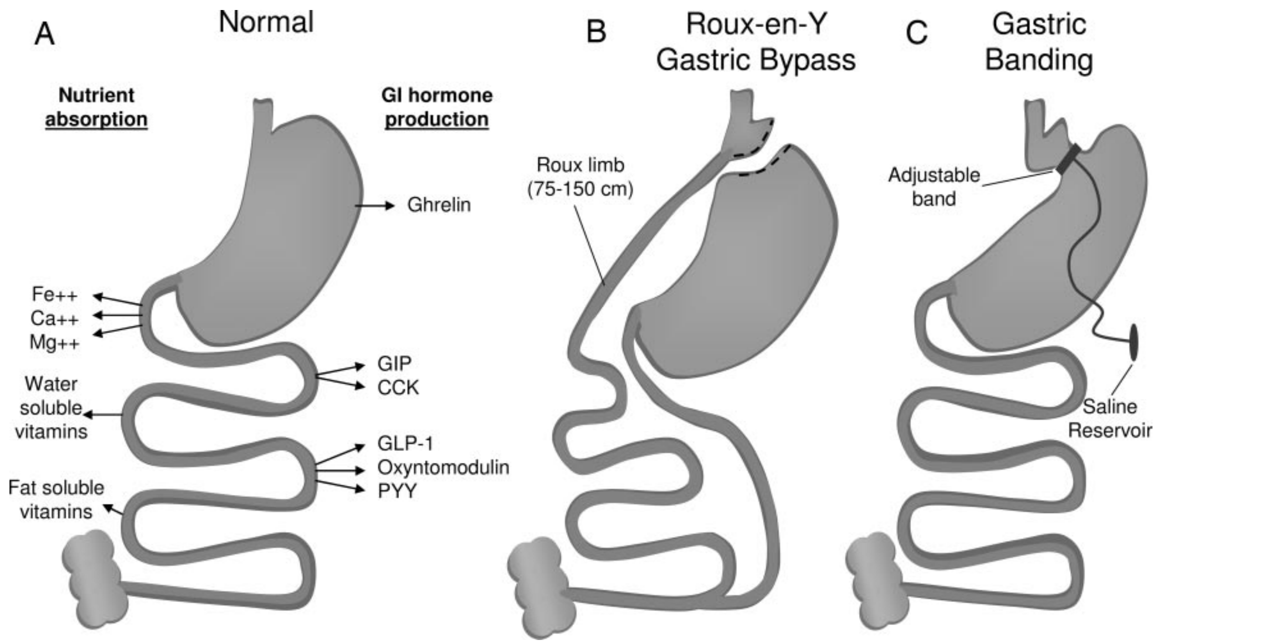

FIG. 2. Schematic representation of the normal gastrointestinal tract (A) and its perturbations in the two common bariatric surgery procedures, RYGB (B) and adjustable GB (C). A, Major sites of micronutrient absorption and gastrointestinal hormone production. Absorption of iron and other minerals such as calcium and magnesium occur mostly from the duodenum and proximal jejunum. Whereas the absorption of dietary fats and concomitantly the fat-soluble vitamins such as vitamins A and D occurs in the distal small intestine, it is facilitated by the action of pancreatic enzymes and bile salts released into the duodenum. Water-soluble vitamins are absorbed throughout the small intestine. Among the gastrointestinal hormones, ghrelin is secreted predominantly from the gastric fundus. Glucose-dependent insulinotropic peptide (GIP) and cholecystokinin (CCK) are secreted mostly from the proximal small intestine, whereas the distal intestines are the primary site of production of the satiety-inducing hormones, GLP-1 and PYY. B, In RYGB, the stomach is divided into a small proximal pouch, excluding much of the ghrelin-secreting regions, and a larger distal segment. The pouch is anastomosed with the proximal jejunum through a narrow end to side anastomosis, whereas the distal segment along with the duodenum and part of the jejunum are attached to the distal jejunum. This surgery combines restrictive and malabsorptive procedures. C, GB is a purely restrictive procedure in which the prosthetic band divides the stomach into a small proximal segment and a larger distal segment. The band aperture between the two segments can be adjusted by changing the volume of the saline reservoir, which has a sc port.

