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Review

Nutrient and fluid requirements in post-bariatric patients performing physical activity: A systematic review

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ABSTRACT

Objectives: The evidence for the benefits of physical activity in post-bariatric patients is growing. Nevertheless, it remains unclear whether nutritional regimens should be adapted to physical activity levels. The aim of this systematic review was to summarize current evidence regarding nutrient and fluid requirements in physically active post-bariatric patients.
Methods: We conducted this systematic review according to the PRISMA guidelines. We searched MEDLINE, Embase, and the Cochrane Library for studies assessing nutritional aspects in physically active post-bariatric patients. Data were extracted based on a predefined, standardized form, and assessed for risk of bias.
Results: Of 582 records, 8 studies were included, mostly implementing general fitness programs (30–60 min/d, 3–4 × /wk). There is no evidence for increased energy requirements in physically active post-bariatric patients. None of the studies determined energy, fat, or carbohydrate requirements. Most studies focused on protein, recommending a minimum intake of 60 g/d to preserve or increase muscle mass (upper limit 1.5 g protein/kg ideal body weight/d). Higher protein intake (108 g/d, thereof 48 g whey protein) combined with physical activity increased muscle strength. The effects of physical activity on micronutrient requirements remain unstudied, whereas fluid requirements appear to be increased.
Conclusion: The present findings strengthen the importance of adequate protein intake in physically active post-bariatric patients. Nutrient reference values for physically active post-bariatric patients are not definable based on the current evidence. Consequently, clinicians should pay special attention to the monitoring of macro- and micronutrients and fluid balance, especially when post-bariatric patients engage in high levels of physical activity.

Introduction

Bariatric surgery is an effective treatment for severe obesity (body mass index [BMI] ≥35 kg/m^2), resulting in sustained weight loss and improvements of obesity-related comorbidities, physical function, and quality of life [1–3]. Worldwide, the number of bariatric procedures has risen steadily in recent years [4]. Approximately 5000 such surgeries are performed every year in Switzerland [5]. The most common bariatric procedures worldwide are Roux-en-Y gastric bypass (RYGB) and sleeve gastrectomy (SG). Biliopancreatic diversion with duodenal switch (BPD-DS) and gastric banding are further rarely performed procedures.

The mechanisms of action of bariatric surgery are manifold and generally include restricting food intake and/or absorption. There are many effects involved in weight loss and include the following:

- volumetric restriction leading to reduced food intake;
- alteration of neurohormonal networks;
- reduction of inflammatory processes and oxidative stress;
- adaptations in energy and bile acid metabolism; and
- changes in the oral and gut microbiome [6,7].

Although these mechanisms lead to the desired weight loss, they simultaneously increase the risk for nutritional deficiencies [8,9]. Therefore, post-bariatric patients require lifelong prophylactic supplementation and close monitoring of micronutrient levels [1].

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Despite supplementation, micronutrient deficiencies are the most frequently reported complication after bariatric surgery [1,10]. The prevalence of deficiencies highly varies among the types of bariatric surgery (Table 1) and depends on the occurrence of post-bariatric complications (e.g., persistent vomiting can lead to thiamin deficiency) [1,16]. Overall, the most common post-bariatric deficiencies include vitamins A and D and calcium. Deficiencies in iron, zincs and copper are highly prevalent in BPD and less prevalent in RYGB and SG [1,9]. Physiologic changes after bariatric surgery often lead to aversions and intolerance of various foods [17]. This may further contribute to the development of malnutrition. Long-term data on malnutrition after bariatric surgery is scarce.

Post-bariatric patients are advised to follow a balanced, protein-rich diet [1]. They are counseled to avoid overeating, to separate eating and drinking (≥30 min between eating and drinking), and to eliminate concentrated sweets from the diet in order to control weight and to prevent post-bariatric complications (e.g., gastrointestinal distress and/or dumping syndrome) [1,12]. The recommendations on the optimal macronutrient ratio of the various guidelines for post-bariatric patients vary greatly [1,18–21].

Bariatric surgery candidates are strongly encouraged to start with physical activity before the surgery and to continue afterwards [1]. The World Health Organization defines physical activity as “any bodily movement produced by skeletal muscles that requires energy expenditure” [22]. Hence, physical activity includes everyday activities and exercise [22]. The recommended physical activity for post-bariatric patients (150–300 min/wk of aerobic activity, including strength training 2–3 × /wk) is similar to the recommendations for the general population, as there are no specified physical activity guidelines for bariatric patients taking specific characteristics of those patients into account such as rapid muscle mass loss during weight loss, history of inactivity, or reduced muscle mass percentage [1]. Physical activity in post-bariatric patients enhances weight loss and prevents weight regain while preserving lean body mass [23]. Physical activity additionally improves cardiometabolic risk factors such as insulin sensitivity and blood lipid profile [23]. Furthermore, it improves mental health by enhancing body awareness, cognitive function, and well-being [24].

The long-term management of post-bariatric patients is multifaceted and not yet fully explored. Although an increasing number of post-bariatric patients engage in physical activity [25], sports nutritional aspects are not considered in the current guidelines. This raises the question of whether post-bariatric patients should adapt their dietary regimen to their physical activity level. This systematic review investigates the effects of physical activity on the nutrient and fluid requirements of post-bariatric patients.

Method

This systematic review was conducted according to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement [26] and registered in the Prospective Register for Systematic Reviews.

