Chung *et al. Metab Target Organ Damage* 2024;4:38
DOI: 10.20517/mtod.2023.51

Metabolism and Target Organ Damage

Review

Open Access

Obesity, kidney and metabolic bariatric surgery: a surgeon's narrative review

Yoona Chung, Bomina Paik, Dongjae Jeon, Yong Jin Kim

Bariatric and Metabolic Surgery Center, Department of Surgery, H+ Yangji Hospital, Seoul 08779, Republic of Korea.

Correspondence to: Dr. Yong Jin Kim, Bariatric and Metabolic Surgery Center, Department of Surgery, H+ Yangji Hospital, 1636, Nambusunhwan-ro, Gwanak-gu, Seoul 08779, Republic of Korea. E-mail: yjgs1997@gmail.com

How to cite this article: Chung Y, Paik B, Jeon D, Kim YJ. Obesity, kidney and metabolic bariatric surgery: a surgeon's narrative review. *Metab Target Organ Damage* 2024;4:38. https://dx.doi.org/10.20517/mtod.2023.51

Received: 11 Dec 2023 **First Decision:** 11 Apr 2024 **Revised:** 26 Sep 2024 **Accepted:** 12 Oct 2024 **Published:** 25 Oct 2024

Academic Editor: Amedeo Lonardo **Copy Editor:** Ting-Ting Hu **Production Editor:** Ting-Ting Hu

Abstract

Excess body weight impacts kidney function in individuals with severe obesity, primarily through metabolic alterations in adipocytes, especially in visceral adipose tissue. The relationship between persistent sterile inflammation associated with obesity and the progression of obesity-related kidney disease to chronic kidney disease (CKD) is an area of growing interest. The beneficial effects of weight loss on the prevention of kidney disease and the improvement of kidney function in individuals with obesity have been well documented. Currently, the most effective weight loss strategy is metabolic bariatric surgery (MBS), which has been proven to not only prevent the progression of CKD but also reverse it. However, awareness and understanding of the impact of obesity on the kidney should also extend to the severely obese population with clinically normal renal function. The purpose of this review is to outline the current knowledge on the pathophysiology of obesity-induced kidney damage, the effects of MBS on renal function in severely obese individuals with or without CKD, and provide the current evidence on perioperative management strategies for CKD patients, including diet and nutrition.

Keywords: Kidney function, severe obesity, metabolic bariatric surgery, chronic kidney disease, albuminuria, proteinuria, obesity-related kidney disease, obesity-related glomerulopathy

INTRODUCTION

Obesity is a global issue that is ever more discussed with its rise in incidence. According to the World

Obesity Atlas 2023, approximately 24% of the global population is projected to have severe obesity [body mass index (BMI) ≥ 30 kg/m^2] by 2035, which represents an alarming increase from the reported rate of 14% in 2020[1]. We are now living in an era where obesity is responsible for more deaths than underweight conditions[2]. Severe obesity is associated with an increased risk of hypertension, type 2 diabetes mellitus (T2DM), dyslipidemia, metabolic dysfunction-associated fatty liver disease (MAFLD), osteoarthritis, sleep apnea, and various cancers. These conditions contribute to higher morbidity and mortality rates within this population, and the detrimental effects of obesity on metabolic dysfunction are the focus of ongoing research[3,4]. The mechanistic links between chronic kidney disease (CKD) and concurrent MAFLD in the severely obese have been consistently reported over the years[5-7]. These findings indicate the interconnected pathogenesis of end-organ damage resulting from severe obesity in the presence of metabolic dysfunction. There has been an increasing interest in understanding the differences between severely obese patients who are metabolically healthy and those who have metabolic dysfunction. Understanding the effects of excess body weight and severe obesity on the function of the kidney and the development of CKD is a relevant subject to distinguish and prevent irreversible damage to end organs.

Severe obesity is associated with a chronic inflammatory state and its impact on metabolism and overall health can be traced back to the adipocyte. Adipocytes are now recognized not only as energy storage cells but also as endocrine organs that influence systemic homeostasis[8]. The relentless inflammatory state of the adipocytes of the visceral adipose tissue (VAT) in the obese produces proinflammatory cytokines that increase insulin resistance while activating the renin-angiotensin-aldosterone system (RAAS). This eventually leads to renal inflammation and hyperfiltration, which may persist in certain patients with high levels of proinflammatory cytokines [Il-1 β and tumor necrosis factor α (TNF-α)] despite weight loss after metabolic bariatric surgery (MBS)[9-11]. Impairment of renal function in super-obese patients can manifest as albuminuria, proteinuria, hyperfiltration, and tubular sodium reabsorption. The steady low degree of inflammation at the cellular level, oxidative stress, and eventual fibrosis contribute to the surprisingly high incidence of stage III to V CKD in the severely obese at 10.6%. This number is higher than that in the patient population with T2DM. In a study by Serra *et al.*, 77% of the 95 patients with severe obesity and clinically normal renal functions exhibited glomerular lesions[12].

Although the intricacies of severe obesity, innate and adaptive immune system, and kidney function are not completely understood, weight loss has been shown to directly improve systemic inflammation and glomerular hyperfiltration, resulting in improved renal function[13]. MBS has become known as the most effective preventive and treatment method for severely obese patients with CKD[13,14]. However, our goal should be not only to prevent and improve renal function in severely obese patients with CKD but also to raise awareness of obesity-induced kidney damage and help prevent the progression of irreversible damage in severely obese patients with clinically normal renal function[15,16].

The purpose of this review was to describe the current knowledge on the pathophysiology of obesity-induced kidney damage, the effect of MBS on renal function in the severely obese with or without CKD and also provide the current evidence on perioperative management strategies for patients with CKD, including diet and nutrition.

The effect of obesity on the kidney

Severe obesity impacts the kidney through both metabolic and hemodynamic (mechanical) mechanisms. The reduced afferent vascular resistance of the glomerulus and increased glomerular flow result in glomerular hypertension. The obesogenic changes in the adipocytes contribute to the pathophysiology starting from defects in glomerular permeability. With increased metabolic dysfunction due to lipotoxicity

(even from the perirenal fat, "fatty kidney"), glomerular hypertension and hyperfiltration develop, leading to renal inflammation[9,17]. With persistent stress, glomerulomegaly occurs, which is considered the marker for increased risk for the eventual development of obesity-related kidney diseases such as obesity-related glomerulonephropathy (ORG) with or without focal and segmental glomerulosclerosis (FSGS) [Figure 1][18].