Mechanisms for Weight Regain

One possible mechanism for weight regain seen after 1 yr is increase in energy intake. Sjostrom *et al.* (11) reported daily intakes of about 2900, 1500, 1700, 1800, 1900, and 2000 kcal/d, respectively, at baseline and 6 months, 12 months, 2 yr, 3 yr, and 4–10 yr after surgery. The role of energy intake in weight regain may be greater than that observed because subjects tend to overadhere to their dietary recommendations on the day that the diet is assessed (25).

A possible reason for the increase in energy intake in RYGB patients may be due to dilatation of the gastric pouch and gastrojejunal anastomosis (26, 27). Late pouch dilatation has been reported in patients who undergo laparoscopic GB surgery (28) and is the leading indication for conversion of GB to a RYGB (29) but is seen less frequently after RYGB surgery (30). Revision surgery to correct these changes leads to improved weight loss (28, 29). However, these complications have been described in only a handful of patients, implying that other factors may be involved in modulating weight regain after bariatric surgery.

Regular physical activity is an important factor in weight loss maintenance (31). According to one survey in RYGB patients with a mean follow-up of 7 yr, successful patients (those who maintained at least 74% of their initial weight loss) exercised regularly (no details given) (32). In the prospective study by Sjostrom *et al.* (11), the approximate proportion of bariatric surgery patients who reported being active at work changed from 70% at baseline to 90% at yr 1 and 80% at yr 10. The proportion of patients who were active during leisure time was 55, 90, and 80%, respectively. The difference in the proportion active at work and during leisure time between the surgery patients and controls was narrower at 10 yr than at 1 yr. This may explain some of the observed weight regain seen in the surgery patients. Also physical activity may be overreported and thus needs to be assessed objectively. Whether increased physical activity in bariatric surgery patients is effective in weight loss maintenance remains to be proven by randomized trials.

Several studies have assessed metabolic rate in bariatric surgery patients (33–36). van Gemert *et al.* (35) and Buscemi *et al.* (33) found a decrease in resting (33) or sleep (35) metabolic rate, even when expressed per kilogram fat-free mass, with weight loss in subjects who were followed up for 12 or 36–42 months, respectively, after surgery. Das *et al.* (36) and Flancbaum *et al.* (34), however, did not observe these changes at 14 and 24 months, respectively. Thus, the role of changes in energy expenditure in weight loss and maintenance needs to be studied more thoroughly.

The changes in energy intake, and perhaps even energy expenditure, seen after bariatric surgery may be affected by alterations in gut and adipocyte hormones. Gut hormones such as ghrelin, peptide YY (PYY), and glucagon-like-peptide (GLP)-1 have an important role in governing satiety (37). Of these, ghrelin is an orexigenic peptide, secreted primarily by the enteroendocrine cells in the fundus of stomach and acts through the hypothalamus (38–41). Ghrelin levels have been found to increase after GB surgery (42, 43), although transiently in the case of one study (43), and suggest a role in weight regain after this procedure. Weight loss in RYGB surgery patients, however, is associated with a decrease in ghrelin levels, compared with weight loss after GB, biliopancreatic diversion, or conventional weight loss treatment (44–47), and has often been considered to contribute to the marked efficacy of the RYGB, compared with the other procedures. This finding has, however, not been universally observed (48, 49). The conflicting data may be due to the different surgical techniques that affect the functional integrity of the gastric fundus from which ghrelin is mostly secreted. Whether the changes in ghrelin levels in bariatric surgery patients are maintained in the long term needs to be evaluated.

PYY secreted primarily by the more distal intestines in response to nutrient contact and GLP-1 secreted by the intestinal L cells induce satiety (50–53). Clements *et al.* (54) reported no difference in fasting GLP-1 level 12 wk after RYGB surgery, compared with preoperative value. In weight-stable RYGB patients with an average follow-up of 35 months, fasting serum PYY level was similar to that of BMI-matched controls, but the PYY response to a test meal (320 kcal) was greater (55). Similarly Borg *et al.* (48) reported no change in fasting serum PYY and GLP-1 values but increased PYY and GLP-1 response to a test meal (420 kcal) at 6 months after RYGB surgery. The responses to a test meal suggest a beneficial effect on weight loss. It is possible that these changes gradually revert to presurgical levels and contribute to increased energy intake in the long term. Only long-term prospective studies can elucidate the influence of these hormones on energy balance.