Eligibility criteria

We developed the criteria for study inclusion using the Population-Intervention-Comparison-Outcomes (PICO) format. We included studies in post-bariatric patients >18 y of age. The included intervention was physical activity from 1 mo after bariatric surgery onward, according to the recommendation of the current American Bariatric Surgery Guidelines [1]. The research question did not involve any specific comparisons. The assessed outcomes were nutritional aspects. Review articles were excluded.

Search strategy

We searched the MEDLINE (via Ovid) and Embase (via Ovid) databases and the Cochrane Library. The last search was conducted on May 19, 2021. The search strategy (Appendix A) combined subject headings and text words in title, abstract, and keywords related to bariatric surgery, physical activity, and nutritional aspects. No search filters were applied. A professional medical research librarian reviewed the literature search strategy. Additionally, we screened the reference lists of eligible studies and reviews.

As the widely accepted American Bariatric Surgery Guidelines [1] were published in 2019, we ran an additional search to find studies published after these guidelines. This search focused on recently investigated nutritional issues and new therapeutic approaches in post-bariatric patients, independently from the physical activity level. The additional search was limited to studies published from 2019 to May 19, 2021.

Study selection

We exported search results to EndNote and removed duplicates. Two authors independently screened titles and abstracts, and reviewed, and evaluated full texts of potentially eligible studies. Any differences were discussed and resolved by consensus.

Data extraction

We created a form to extract data on participant characteristics, study design, intervention, duration, comparison, outcomes, and conclusions of interest. One author extracted the data and a second author double-checked them. Due to the heterogeneity of study design, populations, interventions, and outcomes, a meta-analysis was not feasible.

Quality assessment

We used the standardized Study Quality Assessment Tools by the US National Heart, Lung, and Blood Institute (NHLBI) to rate the quality of the included studies [27]. The NHLBI tools include an assessment of methods including sources of bias, sampling, confounding, study power, and further factors depending on the study design. Each study was subsequently rated as good, fair or poor. Two authors conducted the quality assessment independently. Any differences were discussed and resolved involving a third author if needed.

Results

Our search retrieved 582 records after removing 123 duplicates (Fig. 1). The full texts of 15 articles were reviewed, 8 of which fulfilled the inclusion criteria. Table 2 provides a summary of the included studies, which were highly heterogenic in participant number and study design. All studies were conducted within the previous 10 y. All studies were rated as fair in the quality assessment mainly due to small sample sizes. The detailed results of the quality assessment are presented in Appendix B.

The most common bariatric surgical procedure was standard RYGB (N = 269), followed by SG (N = 73). The participants included in the interventional studies had a mean age of 43 y and 87% were women (N = 221). Four studies reported the 6-mo post-surgery BMI, which was 32.7 kg/m^2 on average. The exercise programs implemented in the studies differed widely and consisted of resistance training [28,29,32] endurance training [30,35], or a combination of both [33], whereas two studies did not implement any exercise program [31,34]. The exercise sessions were partially [30] or completely [28,33] supervised in four studies. The duration of the exercise program ranged from 3 [29,30,33] to 6 mo [32,31].

The additional search resulted in eight eligible publications (Fig. 1). An overview of these studies is presented in Table 3. Studies were rated as good (n = 2) or fair (n = 6) in the quality assessment (Appendix B). Topics of interest were the macro- and micronutrient intake and the influence on muscle strength, hypoglycemia, and dumping syndrome in post-bariatric patients. A further content is the intake of fluids in post-bariatric patients.

Nutrient and fluid intake

None of the studies investigated the potential increase in energy requirements of physically active post-bariatric patients as a primary outcome. Two studies indicated increased energy