Increased glomerular pressure

The initial assault on the kidney starts with the activation of the RAAS and sympathetic system along with insulin resistance, which induces hyperfiltration, the most important pathogenic factor of obesity-related kidney disease, directly and indirectly[15]. The overactive RAAS increases the levels of aldosterone, which induces vasoconstriction of the efferent arteriole. This results in an increased transcapillary pressure difference, which leads to hyperfiltration[19]. The change in the adipocyte of the severely obese promotes the secretion of proinflammatory cytokines (adipocytokines) such as TNF-α, leptin, and interleukins that are known to induce insulin resistance[20]. Insulin resistance itself also contributes to the increased glomerular pressure through vasoconstriction[21]. Because the insulin receptor is expressed on renal tubular cells and podocytes, insulin has a direct effect on the tubular function and viability of the podocytes. Insulin normally activates the phosphatidylinositol 3-kinase pathway, increasing the production of nitric oxide, which results in vasodilation. This pathway is impaired with insulin resistance, causing vasoconstriction and contributing to hyperfiltration. In addition to the vasoconstriction caused by the adipocytokines and insulin resistance, the increased levels of leptin further activate the sympathetic nervous system by promoting the secretion of renin in the kidney, which increases oxidative stress and the secretion of proinflammatory cytokines[19,22].

The tubuloglomerular feedback contributes to the pathophysiology of obesity-related kidney disease by increasing sodium reabsorption in response to an increased sodium filtration rate due to glomerular hypertension[23]. This, in turn, decreases the delivery of solute to the macula densa, which promotes the dilation of the afferent arteriole and further enhances hyperfiltration. Additionally, the activated RAAS stimulates sodium reabsorption at the proximal and distal tubules by activating epithelial Na+ channels and binding to the mineralocorticoid receptors[24,25]. Thus, the RAAS blockers have been found to reduce the degree of hyperfiltration and thus improve albuminuria[26]. Research has demonstrated that individuals with severe obesity are more sensitive to the nephroprotective effects of RAAS blockers than non-obese individuals[17].

The sodium-glucose cotransporter 2 (SGLT2) is activated by hyperglycemia, which results from insulin resistance due to the proinflammatory adipocytokines. The activated SGLT2 induces sodium reabsorption in the proximal tubule and reinforces the tubuloglomerular feedback[27]. These findings contribute to our understanding of the nephroprotective effects of SGLT2 inhibitors, which, in turn, help mitigate hyperfiltration[28]. A systematic review of SGLT2 inhibitors has reported reduced risk of dialysis, transplantation, and death[29]. The nephroprotective properties of SGLT2 inhibitors, irrespective of baseline albuminuria with RAAS blockade, are shifting the paradigm in the prevention and treatment of obesity-related kidney disease[18].

Hyperfiltration is also promoted by the excess adipose tissue. The renal blood flow has been known to be increased in the severely obese due to higher intra-abdominal pressure and increased extracellular fluid volume. The overactive sympathetic system increases the cardiac output and heart rate as these mechanical mechanisms further aggravate the degree of hyperfiltration[24,25].

Consequences of mechanical stress on the glomerulus

Hyperfiltration and sodium reabsorption surmount to induce the hypertrophy of glomerular basement membrane (GBM) and podocytes by an enhanced tensile strength of the capillaries[30]. The combination of

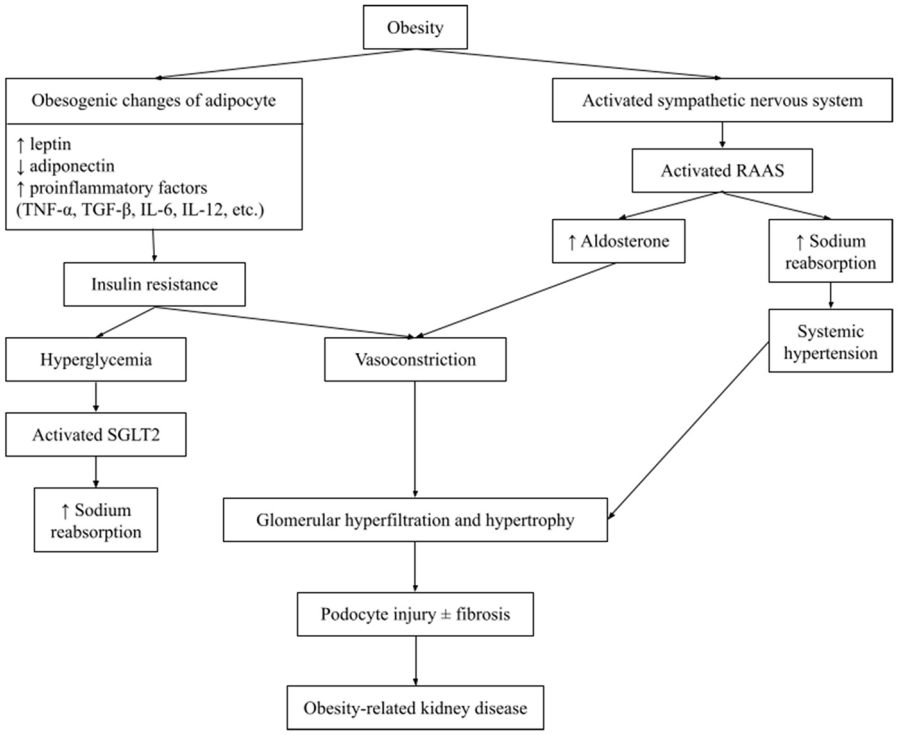

Figure 1. Pathogenesis of obesity-related kidney disease. ↑: increase in; ↓: decrease in. TNF: Tumor necrosis factor; TGF: transforming growth factor; IL: interleukin; SGLT2: sodium-glucose cotransporter 2; RAAS: renin-angiotensin-aldosterone system.

proinflammatory adipocytokines and increased aldosterone additionally promotes the production of type IV collagen, resulting in glomerular hypertrophy or glomerulomegaly[23]. High levels of leptin, low levels of adiponectin, insulin resistance, and oxidative stress further cause endothelial dysfunction and deformed podocytes[26]. Podocytes are unable to divide; instead, they can only stretch to cover the expanded GBM, which can lead to discrepancies in the areas they cover[30]. Because the podocyte becomes thinned and bulges into the urinary space, the pressure from hyperfiltration leads to the detachment of the podocyte from the GBM. These changes result in a compromised glomerular filtration barrier, which precipitates proteinuria that already exists due to hyperfiltration itself[31].

