Review Article

Nutritional care of bariatric/metabolic surgery for the treatment of type 2 diabetes mellitus

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Contributions: (I) Conception and design: WJ Lee;(II) Administrative support: WJ Lee; (III) Provision of study materials or patients: JJ Chou, WJ Lee; (IV) Collection and assembly of data: JJ Chou, JC Chen; (V) Data analysis and interpretation: JJ Chou, JC Chen; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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Abstract: Bariatric/metabolic surgery (BMS) is highly effective in treating obese associated type 2 diabetes mellitus (T2DM) and a commonly performed surgical procedure worldwide now. However, vitamin D, calcium and iron deficiencies are commonly presented in obese patients before operation because of reduced bioavailability and poor dietary intake. These un-recognized or under-treated nutritional deficiencies might lead to devastating complications of bone, immune function, neurologic and muscular systems. Therefore, the benefit of BMS may be tempered by the associated post-operative nutritional deficiencies. Pre-operative nutritional screening and treatment thus are essential for BMS patients. The pre-operative existing nutritional deficiencies might be exacerbated after BMS due to reduced absorption, poor dietary intake and compliance with postoperative supplement instructions. Protein deficiency is the most commonly met macronutrient deficiencies after BMS. Iron, calcium and vitamin D deficiencies are commonly met micronutrient deficiencies after BMS and may bring significant clinical problems to the patients. Some micro-nutrient deficiencies, such as copper, selenium and zinc, are difficult to diagnose because difficult in assessment and frequently confounded by deficiencies in other nutrients. Therefore, post-operative nutritional supplements following established recommendations are essential for patients received BMS. In addition, all the patients should receive regular follow-up by a multidisciplinary team for the prevention and treatment of nutritional deficiencies in order to optimize the outcomes of BMS.

Keywords: Nutritional deficiency; nutritional care; bariatric surgery; metabolic surgery; morbid obesity; type 2 diabetes mellitus (T2DM); dietary plan; supplement; hyperparathyroidism; anemia; thiamin; hair loss; hypoalbuminemia; eating behavior; osteoporosis; encephalopathy, sleeve gastrectomy; gastric bypass; band; calorie

Received: 09 March 2018; Accepted: 28 March 2018; Published: 31 March 2018.
doi: 10.21037/ales.2018.03.10
View this article at: http://dx.doi.org/10.21037/ales.2018.03.10

Introduction

Bariatric surgery, a weight reduction surgery, is the most effective treatment for severe obesity (BMI >35 kg/m^2) with a marked improvement of T2D control (1-3). Encouraged by the success of bariatric surgery, gastrointestinal metabolic surgery has been recently proposed as a new treatment modality for obesity related type 2 diabetes mellitus (T2DM) in patients with BMI <35 kg/m^2 (3,4). Rapid development of bariatric/metabolic surgery (BMS) or the treatment of obesity and T2DM has occurred in recent decades. More than half a million BMSs were performed according to the statistics of International Federation of Surgery of Obesity and Related Disease (IFSO) (5-7). However, the long-term nutritional deficiencies are relatively common after BMS and the prevalence was reported to be more than 80% (8-10). The benefits of BMS might be tempered by the associated nutritional

Table 1 Common nutritional deficiencies in severe obese patients

Nutritional deficiencies	Definition	Prevalence
Vitamin D	Mild <30 ng/mL (75 mmol/L)	45.2–97.5%
	Moderate <20 ng/mL (50 nmol/L)	11.5–46.3%
	Severe <10 ng/mL (25 nmol/L)	2.4–16.3%
SHPT	iPTH >69 pg/mL	22.6–32.4%
Calcium	Deficiency (<8.4 mg/dL)	3–12.2%
Phosphate	Deficiency	16.3%
Iron	Deficiency (≤50 μg/L)	9.6–26%
Hemoglobin (Hb)	Anemia (Hb ≤11.5 g/dL)	2.9–10.8% (female)
Ferritin	Insufficiency (ferrtin<4.6 ng/mL)	1.1–3.0%
Vitamin B_1	<126 nmol/L	22%
Vitamin B_6	<20 nmol/L	24%
Vitamin B_{12}	Insufficiency (<145 pg/mL)	1.8–5.1%
Vitamin E	<21 umol/L	15%
Vitamin A	<1.5 umol/L	6.2–10%
Vitamin C	<5 mg/L	33%
Folic acid	Insufficiency (folate <7.0 nmol/L)	0–25%
Albumin	Insufficiency (<3.4 g/dL)	0.9–8.2%
Homocysteine	Insufficiency	8.1%

SHPT, secondary hyperparathyroidism; iPTH, intact parathyroid hormone.

deficiencies, either preexisting malnutrition or induced by gastrointestinal surgery if no adequate nutritional support is given. The present review summarizes the common nutritional problems before and after BMS, and current recommendations for screening, supplement and treatment.