Table 1
Post-bariatric nutritional recommendations vs sports nutritional support

	Prevalence of deficiencies after bariatric surgery [1,11]	Post-bariatric patients: Nutritional recommendations and basic supplementations [1,11]	Healthy individuals performing a general fitness program* [13]	Healthy individuals performing moderate volumes of intense training† [13]
Energy intake	N/A	1200–1500 kcal/d (with most patients consuming 1500–1800 kcal/d in the long-term)	1800–2400 kcal/d (25–35 kcal·kg·d^{-1})	2000–7000 kcal/d (40–70 kcal·kg·d^{-1})
Protein	N/A	≥60 g/d, ≤1.5 g/kg ideal BW/d ≈10%–35% of DEI	0.8–1.2 g·kg·d^{-1} 15%–20% of DEI	1.4–2 g·kg·d^{-1} Higher protein intakes in combination with resistance exercise may maximize the retention of lean body mass during hypocaloric periods.
Carbo-hydrates	N/A	130 g/d ≈50% of DEI simple sugars: <10% of daily energy intake [10]	~320 g/d (3–5 g·kg·d^{-1}) 45%–55% of DEI	250–1200 g/d (5–8 g·kg·d^{-1}) Throughout exercise: 30–60 g/h carbohydrate–electrolyte solution
Fats	N/A	~35–60 g/d 20%–-35% of DEI [10]	~80 g/d (0.5–1.5 g·kg·d^{-1}) 25%–35% of DEO for weight loss: 0.5–1 g·kg·d^{-1}	30% (max. 50%) of daily energy intake
Fluid intake	N/A	>1.5 L/d; avoid drinking 30 min before/after eating solid food	1–2 L/d, add 0.4–0.8 L sport drink/h of exercise [14]	1–2 L/d, add 0.4–0.8 L sport drink/h of exercise [14]
Vit. A	≤70%	5000–10 000 IU/d suppl. p.o. (BPD-DS: 10 000 IU/d)	RDA ≙850 µg/d (♂), 700 µg/d (♀)	RDA
Vit. B_1	<1%–49% depending on procedure	≥12 mg/d suppl. p.o. (preferably 50–100 mg/d)	RDA ≙1.2 mg/d (♂), 1 mg/d (♀)	RDA
Vit. B_{12}	RYGB: <20% SG: 4%–20%	350–1000 µg/d suppl. p.o. (1000 µg/mo parenteral)	RDA ≙4 µg/d	RDA
Vit. D	≤100%	3000 IU/d vit. D_3-suppl. p.o. until blood level of 25(OH)D is >30 ng/mL	RDA ≙2–4 µg/dd	RDA - Co-suppl. with calcium may prevent bone loss in populations susceptible to osteoporosis.
Calcium	≤100%	Daily calcium from all sources: 1200–1500 mg/d (BPD-DS:1800–2400 mg/d)	RDA ≙1000 mg/d	RDA - Calcium suppl. may prevent bone loss in populations susceptible to osteoporosis, promotes fat metabolism, and helps manage body composition.
Vit. E	Uncommon	15 mg/d suppl. p.o.	RDA ≙11–15 mg/d	RDA - Vit. E suppl. decrease exercise-induced oxidative stress.
Vit. K	Uncommon	90–120 µg/day suppl. p.o. (BPD-DS: 300 µg/day p.o.)	RDA ≙120 µg/d (♂), 90 µg/d (♀)	RDA - Vit. K suppl. may improve balance between bone formation and resorption.
Folate	≤65%	400–800 µg/d suppl. p.o. (800–1000 µg/d in women of child-bearing age)	RDA ≙ 300 µg/d	RDA
Iron	RYGB: 20%–55% SG: <18% BPD-DS: 8%–62%	45–60 mg/d elemental iron p.o.	RDA ≙10 mg/d (♂), 15 mg/d (♀, 19–51 y of age)	RDA - Iron suppl. only improve aerobic performance in iron-depleted and/or anemic individuals.
Zinc	RYGB: ≤40% SG: ≤19% BPD-DS: ≤70%	8–22 mg/d zinc from multimineral preparation‡	RDA ≙14 mg/d (♂), 8 mg/d (♀)	RDA - Zinc suppl. (25 mg/d) during training may minimize exercise-induced changes in immune function.
Copper	RYGB: 10%–20% BPD-DS: ≤90%	1–2 mg/d copper from multimineral preparation‡	RDA ≙1–1.5 mg/d	RDA
Eating behavior	N/A	- Consume 3 small meals during the day - Eat slowly, chew food extensively - Avoid overeating - Do not eat and drink at the same time [12]	- Pre- and post-exercise intake of protein and carbohydrate support improvements in strength and body composition.	- Consume 4–6 meals/d and snacks between meals to meet energy needs. - Pre- and post-exercise intake of protein and carbohydrate support improvements in strength and body composition.

BPD-DS, biliopancreatic diversion with duodenal switch; BW, body weight; RDA, Recommended Dietary Allowance; RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy; suppl., supplements/supplementation; vit., vitamin; 25(OH)D, 25-hydroxyvitamin D
Reference values for nutrient intake published by the German, Austrian, and Swiss Societies for Nutrition (DACH) [15]
Adapted from [1,11–14].
*General fitness program: e.g., 30–60 min/d, 3–4 × /wk.
†Moderate volumes of intense training: e.g., 2–3 h/d of intense exercise, 5–6 × /wk.
‡To minimize the risk for copper deficiency, copper should be supplemented with a ratio of 1 mg of copper per 8–15 mg zinc.

requirements in post-bariatric patients engaging in high volume of intensive physical activity [30,35]. Most studies refer to the current American Bariatric Surgery Guidelines recommending a minimum protein intake of 60 g/d [1]. Oppert et al. and Lamarca et al. investigated the effect of a higher protein intake in post-bariatric patients engaging in a resistance program of 18 and 12 wk, respectively [28,29]. Oppert et al. showed an increased muscle strength in physically active individuals receiving additional whey protein supplementation (48 g whey protein in addition to a basic protein intake of 60 g/d) compared with those receiving only protein (without