In early stages without evidence of glomerular dysfunction, the increased renal flow shortens the contact time between protein (amino acids and albumin) and the proximal tubular epithelium. This reduces the reabsorption of albumin, resulting in albuminuria levels ranging from 30 to 300 mg/day[32]. With time, the increased delivery of proteins promotes their reabsorption, including cytokines and growth factors at the proximal tubule, leading to inflammation and tubulointerstitial fibrosis[33]. These changes precede tubular atrophy, which leads to a more advanced stage of obesity-related kidney disease, namely CKD[34].

Glomerulomegaly with or without FSGS is a pathologic finding of ORG[25]. Typically, ORG patients do not exhibit nephrotic-range proteinuria, which occurs only in approximately 30% of cases[35,36]. Instead, most patients (52%-90%) present with a subnephrotic state characterized by proteinuria, glomerulopathy, and decreased renal function, without accompanying hypoalbuminemia or edema. This phenomenon is thought to be due to the compensatory mechanisms during the indolent progression of the underlying etiology[17]. Moreover, the presence of FSGS in patients with ORG increases the risk of further renal dysfunction[17].

Assessment of renal function in patients before and after MBS

Renal function is typically estimated using glomerular filtration rate (eGFR) or serum creatinine in clinical settings. However, the limitations of these parameters have come to light, particularly in the severely obese patients. The measurement of creatinine clearance for estimation of GFR often leads to significant overestimation, while the adjusted eGFR by body surface area (BSA) tends to underestimate the renal function in overweight individuals[37]. This discrepancy arises because the BSA and muscle mass in severely obese patients are naturally higher than those in lean subjects, resulting in elevated creatinine levels. Additionally, significant weight loss after MBS is associated with muscle mass loss and a subsequent decrease in creatinine generation, which contributes to the overestimation of GFR[38]. Using BSA for GFR correction is inaccurate and not recommended because the number of nephrons does not increase with obesity[17]. In contrast, methods to measure GFR (mGFR) using iohexol plasma clearance have been shown to be more strongly correlated with serum cystatin C than with serum creatinine[39]. Minor weight loss induced by anti-obesity medications (AOMs) does not significantly affect serum creatinine levels, allowing for the continued use of conventional creatinine-based equations to estimate GFR[40]. However, it is important to consider the limitations of estimating or measuring GFR with creatinine-based equations, especially following substantial weight reductions due to MBS.

Other techniques utilizing inulin or transdermal measurements have been suggested but have not been implied due to impracticality and the need for further evidence. The presence of albuminuria or proteinuria can help detect obesity-induced kidney disease, but some patients with histologically proven ORG did not present with albuminuria. Therefore, new biomarkers such as urinary kidney injury molecule-1 (KIM-1), urinary cystatin-C, urinary N-acetyl-beta D glucosaminidase (NAG), and urinary neutrophil gelatinase-associated lipocalin (NGAL) are being researched with promising potential[38]. The accumulation of ectopic lipids in the kidney is also being considered as a biomarker for ORG. Therefore, imaging techniques such as ultrasonography, ultrasound elastography, computed tomography (CR), and magnetic resonance imaging (MRI) are being evaluated as tools to diagnose the progression of ORG[41].

Perioperative management of patients with renal impairment

There are limited data and consensus on the perioperative management of obesity in patients with CKD. Given the growing population of severely obese individuals who are at an increased risk for CKD, a collaborative approach involving nephrologists is urgently needed[42]. Awareness of the indolent clinical course of obesity-related kidney disease is important when managing the severely obese and after MBS. The perioperative risk has been known to be increased in the severely obese with CKD. However, the general consensus has become that MBS is a safe procedure in this population and that the risks outweigh the benefits[43]. Selection criteria should be based on the degree of obesity, treatment goals, and patient preferences with a clear understanding of the risks[9].

The patient with renal impairment undergoing MBS is at further risk of exacerbation of renal insufficiency during pneumoperitoneum. Minimal insufflation and adequate hydration should be applied. Increased intraabdominal pressure at 15 mmHg has been associated with oliguria without change in serum creatinine levels and a low-pressure pneumoperitoneum of 12 mmHg has been shown to not influence kidney injury biomarkers[44,45]. Although there are no specific guidelines, it is generally recommended to maintain minimal insufflation within the accepted clinical range of 12 to 15 mmHg[46]. Postoperative nausea and vomiting (PONV) may put the patient at risk for acute kidney injury (AKI). Prophylactic management of PONV with a multimodal approach is advised[47].

AKI after MBS can become a serious complication, with an incidence ranging from 5.8% to 8.5%[48,49]. The risk is especially higher within the postoperative 30 days in relation to dehydration, male sex, venous thromboembolism, hypertension, limited ambulation, and Roux-en-Y gastric bypass (RYGB). The incidence of AKI has shown a correlation with higher rates of complications, readmissions, and reoperations[48]. Any medications that may worsen the volume depletion, such as angiotensin-converting enzyme inhibitors or angiotensin receptor blockers, should be considered a potential cause and prescribed with discretion[50].

Nephrolithiasis or oxalate nephropathy are common reasons for readmission or visits to the emergency department after MBS. Primary MBS procedures were all shown to increase the risk of nephrolithiasis by six-fold and the recognized risk factors were advanced age, more than two obesity-related comorbidities, and a history of nephrolithiasis[51]. This may lead to AKI and require prompt clinical management or may further contribute to the progression of CKD. The increased risk is thought to be due to the high-oxalate diet and changed gastrointestinal functions, especially after RYGB[52,53]. Hydration is the main preventive measure[38].

Renal function in patients after MBS

As obesity-related kidney disease is caused by excess body fat with metabolic alterations, weight reduction is a key component in preventing the progression of renal impairment[37]. Obesity is a multifactorial disease significantly influenced by genetic factors, as well as by behavioral, psychological, and cultural aspects. Management of obesity should be done in a holistic manner with an understanding of the available treatment modalities, including anti-obesity medication and MBS, with rigorous education on nutrition, eating behavior, and physical activity[20]. The sustained and most effective weight loss provided by MBS reverses many of the obesity-related metabolic dysfunctions by improving insulin sensitivity and glomerular hyperfiltration while reducing perirenal fat, leptin, adipokines, proinflammatory factors, RAAS activity, etc.[37,54,55]. Thus, MBS can be considered a treatment option for obesity-related kidney disease[56].