Nutritional deficiencies in severe obese patients

Although obesity is usually recognized as an over-nutritional status, obese patients actually are commonly associated with mal-nutritional problems. *Table 1* summarized the reported prevalence of nutritional deficiencies in severely obese patients from different literatures (11-35). Some common deficiencies are discussed at below.

Vitamin D and calcium deficiency

Vitamin D deficiency is the most commonly seen nutritional deficiency in obese patients. Although severe deficiency (<10 ng/mL) is not high (2.4–16.3%), the incidence of mild vitamin D deficiency (<30 ng/mL) in morbidly obese patients before operation has been reported to range from 45.2% to 97.5% (11, 17). The high incidence of vitamin D deficiency in obese patients is attributed to an increased uptake of the vitamin D by adipose tissue, limited exposure to sunlight due to inactivity and reduced hepatic synthesis of vitamin due a functionally impaired liver cause by steatosis (32). Previous studies also suggested that vitamin D deficiency is the major cause of secondary hyper parathyroidism (SHPT) defined by intact parathyroid hormone (iPTH) >69 ng/mL which is frequently observed in about 20% obese individuals (21-25,31). Calcium deficiency is not high in severely obese patients before BMS. Thus, SHPT with normal calcium can be regarded as a subclinical calcium deficiency but mostly is attributed to vitamin D deficiency.

Iron deficiency and anemia

Iron deficiency is the second common nutritional deficiency

in severely obese patient, especially in productive age women. The reported incidence varied from 9.6–26% with associated anemia in up to 10.8% female patients (31). Post-operative anemia more frequently develop in patients with pre-operative existed anemia and iron deficiency (34). An optimal preoperative value of hemoglobin 15.6 mg/dL can predict the postoperative anemia after gastric bypass surgery (34). If patients had pre-operative anemia, the reason of iron deficiency and anemia should be investigated and a dietary counseling is essential. If the deficiency is difficult to be corrected, a gastric bypass procedure should be avoided.

Protein deficiency

Protein deficiency is usually evaluated by serum albumin level. Hypoalbuminemia (<3.5 g/dL) can be found in about 5% of bariatric patients in pre-operative assessment. Inadequate protein intake or disease status, such as liver cirrhosis or nephropathy, may be the underlying situation. The reason of hypoalbuminemia should be investigated and corrected if possible. Bypass surgery, Roux-en-Y gastric bypass (RYGB) or single anastomosis gastric bypass (SAGB) is usually avoided in patients with hypoalbuminemia and sleeve gastrectomy (SG) is now more commonly performed in patients with end stage renal or liver disease (36,37).

Others

Other nutritional deficiencies are rare and may not be checked routinely. Some micro-nutrient deficiencies, such as copper and zinc, are difficult to diagnose because difficult in assessment and frequently confounded by deficiencies in other nutrients. However, clinician should keep in mind the possibilities and prevalence of various nutritional deficiencies in obese and T2DM patients.

Pre-operative nutritional evaluation and treatment

Because nutritional deficiencies are commonly presented in obese and T2DM patients and may be aggravated after BMS, pre-operative nutritional evaluation with laboratory test is strongly recommended. The laboratory data can also be used for the reference data at follow-up. Nutritional deficiencies detected before BMS should be aggressively treated. In addition, dietary and behavioral counseling is recommended for detecting the mal eating behavior and meeting the nutrient requirements. An effective dietary counseling will lead to an improvement in the dietary macronutrient and micronutrient intake in BMS patients (38).

Many studies now suggested a higher vitamin D level (>30 ng/mL) is helpful for the optimal outcomes in critically ill patients (39,40). Therefore, an aggressively treatment of vitamin D insufficiency and SHPT before BMS might be indicated and recommended (41).