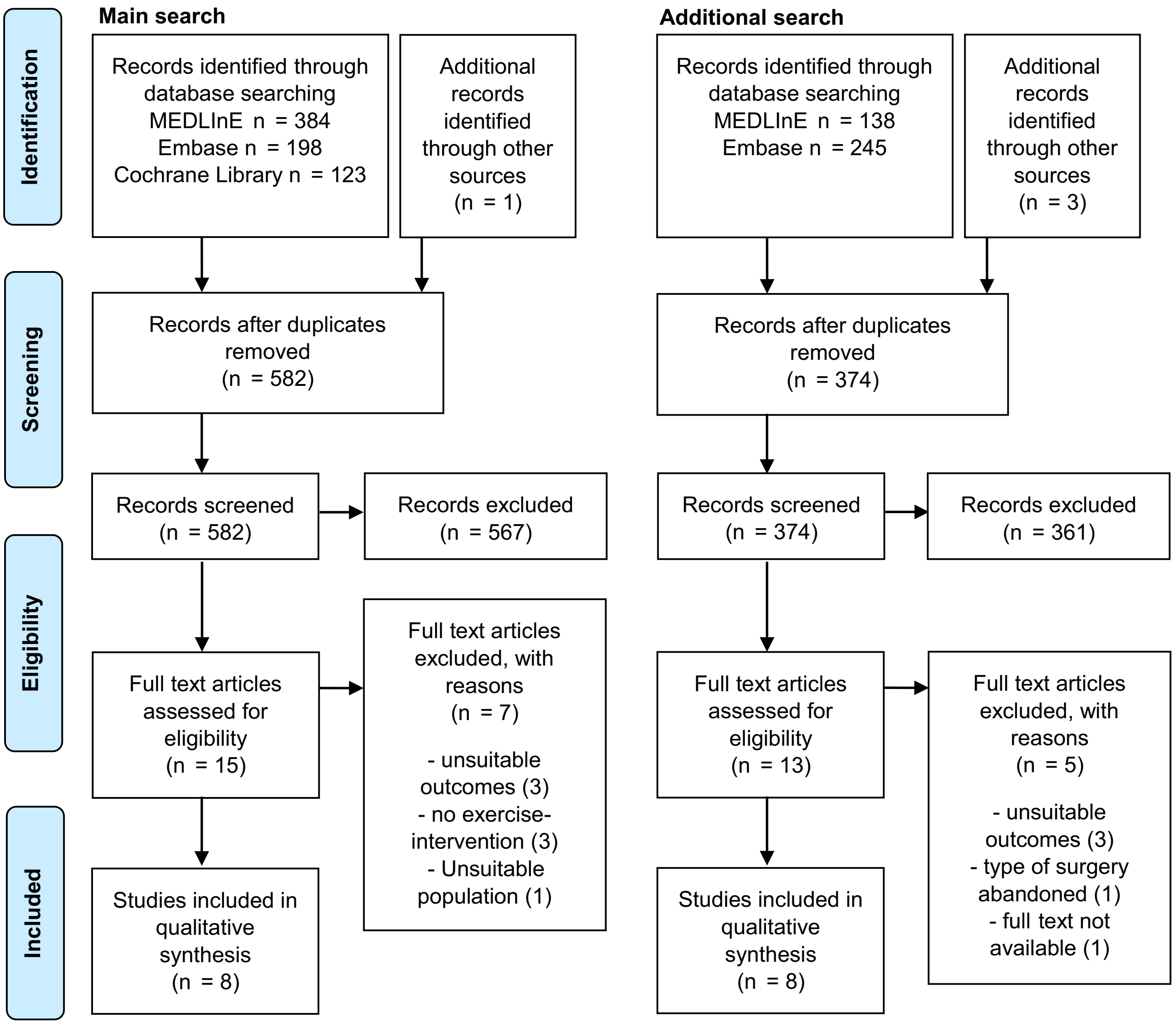

Fig. 1. Flow diagrams according to PRISMA guidelines [26]. The additional search investigated studies published after the latest guidelines (American Bariatric Surgery Guidelines 2019 [1]).

exercise program) or usual care (neither protein supplementation nor exercise program). There was no influence of increased protein supplementation or physical activity on lean body mass [28]. Lamarca et al. found an increased in fat-free mass and skeletal muscle mass in the group undergoing resistance training with protein supplementation (30 g whey protein in addition to a basic protein intake of about 60 g/d) compared with the control group performing resistance training only [29]. Smelt et al. found a higher handgrip strength in post-bariatric patients with a protein intake ≥60 g/d than in those with a lower protein intake, while the general physical capacity remained unaffected [31]. None of the included study analyzed fat, carbohydrate, or micronutrient intake in physically active post-bariatric patients. Clark et al. described that dehydration is a matter of concern in physically active post-bariatric patients [35].

Complications interfering with physical activity

Proulx et al. found that 1.2% of exercise sessions were associated with asymptomatic hypoglycemia (capillary blood glucose ≤3.9 mmol/L) [33]. Cadegiani et al. demonstrated a reduction of early and late dumping syndrome by administering acarbose, an α-glucosidase inhibitor. The exercise capacity was thereby significantly improved [32]. Besides acarbose, anakira [37], empagliflozin [37], and pasireotide [38] showed preventive effects on post-bariatric hypoglycemia in recent studies.

Discussion

It remains unclear whether physical activity induces additional energy requirements in post-bariatric patients due to a lack of data. The recommended extent of physical activity in post-bariatric patients corresponds to a so-called general fitness program (30–60 min/d, 3–4 × /wk) [1,13]. Such programs may include any type of activity and should be adapted to the patient's mobility, interest, and motivation [23]. In two studies, exercise programs with moderate volumes of intense training (2–3 h/d of intense exercise; 5–6 × /wk) proved to be feasible and effective in post-bariatric patients [30,35]. Thus, the optimal level and type of physical activity for this population remains to be determined.

Table 2
Studies assessing nutritional requirements of physically active post-bariatric patients