It is clear that MBS significantly improves albuminuria and proteinuria in severely obese patients with or without CKD[11,14]. Patients with CKD who undergo MBS were shown to have a 58% lower risk of a decline in eGFR of more than 30%[57]. The decrease in VAT contributes to improving the proinflammatory state and reduces reactive oxygen species production by attenuating mitochondrial damage, while weight loss counteracts the previously unregulated RAAS[58]. These, in turn, are understood to decrease hyperfiltration, thus improving renal function in severely obese patients after MBS[59]. The improvement in GFR has been reported to peak between 6 to 12 months postoperatively, and serum creatinine levels show the most significant decrease after 3 to 5 years, which were inconsistent with the weight loss trajectories. This finding indicates that the nephroprotective effect of MBS arises not only from weight loss but also from the remodeling of the metabolic system[60]. The specific relationships and long-term effects on renal function remain to be defined, and comparisons based on the type of procedure are yet to be determined.

The albuminuria in patients with preoperative normal kidney functions who had undergone MBS was shown to decrease significantly[61,62]. However, this change has been repeatedly observed only in diabetic patients[61,62]. Such findings suggest that the improved insulin resistance in the diabetic group due to weight loss has a significant nephroprotective effect. On the other hand, the proven tubular damage in obesity-related kidney disease has been shown to be reversed only in non-diabetic, severely obese patients. These results together indicate that there may be different etiologies in diabetic and non-diabetic, severely obese patients when it comes to kidney function[63].

Proteinuria has been shown to improve in 99% of severely obese diabetic patients after RYGB[64]. In the randomized-controlled STAMPEDE trial conducted by Schauer *et al.*, the results showed that the eGFR in the MBS group improved compared to the intensive medical therapy group among diabetics with preserved GFR and mostly without albuminuria, after a 5-year follow-up. However, there were no significant changes in the rates of albuminuria in both groups[65].

Postoperative weight loss, glycemic control, and blood pressure have been known to be independent parameters in predicting the improvement of CKD. With a 7-year follow-up of CKD patients after MBS in the Longitudinal Assessment of Bariatric Surgery (LABS)-2, an improvement was observed in 53% of the moderate CKD risk group, 56% in the high CKD risk group, and 23% in the very high CKD group based on the Kidney Disease: Improving Global Outcomes (KDIGO) CKD classification[66].

Among the most commonly performed procedures currently, sleeve gastrectomy (SG) and RYGB have been the most extensively investigated. SG has been shown to effectively improve insulin resistance, enhance lipid metabolism, and reduce proinflammatory responses[67,68]. The eGFR improvement was different among the CKD patients depending on their stage. It was more significant in patients with stages II, IIIa, and IIIb CKD compared to those with stages I and IV. Additionally, only patients in CKD stages IIIa and IIIb were more likely to experience downstaging after MBS than those in CKD stage IV[69]. This is surprising as one may suspect that the improvement would be more profound in earlier stages of CKD. On the other hand, RYGB seems to be more effective in increasing long-term survival in patients with CKD. This may be related to the reported superior improvement of blood pressure control after RYGB compared to that of SG, as well as the significantly improved insulin resistance and glucose imbalance[70]. The stabilization of eGFR after RYGB has consistently been reported to be associated with improved regulation of leptins and proinflammatory cytokines. Another advantage of the RYGB would be the well-established improvement of gastroesophageal reflux (GERD) and typically better weight loss outcomes with a lower standard deviation[43]. Although it is too early to determine the optimal procedure, the nephroprotective properties of MBS have been proven to last up to 9 years in patients without impaired renal function[71].

The evidence on renal outcome in CKD stage IV and V patients after MBS is sparse and has only been reported with a small group of patients[72]. A recent study by Billeter *et al.* reported an achievement of the treatment goal (improvement of organ function and gaining access to kidney transplantation) in more than 50% of 27 patients with stage IV and V CKD after MBS[73]. Although the perioperative risks in the CKD group were higher compared to those of patients without renal impairment, dependence on dialysis did not have an impact on the outcomes[43]. There have been reports on the improved 5-year mortality of patients on hemodialysis by 35% compared to nonsurgical patients[74]. The MBS group from this study had a higher kidney transplantation rate of 30%, compared to 20% in the control group. These findings suggest that MBS was beneficial in increasing access to kidney transplantation for severely obese patients on hemodialysis. Although it is clear that patients with stage III and IV CKD are the ones to recover their renal function, MBS can be an option for more advanced-stage CKD patients who are interested in considering the benefits of gaining eligibility for transplantation and stabilizing or improving organ function[75].

Kidney transplantation before and after MBS is another subject of interest in the management of patients with CKD. MBS is being further established as a safe bridge to easier surgical access for transplantation. It has also been suggested as a powerful tool to prevent the weight gain that may be expected after kidney transplantation[76]. The SG has been considered more favorable due to immunosuppressant pharmacokinetics compared to that of other malabsorptive procedures and may be considered for kidney recipients with severe obesity[77].

Dietary and nutritional management in patients with CKD before and after MBS

Severely obese patients with CKD should be carefully evaluated for metabolic dysfunctions and nutritional assessment, including their preoperative eating habits[78]. Serum levels of cholesterol, protein, albumin, and prealbumin should be assessed for diagnosis of protein-energy deficit[78].

The KDIGO guidelines are helpful in assisting the dietary management of patients with CKD[22]. However, there are no available specific dietary recommendations or guidelines to this date. The principle would be to correct any nutritional deficiencies and implement a low-calorie diet with a caloric deficit of 500 to 1,000 kcal for a preoperative weight loss of 10%, as for all patients undergoing MBS. The patient is expected to lose about 0.5 to 1 kg weekly with the low-calorie diet[78]. The efficacy and benefits of a very low-calorie ketogenic diet in patients with mild kidney failure (an eGFR between 60 to 89 mL/min/1.73m2) have been mentioned in current literature. The observed average weight loss was nearly 20% of the initial weight, with no significant change in liver and kidney functions[79]. However, the design of the diet should always be individualized, and a multidisciplinary approach, including consultation with a nephrologist, is recommended[80,81]. Any mineral or vitamin deficiencies should be identified and corrected depending on each patient and the status of dialysis[82].

The postoperative diet for severely obese patients with CKD on dialysis may require a higher caloric intake than that of a typical patient undergoing MBS. Generally, caloric intake starts at 400 kcal/day during the first week, increases to 800 kcal/day by the end of the first month, and eventually reaches 1,200 to 1,500 kcal/day within a few months[83].