Post-operative diet management

Immediate postoperative period

In modern laparoscopic BMS practice, the patient is usually discharged after 24 or 48 hours. Therefore, dietician should give the postoperative diet instruction before the surgery or immediately after surgery so as not to delay the discharge of the patients. If the patient is allowed to start oral intake, it should start from clear liquid diet for 3–7 days, followed by liquid diet and soft diet for the first month. A liquid diet may avoid the vomiting or bowel obstruction at immediate postoperative period which might jeopardize the surgical wound or anastomosis. The patients usually feel restriction at the first 3 months after BMS. Thus, to start a solid food should be delayed after the wound healing is complete and must be very cautiously at starting.

Adequate hydration is the most important thing at the first post-operative week. The patient should drink a minimal 1,500 cc fluid daily and monitor the urine amount. A balance diet is recommended but protein intake should be adequate at immediate postoperative period to help the wound healing. Recommended protein intake is 60 g/day for the patients and is sometimes difficult to achieve. Liquid protein supplement may be recommended for the patients in the first 3 months after BMS. *Table 2* summarized the diet progression schedule for BMS.

For T2DM patients, achievement of postoperative glycemic control (HbA1c ≤7%; blood glucose ≤110 mg/dL fasting and ≤180 mg/dL postprandial) represents a realistic goal. Preoperative glycemic control represented by an HbA1c less than 7% has been associated with decreased perioperative infectious complications (42). Patients with poor control on oral medications or who require high doses of insulin preoperatively may require insulin for several days after surgery to maintain blood glucose concentrations in a desirable range. Patients requiring insulin before surgery should have their blood glucose concentrations monitored regularly and insulin administered as needed to control hyperglycemia (43).

Table 2 Dietary proceedings after bariatric/metabolic surgery

Time after Surgery	Diet recommendation
Days 1–7	Clear liquids under supervision for 1–2 days
	Drink 1,500 mL fluid, in small amount
	May start full liquids after day 3, protein rich prefer
	6 meals a day
	Start multivitamin and mineral supplementation (fluid)
Week 2–4	Increase fluid intake to 2,000 mL
	Replace full liquid diet with soft diet gradually
	6 meals a day
	Eat protein first (60–80 g/d)
Month 2–3	Solid food but by small bites and chew thoroughly before swallowing
	4–6 meals/d
	Fluid 1,500–1,900 mL
	Protein 60–80 g/d
After month 3	Daily calories 1,200–1,500 calories
	Balance diet with protein first, followed by vegetables, fruits and grains
	Chew small bites (aim to 30 chews for each bite)
	3 meals and 2 snacks/d (limit size to 1 cup)
	Total fluid 1,500–1,900 mL/day

Long-term diet management (general instruction)

The principle of diet after BMS is high protein and low-fat diet. The patients should eat on a regular dieting plan, not according to hunger or not. Daily calories should not be lower than 800–1,200 Kcal. Lower than this level may hurt the body. Daily calories higher than this amount may cause inadequate weight loss or weight recidivism. Low fiber diet is recommended in early post-operative period to avoid vomiting or ileus and gradually back to normal fiber diet.

Long-term diet management (protein)

Dietary protein need is often presented as a percentage of energy in-take. It's range as 10–35% of total energy. In general, dietary protein should be established first in any diet in proportion to body weight, and then carbohydrates and fats can be added as determined by energy needs. Protein is an important part of good nutrition at every meal. The daily protein is recommended to have 60–120 g or 1.1–1.5 g/kg ideal body weight (IBW) in all patients with BMS to maintain lean body mass during weight loss and for the long term (44). Protein deficiency is the most commonly seen macronutrient deficiency. One study reported a 4% incidence of protein deficiency after RYGB up to 43 months postoperatively (20). Prevention of protein malnutrition requires regular assessment of protein intake and counseling regarding ingestion of protein from protein-rich foods and modular protein supplements. This is especially important in those treated with mal-absorptive procedures to prevent protein malnutrition and its effects (44).

Long-term diet management (carbohydrate)

Dietary carbohydrate intake is often recommended to be 50–100 g which may completely degrade the lipid into carbon dioxide and water. Patients received BMS should intake enough carbohydrate to maintain the balance of body function but avoid mono-glucose sweets, such as soda, juice and candy, to avoid the dumping syndrome. Patient is recommended to intake polysaccharide food in accompanying with protein and vegetable. The ingestion sequence should be protein first, followed by vegetable and carbohydrate the last.