Topics of interest	Author, year, country	Participant characteristics including surgery type	Study design	Intervention	Duration of intervention	Comparison	Outcomes of interest	Results & conclusions of interest
- Protein intake - Muscle strength - Lean body mass	Oppert et al., 2018, France [28]	N = 76, women undergoing RYGB	RCT	PRO: protein supplementation (48 g/d, additionally to usual protein recommendation of 60 g/d) PRO+EX: protein supplementation + resistance training (45 min, 3 × /wk, supervised) CON: usual care	18 wk	Comparing the 3 groups (PRO vs PRO+EX vs CON)	Pre- to 6 mo post-surgery change in lean body mass (by DXA) Pre- to 6-months post-surgery change in muscle strength	Body composition changes did not differ across groups. Significant increase in muscle strength in the PRO+EX group (+0.6 kg/kg BMI) compared with the PRO group (+0.2 kg/kg BMI) and CON group (+0.1 kg/kg BMI) [P = 0.021].
- Protein intake - Lean body mass - Skeletal muscle mass	Lamarca et al., 2021, Brazil [29]	N = 119, 2–7 y after RYGB	RCT	CON: placebo maltodextrin PRO: 30 g whey protein supplementation/d RTP+CON: Resistance training (1 h, 3 × /wk, supervised) + placebo maltodextrin RTP+PRO: resistance training (1 h, 3 × /wk, supervised) +30 g whey protein supplementation/d	12 wk	Comparing the 4 groups (CON vs PRO vs. RTP +CON vs RTP+PRO)	Effects of resistance training, isolated and combined with protein supplementation, on body composition (by multifrequency electrical bioimpedance) and resting energy expenditure	Combined resistance training and adequate protein intake can increase fat-free mass and skeletal muscle mass in late postoperative phase without changing resting energy expenditure. RTP+PRO: +1.46 ±1.02 kg vs CON −0.24 ±1.64 kg in fat-free mass (P = 0.006) and RTP+CON +0.91 ±0.64 kg vs CON −0.08 ±0.96 kg in skeletal muscle mass (P = 0.008).
- Energy intake	Shah et al., 2011, USA [30]	N = 33 with RYGB (N = 10) or GB (N = 23), ≥3 mo post-surgery	RCT	High-volume exercise program (expenditure of ≥2000 kcal/wk) partially supervised + guidance to limit the energy intake to 1200–1500 kcal/d	12 wk	High-volume exercise program group vs control group with guidance to limit the energy intake to 1200–1500 kcal/d	Feasibility of a high-volume exercise program with a limited energy intake in post-bariatric patients	A high-volume exercise program is feasible in bariatric surgery patients with severe obesity. The intervention group decreased the energy intake to a smaller extent (−358 kcal/d) than the control group (−593 kcal/d; P = 0.47). This suggests that the intervention group may have to cover additional energy requirements caused by exercise.

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Table 2 (*Continued*)

Topics of interest	Author, year, country	Participant characteristics including surgery type	Study design	Intervention	Duration of intervention	Comparison	Outcomes of interest	Results & conclusions of interest
- Protein intake - Muscle strength	Smelt et al, 2019, USA [31]	N = 100 undergoing SG (N = 57) or RYGB (N = 38) or revision surgery (N = 5)	Cohort study, retrospective	Cholecalciferol regimes: 800 IU/d, or 800 IU/d + 50 000 IU/mo Protein intake assessment (recommended intake: 1 g/kg body weight/d or ≥60 g/d)	6 mo	Low vs high cholecalciferol substitution Low vs high protein intake	Physical fitness (measured by handgrip strength & shuttle walk run test) preoperative, 3 and 6 mo postoperative Protein intake assessed by a 24-h dietary record	The protein intake has influence on postoperative handgrip strength ($P = 0.017$] but not on shuttle walk run test. Cholecalciferol regimens do not have significant effects on postoperative physical fitness.
- Dumping syndrome	Cadegiani et al, 2016, Brazil [32]	N = 25, after RYGB with a confirmed diagnosis of dumping syndrome	Pre-post intervention study	Administration of acarbose (4–5 × /d) Resistance training with variable frequency and intensity among participants	6 mo	Compared with pre-study	Occurrence of early and late dumping syndromes Ability to perform resistance exercises	Acarbose administration improved exercise capacity by preventing dumping syndrome ($P < 0.001$).
- Hypoglycemia	Proulx et al., 2018, Canada [33]	N = 29, 3 mo after SG (N = 16) or BPD-DS (N = 13), 24% with T2DM	Pre-post intervention study	Endurance + resistance training (1 h, 3 × /wk, supervised)	12 wk	Pre-exercise CBG vs post-exercise CBG	Change in CBG levels following exercise at various intervals after consumption of a meal	Moderate- to high-intensity exercise in patients with and without T2DM is safe. 7 of 577 exercise sessions (1.2%) were associated with asymptomatic hypoglycemia (CBG ≤3.9 mmol/L).
- Diet-related barriers to exercise - Eating behavior	Peacock et al, 2014, USA [34]	N = 366, from an online support website for patients with any type of bariatric surgery	Cross-sectional study	Online survey with closed- and open-ended questions and text boxes	N/A	N/A	Assessment of postoperative barriers to exercise	9.3% of participants reported physical barriers related to bariatric surgery. Some noted difficulty related to diet that affected energy and endurance.
- Fluid intake - Energy intake - Eating behavior - Hypoglycemia	Clark 2011, USA [35]	N = 1, A 40-y-old woman, with a history of obesity (BMI 58 kg/m^2), who trained for a marathon after RYGB.	Case study	Exercise training to run a half-marathon 7 mo post-surgery and a marathon (42 km) 20 mo post-surgery	2 y	N/A	Potential risks and nutrition challenges associated with endurance exercise in gastric bypass patients	It is possible for some post-bariatric patients to run a marathon. Due to the limited ability to consume food and fluids, difficulties preventing fatigue and dehydration during endurance exercise occurred.