The generally recommended postoperative daily fluid intake is more than 1.5 L[84]. This guideline can be applied to CKD patients who are on conservative management or have undergone kidney transplantation. However, CKD patients on dialysis have the risk of edema and require fluid restriction to ensure weight gain is limited to less than 2 to 2.5 kg between sessions. The recommended daily fluid intake for these CKD patients on dialysis is 500 to 750 mL/day in addition to the daily urine output. Food with a high water content such as yogurt, fruit, and vegetables should not be considered a part of the fluid restriction[85]. However, daily sodium consumption should be restricted to 6g to reduce water retention in all stages of CKD[86].

Protein consumption is crucial in maintaining nitrogen balance and preventing nitrogen catabolism. The recommended daily protein intake in the acute postoperative period for patients with CKD who are not on dialysis is 1.1 to 1.5 g/kg ideal body weight (IBW) to promote healing after MBS. The impaired renal function of the patient with CKD undergoing renal replacement therapy should be taken into consideration. In the acute postoperative period, the recommended daily protein intake for CKD patients undergoing renal replacement therapy is 1 to 1.5 g/kg IBM when on dialysis and 1 to 1.2 g/kg IBW after kidney transplantations[87]. However, the recommended protein intake for the long term differs in each subset of patients. A low-protein diet of 0.6 to 0.8 g/kg/day should be implemented in the long term for those with CKD stages III, IV, and V who are not on dialysis to prevent hyperfiltration[82,86]. The long-term recommended protein intake for the CKD patient is 0.6 to 0.8 g/kg/day of IBW when not on renal replacement therapy and 1.0 to 1.2 g/kg/day when on dialysis.

The supplementation or restriction of phosphate, calcium, potassium, sodium, magnesium, iron, folic acid, and vitamins should be done based on evidence-based guidelines and recent laboratory test results. A summary of the current evidence is shown in Table 1[78,82,87]. Inadequate absorption of nutrients leads to dysfunction of the autonomic system and can affect renal function in the long run. For instance, iron

Table 1. Recommendations for nutrient supplementation or restriction for patients with CKD

Nutrient	Recommended daily intake	Additional information
Iron	At least 200 mg/day	Do not take supplements with foods high in fiber or coffee or tea Absorption may be improved with 250 mg of Vitamin C Intravenous supplementation in the form of low-dose ferrous bisglycinate chelate supplementation may be required as needed
Calcium	1,200-1,500 mg	Calcium absorption may be reduced due to decreased capacity to convert inactive vitamin D to active form 800-1,000 mg in moderate to advanced CKD
Phosphate	800-100 mg/day	Adjustments should be made based on lab results
Potassium	≤ 4,700 mg/day for stage III without hyperkalemia ≤ 3,000 mg/day from stage IV adjusted to hyperkalemia	Constipation may contribute to hyperkalemia Patients should be educated about food high in potassium (avocado, potatoes, broccoli, celery, banana, etc.)
Magnesium	420 mg/day in male 320 mg/day in female	Adjustments should be made based on lab results (may fluctuate depending on dialysate or immunosuppressants)
Folic acid	400-800 μg/day	800 and 1,000 μg in female patients planning on pregnancy or when pregnant In cases of deficiency, 1 mg/day
Vitamin A	5,000-10,000 IU/day	70% of patients develop a deficiency within 4 years
Vitamin B1 (thiamine)	50-100 mg/day	In cases of deficiency, an oral dose of 100 mg bid or tid or an intravenous 200 mg tid for 3 to 5 days, followed by 250 mg/day for 3 to 5 days or until symptoms resolve
Vitamin B12	Only when deficient	Signs of deficiency include megaloblastic anemia, peripheral neuropathy, and neuropsychiatric symptoms In cases of deficiency, an oral dose of 350-500 μg/day or an intramuscular injection of 1 mg monthly or 3 mg every 3 months
Vitamin D	3,000 IU/day of cholecalciferol	Measurement of calcium and phosphate should be done to diagnose fluctuations due to excess or deficiencies A level of more than 30 ng/mL should be achieved In cases of deficiency, an oral dose of 50,000 IU 3 times per week or 3,000 to 6,000 IU/day
Vitamin E	15 mg/day	Screening is recommended
Vitamin K	90-120 μg/day	Screening is recommended

CKD: Chronic kidney disease.

deficiency in RYGB patients is associated with a greater risk of renal function deterioration. This is due to the crucial role of iron as an anti-inflammatory agent in the mitochondrial function[59,88]. Therefore, vigilant patient care and education are crucial to avoid long-term complications arising from preventable nutritional deficiencies in patients with CKD.

CONCLUSION

As the prevalence of severe obesity continues to grow, there is an urgent need for a collaborative approach among researchers from various fields to understand the pathophysiology of obesity-related kidney disease. This understanding is crucial not only for preventing and reversing the progression of obesity-related kidney disease in patients with clinically normal renal function but also for determining perioperative management strategies for those considering MBS. MBS is a powerful preventive and therapeutic tool for achieving sustained significant weight loss. Future research focusing on renal outcomes following massive weight loss from MBS, particularly concerning the preoperative stage of disease, would enhance our understanding of how excess body weight affects kidney function in relation to metabolic dysfunction.

DECLARATIONS

Authors' contributions

Wrote the manuscript: Chung Y

Revised the manuscript: Paik B, Jeon D

Provided the idea and reviewed the manuscript: Kim YJ

Availability of data and materials
Not applicable.

Financial support and sponsorship
None.