Long-term diet management (fat)

Daily fat ingestion should be lower than 50 g daily after BMS. Dietary fat contains essential fatty acids which can't be synthesized by the body but are important components of cell membrane and lipoprotein. Deficiency in essential fatty acid may cause growth retard, dermatitis and alopecia. At the same, dietary fat also contains fat soluble vitamins (vitamin A, D, E, K) and facilitates the absorption of these vitamins in small intestine. Thus, care should be given to the absorption of fat soluble vitamins when the fat intake was decreasing. Most of the dietary fat was first degraded in stomach, then in small intestine and absorbed. Ninety-five per cent of fatty acids are absorbed in duodenum and jejunum. Gastric bypass surgery might reduce acid secretion, decrease absorption from small intestine and inadequate degradation of fat. Therefore, over intake of dietary fat may cause oil stool or diarrhea and influence the

gastrointestinal quality of life in patients with gastric bypass procedure.

Post-operative supplement recommendation

Micro nutrients (vitamins and minerals) deficiencies are very easily developing after BMS because decreasing ingestion (gastric restriction and change of gut hormones). Different procedures may have influences on nutrients absorption (usually mal-absorptive procedure, biliopancreatic diversion (BPD)/duodenal switch (DS), may have the highest nutritional problem). Individual difference also exists. Therefore, standardized nutritional supplement is usually recommended but should be individualized suggested according to the follow-up laboratory data (45). Commonly developed micronutrients deficiencies include vitaminB_1, B_{12}, folic acid, A, D, E and K; iron, calcium, copper, zinc and selenium. According to the ASMBS guideline, multivitamins and minerals tablet should be given for all sleeve gastrectomy (SG) and bypass patients (46). Additional supplement of iron, vitamin B_{12}, or calcium with vitamin D should be considered in patients at increased risk (*e.g.*, existing osteoporosis and heavy menstruation).

The daily multivitamins and mineral tablets should include the following components:

Thiamin: 12 mg thiamin daily and preferably a 50 mg dose of thiamin from a B-complex supplement or multivitamin once or twice daily to maintain blood levels of thiamin and prevent thiamine deficiency.

Vitamin B_{12}: 350–500 mcg daily or 1,000 mcg parental monthly is recommended.

Folate (vitamin B_9): 400–800 mcg oral folate daily from their multivitamin. Women of childbearing age should take 800–1,000 mcg oral folate daily.

Fat soluble vitamins A, D, E, K: vitamin A (5,000–10,000 IU/d), Vitamin K dose (90–120 ug/day) and Vitamin E dose (15 mg/d). Additional supplementation of vitamin A (10,000 IU/d) and vitamin K (300 μg/d) is recommended for mal-absorptive procedure, BPD or DS. Recommended vitamin D_3 dose is 3,000 IU daily, until blood levels of 25 (OH)D are greater than sufficient (30 ng/mL)

Calcium: recommended doses of elemental calcium after bariatric surgery range from 1,200–2,000 mg daily, and these usually contain vitamin D as well. All post-BMS patients should take calcium supplementation, 1,200–1,500 mg/day. Calcium citrate preparations are preferred because this salt is better absorbed in the absence of gastric acid production. The appropriate dose of daily calcium for BPD/DS is 1,800–2,400 mg/day

Iron: post-BMS patients at low risk (males and patients without history of anemia) for post-WLS iron deficiency should receive at least 18 mg of iron from their multivitamin. Menstruating females and patients who have undergone RYGB, SG or BPD/DS should take at least 45–60 mg of elemental iron daily (cumulatively, including iron from all vitamin and mineral supplements). Oral supplementation should be taken in divided doses separately from calcium supplements, acid reducing medications, and foods high in phytates or polyphenols.

Zinc: all post BMS patients should take zinc with 100–200% of the recommended daily dose (8–22 mg/day) based upon type of procedure. To minimize the risk of copper deficiency in post-BMS patients, it is recommended that the supplementation protocol contain a ratio of 8–15 mg of supplemental zinc per 1 mg of copper.

Copper: all post-BMS patients should take copper as part of routine multivitamin and mineral supplementation, with dosage 1–2 mg/day based upon type of procedure.