BPD-DS, biliopancreatic diversion with duodenal switch; CBG, capillary blood glucose; DXA, dual-energy X-ray absorptiometry; GB, gastric band; RCT, randomized controlled trial; RYGB, Roux-en-Y gastric bypass, SG, sleeve gastrectomy; T2DM, type 2 diabetes mellitus

Table 3
Recent studies assessing post-bariatric nutritional issues and their therapeutic approaches

Topics of interest	Author, year, country	Participant characteristics including surgery type	Study design	Intervention	Duration of the study	Comparison	Outcomes of interest	Results & conclusions of interest
- Hypoglycemia	Gasser et al., 2019, Switzerland [36]	N = 113, ~1 y after RYGB	Cohort study, prospective	Standardized carbohydrate-rich solid mixed meal (simulation of normal habits) Protein-rich solid meal for testing a second time in patients with hypoglycemia after first meal	Measured over 150 min after standardized meal	Comparison of outcomes at several points after carbohydrate-rich/protein-rich meal	Plasma glucose and insulin 30, 60, 90, 120, and 150 min after a standardized carbohydrate-rich solid mixed meal Symptoms (autonomous/ neuroglycopenic)	The frequency of postprandial hyperinsulinemic hypoglycemia (11.5%, thereof 5.3% asymptomatic) was higher than generally reported in the literature. A screening of all patients after RYGB with solid mixed meals is suggested. At-risk patients should avoid carbohydrate-rich meals.
- Hypoglycemia	Hepprich et al., 2020, Switzerland [37]	N = 12, after RYGB	RCT (cross-over trial)	Patients received anakinra (IL-1 receptor antagonist) or empagliflozin (SGLT2-inhibitor) or placebo followed by a MMTT.	3 study days, separated by a 4- to 7-d washout period	Comparison between the 3 groups	Symptomatic postprandial hypoglycemia MMTT at every study day measuring, BG, C-peptide, insulin, etc.	Anakinra and empagliflozin reduced postprandial insulin release and prevented hypoglycemia. This study assumes that glucose-induced IL-1β leads to exaggerated insulin response and plays a role in postprandial hypoglycemia.
- Hypoglycemia	Øhrstrøm et al., 2019, Denmark [38]	N = 11, women after RYGB with reported hypoglycemia	RCT (cross-over trial)	Each patient evaluated during following interventions: acarbose 50 mg for 1 wk, sitagliptin 100 mg for 1 wk, verapamil 120 mg for 1 wk, liraglutide 1.2 mg for 3 kw, and pasireotide 300 µg as a single dose.	Baseline period + 5 treatment periods, all separated by ≥7-d washout periods	Comparison of different treatments	MMTT at end of each study period, measuring BG, insulin, C-peptide, etc. BG levels were measured using CGM for 6 d after all treatments, except pasireotide.	In an experimental setting, treatment with acarbose and pasireotide reduced post-bariatric hypoglycemia. Acarbose appears to have an overall glucose-stabilizing effect, whereas pasireotide leads to increased and sustained hyperglycemia.

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Table 3 (*Continued*)

Topics of interest	Author, year, country	Participant characteristics including surgery type	Study design	Intervention	Duration of the study	Comparison	Outcomes of interest	Results & conclusions of interest
- Micronutrient disorder	Ergun et al., 2020, Turkey [39]	N = 60 (n = 30 undergoing laparoscopic SG, n = 30 healthy control group with regular BMI)	Cohort study, prospective	Laparoscopic SG	12 mo	In comparison with healthy control group and pre-intervention	Serum level of Zn, Cu, Se, Fe, Mg, and biochemical parameters analyzed preoperatively and postoperatively at months 1 and 12.	Zn and Cu levels decreased through bariatric surgery. Mg level did not differ between groups but increased through bariatric surgery. Fe and Se levels were lower in the morbid obesity group than in the healthy control group but increased through bariatric surgery.
- Micronutrient disorder	Winzer et al., 2019, Austria [40]	N = 50, all with vitamin D deficiency after single anastomosis gastric bypass; 50% with T2DM	RCT, secondary analysis [a]	Intervention group: conventional vitamin D supplementation plus additional vitamin D doses in first month postoperatively Control group: conventional vitamin D supplementation*	12 mo	Secondary analysis evaluating changes of serum Mg level over time and between patients with/without T2DM	Serum Mg level before surgery, at 6 and 12 mo postoperatively	Patients neither with nor without T2DM showed changes in mean concentration of serum Mg after bariatric surgery.
- Micronutrient disorder	Lemieux et al., 2019, USA [41]	N = 1; A 68-y-old with history of BPD surgery in 1987	Case study	N/A	N/A	N/A	Blindness with irreversible retinopathy caused by extremely low vitamin A level (4 μg/dL)	BPD can lead to symptomatic vitamin A deficiency in the long-term if supplementation is lacking.
- Fluid intake	Elward et al, 2019, Egypt [42]	N = 102, after laparoscopic SG	Pre-post-intervention study	Laparoscopic SG	Measured at 24 h and 3 mo post-surgery	Early vs late tolerance Water vs juice tolerance Subjective vs objective (contrast flow pattern) findings	Early (24 h)/late (3 mo) post-surgery tolerance of drinking water vs of drinking juice Contrast flow pattern 24 h and 3 mo post-surgery	Significantly better early and late subjective tolerance of juice than of water. 29% showed late difficulties of drinking water; 5.9% showed late difficulties of drinking juice. Contrast flow pattern did not show a similar difference between juice and water.

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Table 3 (*Continued*)

Topics of interest	Author, year, country	Participant characteristics including surgery type	Study design	Intervention	Duration of the study	Comparison	Outcomes of interest	Results & conclusions of interest
- Orthostatic Intolerance - (Fluid intake)	Zhang et al., 2019, USA [43]	N = 4547, after RYGB (N = 3574) or SG (N = 973)	Cohort study, retrospective	Structured chart reviews of all patients with new-onset orthostatic intolerance post-surgery	N/A	N/A	Cumulative incidence and severity of orthostatic intolerance	Orthostatic intolerance is frequent in the bariatric population, affecting 4.2% of patients within the first 5 y post-surgery. 16.5% of those patients had severe symptoms that warranted treatment with vasopressor agents.