Conflicts of interest
All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

REFERENCES
1. World Obesity Federation. World Obesity Atlas 2023. Available from: https://www.worldobesity.org/resources/resource-library/world-obesity-atlas-2023. [Last accessed on 14 Oct 2024].
2. World Health Organization. Obesity and overweigh. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight. [Last accessed on 14 Oct 2024].
3. Afshin A, Forouzanfar MH, Reitsma MB, et al; GBD 2015 Obesity Collaborators. Health effects of overweight and obesity in 195 countries over 25 years. *N Engl J Med* 2017;377:13-27. DOI PubMed PMC
4. Stefan N, Schulze MB. Metabolic health and cardiometabolic risk clusters: implications for prediction, prevention, and treatment. *Lancet Diabetes Endocrinol* 2023;11:426-40. DOI PubMed
5. Musso G, Cassader M, Cohney S, Pinach S, Saba F, Gambino R. Emerging liver-kidney interactions in nonalcoholic fatty liver disease. *Trends Mol Med* 2015;21:645-62. DOI PubMed
6. Marcuccilli M, Chonchol M. NAFLD and chronic kidney disease. *Int J Mol Sci* 2016;17:562. DOI PubMed PMC
7. Lonardo A, Mantovani A, Targher G, Baffy G. Nonalcoholic fatty liver disease and chronic kidney disease: epidemiology, pathogenesis, and clinical and research implications. *Int J Mol Sci* 2022;23:13320. DOI PubMed PMC
8. Gómez-Hernández A, Beneit N, Díaz-Castroverde S, Escribano Ó. Differential role of adipose tissues in obesity and related metabolic and vascular complications. *Int J Endocrinol* 2016;2016:1216783. DOI PubMed PMC
9. Ardiles LG. Obesity and renal disease: benefits of bariatric surgery. *Front Med* 2023;10:1134644. DOI PubMed PMC
10. Moriconi D, Antonioli L, Masi S, et al. Glomerular hyperfiltration in morbid obesity: role of the inflammasome signalling. *Nephrology (Carlton)* 2022;27:673-80. DOI PubMed
11. Moriconi D, Nannipieri M, Dadson P, Rosada J, Tentolouris N, Rebelos E. The beneficial effects of bariatric-surgery-induced weight loss on renal function. *Metabolites* 2022;12:967. DOI PubMed PMC
12. Serra A, Romero R, Lopez D, et al. Renal injury in the extremely obese patients with normal renal function. *Kidney Int* 2008;73:947-55. DOI PubMed
13. Park JY, Kim YJ. Improvement of end-stage renal disease in an obese diabetic patient after gastric bypass: bariatric times. *Bariatric Times* 2013;10:22-4. Available from: https://bariatrictimes.com/improvement. [Last accessed on 24 Oct 2024].
14. Park S, Kim YJ, Choi CY, Cho NJ, Gil HW, Lee EY. Bariatric surgery can reduce albuminuria in patients with severe obesity and normal kidney function by reducing systemic inflammation. *Obes Surg* 2018;28:831-7. DOI PubMed
15. Schwartz P, Capotondo MM, Quaintenne M, Musso-Enz GM, Aroca-Martinez G, Musso CG. Obesity and glomerular filtration rate. *Int Urol Nephrol* 2023;56:1663-68. DOI PubMed
16. Kim EY, Kim YJ. Does bariatric surgery really prevent deterioration of renal function? *Surg Obes Relat Dis* 2016;12:856-61. DOI PubMed
17. D'Agati VD, Chagnac A, de Vries AP, et al. Obesity-related glomerulopathy: clinical and pathologic characteristics and pathogenesis. *Nat Rev Nephrol* 2016;12:453-71. DOI PubMed
18. Sandino J, Luzardo L, Morales E, Praga M. Which patients with obesity are at risk for renal disease? *Nephron* 2021;145:595-603. DOI

PubMed
19. Schütten MT, Houben AJ, de Leeuw PW, Stehouwer CD. The link between adipose tissue renin-angiotensin-aldosterone system signaling and obesity-associated hypertension. *Physiology (Bethesda)* 2017;32:197-209. DOI PubMed
20. García-Carro C, Vergara A, Bermejo S, Azancot MA, Sellarés J, Soler MJ. A nephrologist perspective on obesity: from kidney injury to clinical management. *Front Med (Lausanne)* 2021;8:655871. DOI PubMed PMC
21. Artunc F, Schleicher E, Weigert C, Fritsche A, Stefan N, Häring HU. The impact of insulin resistance on the kidney and vasculature. *Nat Rev Nephrol* 2016;12:721-37. DOI PubMed
22. Stasi A, Cosola C, Caggiano G, et al. Obesity-related chronic kidney disease: principal mechanisms and new approaches in nutritional management. *Front Nutr* 2022;9:925619. DOI PubMed PMC
23. Praga M, Morales E. The fatty kidney: obesity and renal disease. *Nephron* 2017;136:273-6. DOI PubMed
24. Verde L, Lucà S, Cernea S, et al. The fat kidney. *Curr Obes Rep* 2023;12:86-98. DOI PubMed PMC
25. Yang S, Cao C, Deng T, Zhou Z. Obesity-related glomerulopathy: a latent change in obesity requiring more attention. *Kidney Blood Press Res* 2020;45:510-22. DOI PubMed
26. Kotsis V, Martinez F, Trakatelli C, Redon J. Impact of obesity in kidney diseases. *Nutrients* 2021;13:4482. DOI PubMed PMC
27. Alicic RZ, Rooney MT, Tuttle KR. Diabetic kidney disease: challenges, progress, and possibilities. *Clin J Am Soc Nephrol* 2017;12:2032-45. DOI PubMed PMC
28. Górriz JL, Navarro-González JF, Ortiz A, et al. Sodium-glucose cotransporter 2 inhibition: towards an indication to treat diabetic kidney disease. *Nephrol Dial Transplant* 2020;35:i13-23. DOI PubMed PMC
29. Neuen BL, Young T, Heerspink HJL, et al. SGLT2 inhibitors for the prevention of kidney failure in patients with type 2 diabetes: a systematic review and meta-analysis. *Lancet Diabetes Endocrinol* 2019;7:845-54. DOI PubMed
30. Chagnac A, Zingerman B, Rozen-Zvi B, Herman-Edelstein M. Consequences of glomerular hyperfiltration: the role of physical forces in the pathogenesis of chronic kidney disease in diabetes and obesity. *Nephron* 2019;143:38-42. DOI PubMed
31. Denic A, Glassock RJ. Obesity-related glomerulopathy and single-nephron GFR. *Kidney Int Rep* 2020;5:1126-8. DOI PubMed PMC
32. Ruggenenti P, Remuzzi G. Time to abandon microalbuminuria? *Kidney Int* 2006;70:1214-22. DOI PubMed
33. Zoja C, Abbate M, Remuzzi G. Progression of renal injury toward interstitial inflammation and glomerular sclerosis is dependent on abnormal protein filtration. *Nephrol Dial Transplant* 2015;30:706-12. DOI PubMed
34. Yim HE, Yoo KH. Obesity and chronic kidney disease: prevalence, mechanism, and management. *Clin Exp Pediatr* 2021;64:511-8. DOI PubMed PMC
35. Xu T, Sheng Z, Yao L. Obesity-related glomerulopathy: pathogenesis, pathologic, clinical characteristics and treatment. *Front Med* 2017;11:340-8. DOI PubMed
36. Lakkis JI, Weir MR. Obesity and kidney disease. *Prog Cardiovasc Dis* 2018;61:157-67. DOI PubMed
37. Martínez-Montoro JI, Morales E, Cornejo-Pareja I, Tinahones FJ, Fernández-García JC. Obesity-related glomerulopathy: current approaches and future perspectives. *Obes Rev* 2022;23:e13450. DOI PubMed PMC
38. Herman-Edelstein M, Weinstein T, Chagnac A. Obesity-related glomerulopathy: clinical management. *Semin Nephrol* 2021;41:358-70. DOI PubMed
39. Friedman AN, Moe S, Fadel WF, et al. Predicting the glomerular filtration rate in bariatric surgery patients. *Am J Nephrol* 2014;39:8-15. DOI PubMed PMC
40. Scholten BJ, Persson F, Svane MS, Hansen TW, Madsbad S, Rossing P. Effect of large weight reductions on measured and estimated kidney function. *BMC Nephrol* 2017;18:52. DOI PubMed PMC
41. de Vries AP, Ruggenenti P, Ruan XZ, et al; ERA-EDTA Working Group Diabesity. Fatty kidney: emerging role of ectopic lipid in obesity-related renal disease. *Lancet Diabetes Endocrinol* 2014;2:417-26. DOI PubMed
42. Friedman AN, Schauer PR, Beddhu S, et al. Obstacles and opportunities in managing coexisting obesity and CKD: report of a scientific workshop cosponsored by the National Kidney Foundation and The Obesity Society. *Am J Kidney Dis* 2022;80:783-93. DOI PubMed
43. Aboueisha MA, Evans L, Allotey JK, et al. A 5-year propensity-matched analysis of perioperative outcomes in patients with chronic kidney disease undergoing bariatric surgery. *Surg Endosc* 2023;37:2335-46. DOI PubMed
44. Nguyen NT, Wolfe BM. The physiologic effects of pneumoperitoneum in the morbidly obese. *Ann Surg* 2005;241:219-26. DOI PubMed PMC
45. Filho MA, Alves RL, Nascimento PD Junior, Tarquinio GDS, Mega PF, Pinheiro Módolo NS. Effects of pneumoperitoneum on kidney injury biomarkers: a randomized clinical trial. *PLoS One* 2021;16:e0247088. DOI PubMed PMC
46. Brethauer SA, Schauer PR, Schirmer BD. Minimally invasive bariatric surgery. Springer New York; 2015. Available from: https://link.springer.com/content/pdf/10.1007/978-1-4939-1637-5.pdf. [Last accessed on 14 Oct 2024].
47. The ASMBS Textbook of Bariatric Surgery. Cham: Springer International Publishing; 2020. Available from: https://link.springer.com/book/10.1007/978-3-030-27021-6. [Last accessed on 14 Oct 2024].
48. Valera RJ, Sarmiento-Cobos M, Montorfano L, et al. Predictors and outcomes of acute kidney injury after bariatric surgery: analysis of the metabolic and bariatric surgery accreditation and quality improvement program data registry. *Surg Obes Relat Dis* 2023;19:1302-7. DOI PubMed
49. Thakar CV, Kharat V, Blanck S, Leonard AC. Acute kidney injury after gastric bypass surgery. *Clin J Am Soc Nephrol* 2007;2:426-30. DOI PubMed