Post-operative follow-up and treatment of common nutrition deficiencies

Nutrition deficiencies are very easily developing after BMS because of two main factors: (I) mal-absorption induced by gastrointestinal anatomic change (gastric restriction and change of gut hormones); (II) poor compliance of the patient to supplement and treatment. While the first one is not modifiable, proper supplementation combined with dietary education may be efficient in managing malnutrition. Therefore, every patient should be evaluated before BMS and regularly followed after surgery for the ability to comply with nutrition supplement, life modification, detecting nutritional deficiencies and given appropriate treatment. Nutritional deficiencies after BMS are related to surgical procedures. Adjustable gastric banding had the lowest incidence where malabsorptive procedure (BPD/DS) had the highest incidence (47-50). SG had a similar incidence or lower incidence than RYGB. SAGB sit between RYGB and BPD/DS (51). Some commonly met nutritional problems after BMS were listed in *Table 3* and discussed below:

Anemia and related deficiencies

Anemia is the commonly seen clinical nutritional problem, commonly secondary to iron, vitamin B_{12} and folic acid

Table 3 Common nutritional deficiencies after bariatric/metabolic surgery

Prevalence	Band	Sleeve	Bypass	BPD/DS
Vitamin D <30 ng/mL	–	0–90%	21.6–83%	63–73%
SHPT (iPTH >69 ng/mL)	38.5%	16.7–41.7%	11.7–57.1%	73.6%
Calcium<8.4 mg/dL	0	3.1–12.5%	1.9–13.9%	–
Iron ≤50 μg/dL	12%	4.3–30%	10.6–50%	23%
Hb ≤11.5 g/dL	10%	11.2–54.2%	17.2–64.3%	–
Ferritin <4.6 ng/mL	–	6.5–23.8%	18.8–36.2%	–
Vitamin B_1 <126 nmol/L	–	0–25%	1.8–8.4%	18%
Vitamin B_6 <20 nmole/L	–	0–26.3%	1.8–8.4%	–
Vitamin B_{12} <145 pmol/L	–	0–12.5%	2.9–61.8%	–
Vitamin A <1.5 umol/L	–	–	28–56.8%	61–69%
Vitamin C <5 mg/L	–	–	10–34.6%	–
Folic acid <7.0 nmol/	–	20–38%	18.4%	–
Albumin <3.5 g/dL	6%	0–4.8%	1–4%	3.4–25%
Potassium	0%	3.1–12.5%	1.9–13.9%	–
Magnesium	0%	6.3–14.1%	4.3–32.1%	–
Zinc	–	12.5%	25.7–40.5%	90.3%
Cupper	–	–	3.8%	30–90.7%

Band, adjustable gastric banding; Sleeve, sleeve gastrectomy; Bypass, gastric bypass; BPD/DS, biliopancreatic bypass/duodenal switch; SHPT, secondary hyper parathyroidism; iPTH, intact parathyroid hormone.

deficiencies, may complicate BMS in the long-term. Most of the anemia after BMS was attributed to iron deficiency with the reported incidence from 0–64.3% (*Table 3*). Many factors such as the bypass of duodenum, absence of acid in the gastric pouch, and the decreased food intake contributed the high incidence of anemia after BMS, especially bypass procedures. However, anemia not only is commonly seen in bypass patients but also seen in sleeve gastrectomy patients (52-54). Systemic inflammation may decrease the absorption of iron and contribute to the development of anemia as well as the low efficiency of oral iron. The bioavailability of vitamin B_{12} requires an acid environment, the intrinsic factor produced by parietal cell and intact ileum. Folic acid deficiency is related to decreased diet intake. Folic acid may present in 38% of patients after BMS but vitamin B_{12} deficiency is rare if vitamin supplementation is taken.

For anemia treatment, oral iron with vitamin B_{12} and folic acid was the first line treatment. Hemo iron has a better absorptive efficiency than mineral iron but may not be appropriate in Muslim because it was made by pig blood. Parental iron might be need in patients with persistent iron deficient anemia.

Anemia was less found in patients with regular postoperative visits highlight the importance of diet counseling (37). Diet behavior was found to influence the development of anemia after gastric bypass (55). Diet counseling should be given in patients with anemia with the emphasis of increasing the ingestion of high-protein drinks, food or alcohol (55). Other rare nutrients deficiencies which might be related to anemia are copper, vitamin A and selenium (33).

Secondary hyperparathyroidism, vitamin D and calcium

SHPT (PTH >69 pg/m), the most commonly seen laboratory abnormality after BMS is an indicator of subclinical calcium deficiency. SHPT may present in 20% of severe obese patients before BMS but increase to 40–80% after surgery (31). Vitamin D deficiency is the major cause of SHPT before BMS (31). The rapid increase of the incidence of SHPT after

BMS was attributed to vitamin D and calcium deficiency, especially in mal-absorptive procedure (31). However, controversy existed. Signori found that postoperative PTH and vitamin D was unrelated (19).