According to a number of case series, serum leptin levels decreased with weight loss after bariatric surgery (56–60). The decrease was beyond the expected value based on body composition (57, 60). In a case-control study, serum leptin levels were lower in weight-stable RYGB patients 35 months after surgery, compared with BMI-matched controls (55). Given the putative adipostatic role of leptin, it is possible that relative hypoleptinemia may play a role in weight regain. Observational studies with very limited sample sizes, however, do not support the hypothesis that relative hypoleptinemia predicts weight regain in moderately obese or overweight subjects who lost modest amount of body weight (8–12 kg) (61, 62). Nevertheless, leptin administration in weight-stable subjects who lost weight via a liquid formula diet resulted in return of energy expenditure to preweight-loss levels (63). Information on energy intake was not reported (63).

Effect of Bariatric Surgery on Nutritional Status and Intolerance

Micronutrient deficiency

Deficiency of iron, vitamin B12, folate, calcium, and vitamin D has been frequently observed after RYGB surgery. Deficiency of vitamin A has also been observed, although less frequently. Nutrient deficiencies after GB surgery are less common because it does not have a malabsorptive component, and an adult multiple vitamin and mineral supplement is considered sufficient to prevent these problems (64). Reviewed below are the studies that have reported nutritional deficiencies in RYGB surgery patients (Table 2). The majority of these studies were uncontrolled case series, and so it is important to note that the studies may have somewhat overestimated the effect of surgery on nutritional status, especially given that nutritional deficiencies have been noted in severely obese subjects before surgery (65) and that many of the patients are menstruating women who are more likely to have poor iron status.

Serum iron deficiency is seen frequently in RYGB patients (66–69), with the incidence rate as high as 52% (66). The incidence of anemia (type not specified) has been reported to be as high as 74% (66). Supplements containing usual daily

TABLE 2. Effect of RYGB surgery on incidence of nutritional deficiencies

Study	Roux limb	n	Follow-up, months	Study design	Incidence of nutritional deficiencies							
					Fe	B12	Folate	Anemia	A	D	Alb	Ca
Brolin *et al.* (66)	50–75 cm	80	≥24	Prospective	52	37	–	41	–	–	–	–
	150 cm	102	≥24		45	33	–	35	–	–	–	–
	265–570 cm	39	≥24		49	8	–	74	10	51	13	10
Halverson (67)		74	36	Case series	49	64	38	35	10	–	0	–
Kalfarentzos *et al.* (68)	Standard distal	38	17	Case series	13	21	–	32	–	–	0	–
		17	14		6	12	–	18	–	–	6	–
Marcuard *et al.* (73)		429	22	Case series	–	36	–	–	–	–	–	–
Skroubis *et al.* (69)[a]	60–80 cm	55	24	Case series	29	36	0	47	–	–	0	–
			48		39	33	0	44	–	–	0	–
			60		25	25	0	50	–	–	0	–

Fe deficiency was not defined (66) or defined as serum iron levels less than 60 (67), less than 35 (68), or 50 μg/dl or less (69). Vitamin B12 deficiency was not defined (66) or defined as serum vitamin B12 levels less than 200 (67–69) or less than 180 pg/ml (73). Folate deficiency was defined as serum folate levels less than 3 (67) or 1.5 ng/ml or less (69). Anemia was not defined (66) or defined as hematocrit 39% or less for men and 34% or less for women (67), hematocrit less than 40% or hemoglobin less than 13.5 g/dl for men and hematocrit less than 37% or hemoglobin less than 12.5 g/dl for women (68), or hemoglobin 13.5 g/dl or less for men and 12.5 g/dl or less for women (69). Vitamin A deficiency was not defined (66) or defined as serum vitamin A levels less than 20 μg/dl. Vitamin D and calcium deficiencies were not defined (66). Protein deficiency was not defined (66) or defined as serum albumin levels less than 3 (67, 69) or less than 3.5 g/dl (68). Fe, Iron; B12, vitamin B12; A, vitamin A; D, 25-hydroxyvitamin D; Alb, serum albumin; Ca, calcium; –, data not available.