50. Chang AR, Grams ME, Navaneethan SD. Bariatric surgery and kidney-related outcomes. *Kidney Int Rep* 2017;2:261-70. DOI PubMed PMC
51. Laurenius A, Sundbom M, Ottosson J, Näslund E, Stenberg E. Incidence of kidney stones after metabolic and bariatric surgery-data from the scandinavian obesity surgery registry. *Obes Surg* 2023;33:1564-70. DOI PubMed PMC
52. Froeder L, Arasaki CH, Malheiros CA, Baxmann AC, Heilberg IP. Response to dietary oxalate after bariatric surgery. *Clin J Am Soc Nephrol* 2012;7:2033-40. DOI PubMed PMC
53. Bhatti UH, Duffy AJ, Roberts KE, Shariff AH. Nephrolithiasis after bariatric surgery: a review of pathophysiologic mechanisms and procedural risk. *Int J Surg* 2016;36:618-23. DOI PubMed
54. Guan Y, Wei X, Li J, Zhu Y, Luo P, Luo M. Obesity-related glomerulopathy: recent advances in inflammatory mechanisms and related treatments. *J Leukoc Biol* 2024;115:819-39. DOI PubMed
55. He J, Xiao Y, Wang J. Potential therapeutic targets of obesity-related glomerulopathy. *Metab Syndr Relat Disord* 2021;19:367-71. DOI PubMed
56. Wahab R, Cohen RV, le Roux CW. Recent advances in the treatment of patients with obesity and chronic kidney disease. *Ann Med* 2023;55:2203517. DOI PubMed PMC
57. Rogula TG, Schauer PR, Fouse T. Prevention and management of complications in bariatric surgery. Oxford University Press; 2018. Available from: https://books.google.com/books?hl=zh-CN&lr=&id=X39XDwAAQBAJ&oi=fnd&pg=PP1&dq=Prevention+and+Management+of+Complications+in+Bariatric+Surgery&ots=zLBMZvkb_-&sig=W990pbqaDCYCkZbUyxfhbnD_oyQ#v=onepage&q=Prevention%20and%20Management%20of%20Complications%20in%20Bariatric%20Surgery&f=false. [Last accessed on 14 Oct 2024].
58. Lee H, Oh S, Yang W, et al. Bariatric surgery reduces elevated urinary mitochondrial DNA copy number in patients with obesity. *J Clin Endocrinol Metab* 2019;104:2257-66. DOI PubMed
59. Cañizares S, Guaillas A, Velarde F, de Vaca VC, Terán F, Caicedo A. Is bariatric surgery improving mitochondrial function in the renal cells of patients with obesity-induced kidney disease? *Pharmacol Res* 2022;185:106488. DOI PubMed
60. Huang H, Lu J, Dai X, et al. Improvement of renal function after bariatric surgery: a systematic review and meta-analysis. *Obes Surg* 2021;31:4470-84. DOI PubMed
61. Currie A, Chetwood A, Ahmed AR. Bariatric surgery and renal function. *Obes Surg* 2011;21:528-39. DOI PubMed
62. Saliba J, Kasim NR, Tamboli RA, et al. Roux-en-Y gastric bypass reverses renal glomerular but not tubular abnormalities in excessively obese diabetics. *Surgery* 2010;147:282-7. DOI PubMed PMC
63. Chagnac A, Weinstein T, Herman M, Hirsh J, Gafter U, Ori Y. The effects of weight loss on renal function in patients with severe obesity. *J Am Soc Nephrol* 2003;14:1480-6. DOI PubMed
64. Izzedine H, Coupaye M, Reach I, Deray G. Gastric bypass and resolution of proteinuria in an obese diabetic patient. *Diabet Med* 2005;22:1761-2. DOI PubMed
65. Schauer PR, Bhatt DL, Kirwan JP, et al. Bariatric surgery versus intensive medical therapy for diabetes - 5-year outcomes. *N Engl J Med* 2017;376:641-51. DOI PubMed PMC
66. Friedman AN, Wahed AS, Wang J, et al. Effect of bariatric surgery on CKD risk. *J Am Soc Nephrol* 2018;29:1289-300. DOI PubMed PMC
67. Li Z, Chen Y, Xiong J, Lyu Q, Jiang B. Renal function following bariatric surgery: a literature review of potential mechanisms. *Obes Surg* 2022;32:1734-40. DOI PubMed
68. Zubiaga L, Ruiz-Tovar J. Correlation of preoperative neutrophil-to-lymphocyte ratio and platelet-to-lymphocyte ratio with metabolic parameters in patients undergoing sleeve gastrectomy. *Surg Obes Relat Dis* 2020;16:999-1004. DOI PubMed
69. Kassam AF, Taylor ME, Morris MC, et al. The impact of sleeve gastrectomy on renal function in patients with chronic kidney disease varies with severity of renal insufficiency. *Surg Obes Relat Dis* 2020;16:607-13. DOI PubMed
70. Johnsen EM, Sidhu G, Chen J, Moore R, Le Jemtel T, Samson R. Roux-en-Y gastric bypass and sleeve gastrectomy for obesity-associated hypertension. *J Investig Med* 2021;69:730-5. DOI PubMed
71. Hou CC, Shyu RS, Lee WJ, Ser KH, Lee YC, Chen SC. Improved renal function 12 months after bariatric surgery. *Surg Obes Relat Dis* 2013;9:202-6. DOI PubMed
72. Imam TH, Fischer H, Jing B, et al. Estimated GFR before and after bariatric surgery in CKD. *Am J Kidney Dis* 2017;69:380-8. DOI PubMed PMC
73. Billeter AT, Zumkeller M, Brock J, et al. Obesity surgery in patients with end-stage organ failure: is it worth it? *Surg Obes Relat Dis* 2022;18:495-503. DOI PubMed
74. Sheetz KH, Woodside KJ, Shahinian VB, Dimick JB, Montgomery JR, Waits SA. Trends in bariatric surgery procedures among patients with ESKD in the United States. *Clin J Am Soc Nephrol* 2019;14:1193-9. DOI PubMed PMC
75. Pané A, Claro M, Molina-Andujar A, et al. Bariatric surgery outcomes in patients with chronic kidney disease. *J Clin Med* 2023;12:6095. DOI PubMed PMC
76. Pané A, Molina-Andujar A, Olbeyra R, et al. Bariatric surgery outcomes in patients with kidney transplantation. *J Clin Med* 2022;11:6030. DOI PubMed PMC
77. Fernando S, Varma J, Dengu F, Menon V, Malik S, O'Callaghan J. Bariatric surgery improves access to renal transplantation and is safe in renal failure as well as after transplantation: a systematic review and meta-analysis. *Transplant Rev (Orlando)* 2023;37:100777. DOI PubMed