Vitamin D with calcium supplement was the standard treatment of SHPT. For vitamin D depletion patients, weekly high dose vitamin D (50,000 IU) was found more effectively than the tradition daily supplement in correcting vitamin D depletion, attenuates cortical bone loss and improving resolution of hypertension (56). Untreated SHPT might cause osteoporosis and increase the risk of bone fracture at long-term (57,58).

Protein deficiency

Hypoalbuminemia (<3.5 g/dL) can be found in around 5–8% of bariatric patients after BMS, mostly after bypass surgery. Patients with low serum albumin may suffer from lower legs pitting edema, anemia, hair loss and weakness. Inadequate protein intake and decrease of absorption due to gastric restriction and intestinal bypass are the main reason. Some disease status, such as liver cirrhosis or nephropathy, may be the underlying situation. However, inadequate protein intake is the main correctable reason of protein deficiency. The reason of hypoalbuminemia should be investigated and corrected if possible. The protein intake after BMS is usually below recommended levels (53). Diet counseling is advisable and helpful. Sometimes, liquid protein formulas are required to supply a diet of high-quality protein. Thus, bypass surgery is usually avoided in patients with pre-operative hypoalbuminemia. Some patients with intractable hypoalbuminemia after bypass surgery can be converted to normal anatomy or to sleeve gastrectomy (59).

Hair loss

Hair loss after BMS is common, but the cause is not easily diagnosed. Protein, iron and zinc deficiencies are common nutritional causes. Stress and acute weight loss may also be the causes. However, hair loss usually occurred at the 3–6 months period after surgery and stabilized after 6 months. Supplement of zinc and iron may be helpful (60,61).

Thiamine

Although rare, thiamine deficiency is one of the serious nutritional deficiencies might occur after BMS (62). The most important risk is prolonged and severe vomiting after BMS because thiamin can be rapidly depleted due to its short half-life of 9–18 days. Thiamine deficiency is also common in individuals have small bowel bacterial overgrowth (63). Small intestinal bacterial overgrowth may also reduce vitamin B_{12} level and deconjugate bile acid that are required for micelle function, which is important for the absorption of fat-soluble vitamins. Thiamin deficiency will result in Wernicke's encephalopathy and Korsakoff's psychosis. Intravenous thiamin infusion may be indicated in severe deficiency cases. Other nutrients that might be associated with neuropathy included thiamin, copper, calcium, folate, homocysteine, magnesium, vitamin B_{12}, phosphorous, vitamin B_1, vitamin B_6, and vitamin D (64).

Others

Most of the studies of essential nutrients after BMS include iron and calcium. Other long-term deficiencies of other minerals after BMS have not been evaluated. These deficiencies are cofactors in antioxidant enzymes and proteins. Zinc, copper, selenium, magnesium and chromium are acceptor or domain of electrons. Other nutritional deficiencies are rare and may not be checked routinely. However, clinician should keep in mind the possibilities and prevalence of various nutritional deficiencies in obese and T2DM patients.

Conclusions

Nutritional deficiencies are commonly present in severe obese and T2DM patients, including vitamin D and iron deficiency. Undetected nutritional deficiency in severely obese and T2DM may be aggravated after BMS and jeopardize the patients. On the other hand, many *de novo* nutritional deficiencies may develop after BMS and bring serious complication to BMS patients. Thus, all patients should receive comprehensive nutritional screening and dieting education before undergoing BMS. Nutritional supplements and regular follow-up for nutritional check-up and treatment are also mandatory for all the BMS patients.

Acknowledgments

Funding: None.

Footnotes

Provenance and Peer Review: This article was commissioned by the editorial office, *Annals of Laparoscopic and Endoscopic*

Surgery for the series "Laparoscopic Metabolic Surgery for the Treatment of Type 2 Diabetes in Asia". The article has undergone external peer review.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/ales.2018.03.10). The series "Laparoscopic Metabolic Surgery for the Treatment of Type 2 Diabetes in Asia" was commissioned by the editorial office without any funding or sponsorship. WJL served as the unpaid Guest Editor of the series and serves as an unpaid editorial board member of *Annals of Laparoscopic and Endoscopic Surgery* from Jun 2016 to May 2018. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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doi: 10.21037/ales.2018.03.10
Cite this article as: Chou JJ, Chen JC, Lee WJ. Nutritional care of bariatric/metabolic surgery for the treatment of type 2 diabetes mellitus. Ann Laparosc Endosc Surg 2018;3:29.