[a] The sample size decreased from 55 to 18 at 48 months and eight at 60 months.

doses of multivitamins (70), and even high doses of oral iron (320 mg twice daily) (71), do not consistently prevent anemia in menstruating women. Contributing factors to iron deficiency anemia include malabsorption due to bypassing of the duodenum and proximal jejunum, the main sites for iron absorption (Fig. 2); intolerance to iron-rich foods, especially red meat (15); and reduced stomach production of hydrochloric acid (72) required to reduce ferric iron to the ferrous state before it can be absorbed.

Vitamin B12 deficiency, assessed by serum vitamin B12 levels, is also frequently seen in RYGB patients (66–69, 73) with the incidence rate as high as 64% (67). Most vitamin B12 deficiencies in RYGB patients may be corrected by 500 μg/d oral B12 supplementation (74), and a minimum dose of 300 μg crystalline B12 per day is necessary to maintain normal serum levels (75). Only a small number of patients require parenteral administration of B12 (2000 μg/month) (64). Possible factors that contribute to B12 deficiency include achlorhydria (72), which prevents its cleavage from foods; decreased consumption due to intolerance to its main sources (milk and meat) (15); and poor secretion of intrinsic factor needed for its absorption (73). Because of the latter problem, Elliot (64) recommended taking the supplement in a sublingual form.

Serum folate deficiency has been reported to be as high 38% after RYGB surgery (67). Brolin *et al.* (74) reported that a supplement containing 400 μg of folate per day consistently corrected low folate levels in patients who underwent RYGB surgery, although 1000 μg/d have been recommended by others (64). Primary reason for folate deficiency is decreased folate intake. Malabsorption may not play a big role, even though folate is preferentially absorbed in the proximal part of the small intestine, because absorption can occur along the entire part of the small intestine with adaptation after surgery (76). Maintaining adequate folate levels is important, however, because of the possibility of megaloblastic anemia. Also, there have been reports of neural tube defects in infants born to mothers who underwent RYGB surgery (77, 78).

Calcium and vitamin D deficiency may occur in patients who undergo RYGB surgery, and a deficiency rate of 10% for serum calcium and 51% for serum 25-hydroxy vitamin D levels has been reported (66). PTH levels, however, were not reported (66). Possible contributors to calcium deficiency in the RYGB patients include malabsorption of calcium because of bypassing the duodenum and proximal jejunum in which calcium is mostly absorbed; intolerance to rich sources of calcium such as milk; and defective absorption of vitamin D because of fat malabsorption. Fat malabsorption is due to the short common channel and delayed mixing of fat with pancreatic enzymes and bile salts as a result of bypassing the duodenum. Deficiency of calcium is not always apparent, however, because of release of calcium from bone. Coates *et al.* (79) and von Mach *et al.* (80), who followed subjects for 9 and 24 months, respectively, reported elevated markers of bone turnover and/or decreased bone mass in patients who underwent RYGB surgery, compared with patients who underwent GB surgery (80) or the matched obese controls (79, 80). The higher bone turnover in the RYGB patients, however, may be partly due to the increased weight loss in these patients, compared with the other patients. PTH levels were not different between the RYGB and obese control groups (80) nor did they change over time after surgery (79). Nevertheless, to prevent metabolic bone disease, 1200–1500 mg/d of calcium and 400 IU/d of vitamin D supplements are recommended (64, 65). These amounts, however, may not suppress serum PTH or bone resorption, and increased supplementation may need to be considered (81). Because of reduced stomach acid content, calcium citrate rather than calcium carbonate is recommended because the latter requires acid for absorption (64, 65). Regular monitoring of markers of bone resorption such as urinary *N*-telopeptide level and markers of bone formation such as serum osteocalcin level may also be necessary.