BPD, biliopancreatic diversion; (C)BG, (capillary) blood glucose; CGM, continuous glucose monitoring; Cu, copper; Fe, iron; IL, interleukin; Mg, magnesium; MMTT, mixed-meal tolerance test; RCT, randomized controlled trial; RYGB, Roux-en-Y-gastric bypass; Se, selenium; SG, sleeve gastrectomy; T2DM, type 2 diabetes mellitus; Zn, zinc

*This study was a secondary analysis of the data and blood samples from the LOAD (Link Between Obesity and Vitamin D) study [44].

Numerous guidelines on post-bariatric follow-up exist, which are inconsistent regarding fluid, macro- and micronutrient intake [18–21]. We based our discussion and comparisons on the latest American Bariatric Surgery Guidelines, as they are timely, comprehensive, and popular in the international literature [1]. These guidelines set energy requirements for post-bariatric patients at 1200 to 1500 kcal/d, disregarding physical activity level, BMI, sex, and age [1]. Furthermore, recommendations are not adapted to body weight, which differs widely within the target population.

In healthy individuals, the additional energy requirements induced by the recommended physical activity can be covered by a regular diet (1800–2400 kcal/d). Consequently, post-bariatric patients following the recommended volume of physical activity may not need additional energy intake. Table 1 summarizes the nutritional recommendations for post-bariatric patients and healthy individuals performing physical activity [1,11–14]. However, additional energy requirements strongly depend on the intensity and volume of physical activity in healthy individuals and likely also in the post-bariatric population [13]. If so, post-bariatric patients may have difficulties to meet the additional energy and protein requirements considering the small residual stomach volume and the gastrointestinal intolerances. In Shah et al.'s study, post-bariatric patients performing a high-volume exercise program (60–70% of VO_2 max) were unable to reduce their energy intake as much as the inactive [30]. Thereby, they may have compensated for an energy deficit caused by exercise. Peacock et al. assumed that insufficient energy intake of post-bariatric patients leads to reduced endurance, which was found to be a common barrier to physical activity [34]. The additional energy requirements may, however, intentionally not be covered in order to induce weight loss. The main concern of insufficient energy supply is the loss of lean body mass, but physical activity and adaptions in the macronutrient ratio may help to preserve it.

The current evidence does not allow the determination of the optimal energy intake and macronutrient ratio for physically active post-bariatric patients. Along with the current guidelines, the findings of the present review suggest prioritizing proteins over carbohydrates and fats to maintain/increase lean body mass. Our results strengthen the importance of the recommended protein intake ($\geq$60 g/d or $\leq$1.5 g protein/kg ideal body weight/d) [31] and suggest a benefit of higher protein intake [28,29]. A protein intake of 90 to 108 g/d (thereof 30–48 g whey protein) increases muscle strength and possibly skeletal muscle mass in physically active post-bariatric patients. The differences in skeletal muscle mass in the studies of Lamarca et al. and Oppert et al. may have arisen from differences in training program (45 versus 60 min of resistance training), different methods of measurement (dual-energy x-ray absorptiometry versus multifrequency electrical bioimpedance) and differences in study design. Muscle strength is an important marker for functional capacity, cardiovascular risk, and mortality [45,46]. Although it is controversial whether the protein requirements for a general fitness program in healthy individuals exceed the recommended dietary allowance (RDA) of 0.8 g protein/kg body weight/d, it is widely acknowledged that protein requirements may increase up to double (1.4–2 g/kg body weight/d) for high-volume or high-intensity exercise [13]. Current post-bariatric guidelines state 1.5 g protein/kg ideal body weight/d as the upper limit for daily protein intake, which is almost double the RDA of healthy individuals. This upper limit should not be exceeded since higher protein intake could harm the kidneys. Such a high protein intake may be hard to reach in everyday life, given frequent intolerances and aversions of post-bariatric patients to protein-rich foods, such as meat [17,47]. Additionally, the limited fluid tolerance of post-bariatric patients may interfere with the ingestion of