78. Potrykus M, Czaja-Stolc S, Małgorzewicz S, Proczko-Stepaniak M, Dębska-Ślizień A. Diet management of patients with chronic kidney disease in bariatric surgery. *Nutrients* 2022;15:165. DOI PubMed PMC
79. Bruci A, Tuccinardi D, Tozzi R, et al. Very low-calorie ketogenic diet: a safe and effective tool for weight loss in patients with obesity and mild kidney failure. *Nutrients* 2020;12:333. DOI PubMed PMC
80. Watanabe M, Tuccinardi D, Ernesti I, et al. Scientific evidence underlying contraindications to the ketogenic diet: an update. *Obes Rev* 2020;21:e13053. DOI PubMed PMC
81. Moriconi E, Camajani E, Fabbri A, Lenzi A, Caprio M. Very-low-calorie ketogenic diet as a safe and valuable tool for long-term glycemic management in patients with obesity and type 2 diabetes. *Nutrients* 2021;13:758. DOI PubMed PMC
82. Majorowicz RR, Attia A, Bamlet HM, et al. Nutritional considerations for patients with renal failure undergoing sleeve gastrectomy. *J Ren Nutr* 2024;34:76-86. DOI PubMed
83. Mechanick JI, Apovian C, Brethauer S, et al. Clinical practice guidelines for the perioperative nutrition, metabolic, and nonsurgical support of patients undergoing bariatric procedures - 2019 update: cosponsored by american association of clinical endocrinologists/ American college of endocrinology, the obesity society, American society for metabolic and bariatric surgery, obesity medicine association, and american society of anesthesiologists. *Obesity (Silver Spring)* 2020;28:O1-58. DOI PubMed
84. Tabesh MR, Maleklou F, Ejtehadi F, Alizadeh Z. Nutrition, physical activity, and prescription of supplements in pre- and post-bariatric surgery patients: a practical guideline. *Obes Surg* 2019;29:3385-400. DOI PubMed
85. Fouque D, Vennegoor M, ter Wee P, et al. EBPG guideline on nutrition. *Nephrol Dial Transplant* 2007;22 Suppl 2:ii45-87. DOI PubMed
86. Favre G, Schiavo L, Lemoine S, Esnault VLM, Iannelli A. Longitudinal assessment of renal function in native kidney after bariatric surgery. *Surg Obes Relat Dis* 2018;14:1411-8. DOI PubMed
87. Ben-Porat T, Weiss-Sadan A, Rottenstreich A, et al. Nutritional management for chronic kidney disease patients who undergo bariatric surgery: a narrative review. *Adv Nutr* 2019;10:122-32. DOI PubMed PMC
88. Vaugier C, Amano MT, Chemouny JM, et al. Serum iron protects from renal postischemic injury. *J Am Soc Nephrol* 2017;28:3605-15. DOI PubMed PMC