Serum vitamin A deficiency has been reported in 10% of RYGB patients (66, 67). Whereas symptoms of vitamin A deficiency are rare in this population, a case study reported xerophthalmia and nyctalopia in a patient after a duodenal switch gastric bypass surgery due to inadequate vitamin A supplementation (82). A contributing factor to vitamin A deficiency in RYGB patients is fat malabsorption. Careful monitoring of serum vitamin A status and supplementation as needed is necessary to avoid a deficiency.

Despite the evidence of nutritional deficiencies, many surgeons do not recommend adequate supplements or evaluate serum nutrient levels (83), and most patients do not comply with the recommended supplement regimen (70). Education of both the physicians and patients is thus necessary to prevent malnutrition after RYGB surgery.

Macronutrient deficiency and intolerance

Protein deficiency, assessed by serum albumin levels, is less common than most other nutrient deficiencies (Table 2) (66–69). To consume enough protein, patients should be advised to consume fish, which is better tolerated than meat.

Simple sugar intake, especially added sugars (64), has been reported to cause dumping syndrome in as many as 76% (84) of the RYGB patients. The food rapidly enters the small intestine causing an osmotic load, which leads to movement of fluid from the blood into the intestine (85, 86). Rapid food entry into the jejunum also stimulates a substantial release of peptide hormones (85, 86). Clinical manifestations of the dumping syndrome include gastrointestinal symptoms such as early satiety, nausea, cramps, and explosive diarrhea and vasomotor symptoms such as sweating, flushing, palpitations, dizziness, and an intense desire to lie down (85). The insulin response is exaggerated and causes hypoglycemia (85, 86). To prevent dumping syndrome, patients should avoid consuming fruit juices and foods and drinks with added sugar (64); consume frequent, small, dry meals because water can make the food more soluble; include dietary fiber; increase dietary protein (especially fish and chicken); and modestly increase dietary fat (to delay gastric emptying) (86).

Recommendations

It is often stated that bariatric surgery is the most effective way of treating morbid obesity. Yet this conclusion has been based on largely uncontrolled case series. Randomized, controlled studies comparing morbidly obese subjects who undergo either bariatric surgery or conventional treatment have not been conducted for the following reasons: many surgeons believe that conventional therapy is inferior to surgery, and therefore it may be unethical to randomize; and patients may not be willing to be randomized to a nonsurgical group because they believe they have already tried all the conventional approaches to lose weight. Despite the difficulty of randomizing subjects, it is imperative that the effect of bariatric surgery *vs.* traditional weight loss strategies on long-term outcomes such as weight maintenance, comorbidities, and mortality be compared by well-designed, long-term (at least 5 yr), randomized, controlled studies.

Other weaknesses of many bariatric surgery studies include a lack of information on sample size at each follow-up and a nonstandardized way of presenting data on weight loss. Data analysis should be conducted on subjects with a complete set of data as well as the entire group with missing data replaced by baseline data. To facilitate comparison of weight loss across studies, all studies should provide information on body weight and BMI at each time point. Patient characteristics such as gender, age, socioeconomic status, fat distribution, race/ethnicity, *etc.* that may determine weight change need to be reported.

The role of energy intake and expenditure, physical activity, gut and adipocyte hormones, and stoma changes in weight regain need to be further elucidated by long-term prospective studies. Effect of exercise on weight loss maintenance in bariatric surgery patients needs to be evaluated by randomized, controlled studies.

Because nutritional deficiencies are common in RYGB patients, aggressive supplementation with iron, vitamin B12, folate, calcium, and vitamin D and regular monitoring of nutrition status are necessary. Careful screening before surgery may help to select patients who are more likely to be compliant to supplement recommendations. Women of child-bearing age should be counseled to avoid getting pregnant while actively losing weight and until the serum nutrient levels are normalized. To prevent dumping syndrome, patients should be encouraged to consume frequent, small meals, avoiding fruit juices and added sugars.

In conclusion, bariatric surgeries have a place in treatment of carefully selected patients with morbid obesity. These patients should be encouraged to increase physical activity to possibly prevent weight regain over the long term and consume vitamin and mineral supplements to prevent nutritional deficiencies.

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