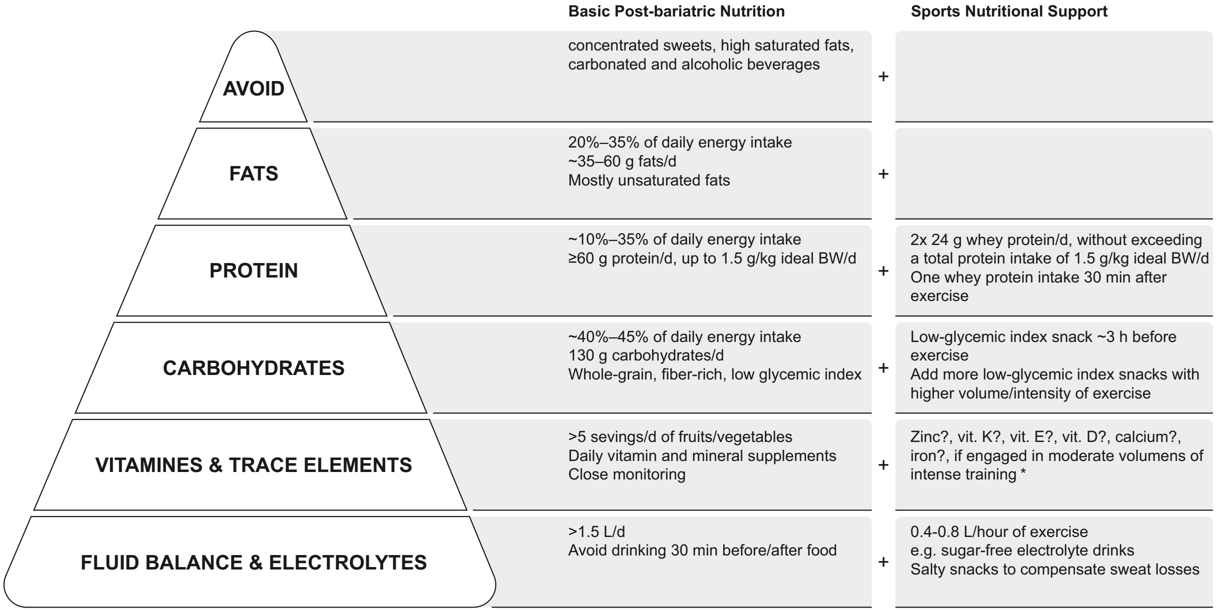

Fig. 2. Food pyramid for physically active post-bariatric patients. *Moderate volume of intense training: 2−3 h/d of intense exercise; 5−6 × /wk. Basic post-bariatric nutrition according to [1,54]. BW, body weight.

protein drinks. Branched-chain amino acid powder might be an alternative to whey protein drinks to maintain lean body mass during rapid weight loss [23,48].

The carbohydrate intake in post-bariatric patients is limited by the dumping syndrome and hypoglycemia [12], especially after intake of monosaccharides. The occurrence of hypoglycemia in post-bariatric patients is a relevant complication as it may interfere with safe exercising. Proulx et al. found only rare episodes of asymptomatic hypoglycemia (capillary blood glucose ≤3.9 mmol/L) during exercise sessions and therefore considered exercise as safe for post-bariatric patients [33]. This should be regarded critically given the short follow-up period since hypoglycemia most frequently appears 1 to 2 y post-surgery [36]. Nutrient timing and food composition are of prime importance to prevent hypoglycemic episodes during physical activity. Sports nutrition guidelines recommend a preactivity intake of protein and carbohydrates, which might provoke meal-induced hyperinsulinemic hypoglycemia in post-bariatric patients [13,33,38]. Post-bariatric patients might best tolerate low glycemic index snacks (15 g low glycemic index carbohydrate and 5−8 g fat) 30 to 120 min before the activity session [49,50]. High-glycemic index snacks are not recommended for post-bariatric patients as they might provoke meal-induced hyperinsulinemic hypoglycemia, which must be avoided during exercise [36]. Several drugs have recently been investigated to prevent post-bariatric dumping syndrome and hypoglycemia but they are not yet established in post-bariatric care [37,38].

The fat intake recommended in the guidelines is considered to be adequate regardless of physical activity level. A higher fat intake could eventually conflict with weight control [1]. The recommended micronutrient supplementation is considered sufficient for physically active post-bariatric patients. However, the loss of iron through sweating during high-intensity training such as running or triathlon (≤1 mg iron) may require an increased iron substitution [51]. It may be convenient to schedule timing for iron supplements intake, separated from training time, in trainings with high amounts of sweating expected. Since the interaction between bariatric surgery, physical activity, and micronutrient requirements is not completely understood, regular screening for micronutrient deficiency is of particular importance for physically active post-bariatric patients.

The recommended fluid intake for post-bariatric patients is ≥1.5 L/d [1]. According to sports nutrition guidelines, an additional fluid intake of 0.4 to 0.8 L for each hour of physical activity is needed to avoid dehydration [14]. Drinking such amounts of fluids may be challenging for post-bariatric patients as they often suffer from impaired fluid tolerance, especially water [52]. The following better-tolerated alternatives to water may be used to minimize symptoms of fluid intolerance, while providing sufficient hydration: yogurt-based drinks, coconut water [52], juices [42], or watery foods such as fruits or yogurt [35]. However, the intake of juices and fruits to increase fluid intake is controversial as it increases the sugar consumption. Furthermore, eating salty snacks or drinking isotonic beverages is recommended to replace sodium losses through sweating [35]. Overall, it is crucial for post-bariatric patients to compensate for physical activity-induced fluid and electrolyte losses because dehydration may further aggravate post-bariatric complaints (e.g., postprandial hypotension, orthostasis [43], or gastrointestinal distress [1,53]).

This is the first systematic review analyzing nutritional requirements in post-bariatric patients performing physical activity. We summarized the current state of knowledge about the basic requirements of post-bariatric patients and their additional needs induced by physical activity. This represents an important basis for further research. The recommendations should be regarded with caution, as they are based on few, heterogeneous, and small studies, especially when extrapolating them to the long-term since most studies were conducted in the first years post-surgery and have short follow-ups. At the review level, publication bias might affect the cumulative evidence.

Conclusion

This systematic review strengthens the importance of an adequate protein intake in physically active post-bariatric patients. Nutrient reference values of physically active post-bariatric patients are not definable based on the current evidence.

Consequently, clinicians caring for this population should pay special attention to the monitoring of macro- and micronutrients as well as fluid balance, especially when patients engage in high levels of physical activity. Physically active post-bariatric patients may benefit from some nutritional adaptions, as proposed in the food pyramid for physically active post-bariatric patients (Fig. 2).

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

CRediT authorship contribution statement

Rahel Stocker: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Visualization. **Meral Ceyhan:** Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Visualization. **Katja A. Schönenberger:** Writing – review & editing. **Zeno Stanga:** Writing – review & editing, Project administration, Supervision. **Emilie Reber:** Conceptualization, Methodology, Validation, Writing – review & editing, Project administration, Supervision.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.nut.2021.111577.

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