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Bariatric surgery does not affect kidney stone disease

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Background: numerous epidemiological studies demonstrate the correlation between obesity and urolithiasis. Bariatric surgery is effective in significant weight loss, reducing mortality rates, and lowering the incidence of obesity-related comorbidities. However, it may be associated with long-term complications such as urolithiasis, with an estimated increase of 7.6% in bariatric patients. This study investigates the impact of various bariatric surgical techniques and personal and nutritional habits on post-operative urolithiasis. Material and method: 185 patients were prospectively enrolled in the study. All patients underwent nutritional assessment two years after surgery, and urinary stone disease was evaluated through urinalysis. Patients with urinary crystals were subsequently sent to the division of Urology to evaluate the possible presence of urinary stones through an abdominal CT scan. Results: kidney stone disease was present in 12 female patients (12/ 185 – 6.49%) out of the 25 (12/25–48%) with urinary crystals. Among the various surgical techniques, 8 patients underwent SG, 2 patients each for OAGB and RYGB, without a proven significant correlation. Hypertension, Dyslipidemia, and OSAS were significantly correlated with the incidence of urolithiasis (p-value < 0.05). BMI > 30 kg/m2 was significantly correlated with urinary stone formation (p-value < 0.05). Conclusion: patients undergoing bariatric surgery should receive counseling about the risk of developing urolithiasis (6.49%) independently from the surgical treatment, highlighting the necessity of adhering to nutritional guidelines. Evaluation for urinary stones could be recommended during follow-up, especially for patients with a BMI > 30 kg/m^2.

Keywords Kidney stones, Kidney calculi, Obesity, Bariatric surgery, Sleeve gastrectomy, One-anastomosis gastric bypass, Roux-n-Y gastric bypass

Abbreviations

T2DM	Type 2 diabetes
HTN	Hypertension
DLP	Dyslipidemia
OSAS	Obstructive sleep apnea syndrome
BS	Bariatric surgery
BMI	Body mass Index
%EWL	% Excess weight loss
EAU	European Association of Urology
CT	Computed tomography
SD	Standard deviation
HRs	Hazard ratio
CIs	Confidence intervals
HU	Hounsfield units
SG	Sleeve gastrectomy
OAGB	One-anastomosis gastric bypass
RYGB	Roux-n-Y gastric bypass

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Urolithiasis is a common disease affecting 5–10% of the global population. It has a high recurrence rate of up to 50% at 10 years[1]. In recent years, a global rise in the prevalence of urinary stone disease among women and men, and further increases are expected due to changes in lifestyle, dietary habits, and global warming[2]. Urinary stone formation is caused by metabolic disease, genetic factors, and anatomical and functional abnormalities. Conditions such as obesity, type 2 diabetes (T2DM), hypertension (HTN), and metabolic syndrome are risk factors for this pathology[3].

Many studies support the crucial role of diet in the formation and prevention of urolithiasis. Nutrition is a key modifiable risk factor associated with urinary stone disease[2].

Reduced fluid intake is a major predisposing factor, as low fluid intake is related to less urine production and can predispose to solute hypersaturation and stone formation. Conversely, increased consumption of sugar-sweetened beverages is associated with a higher risk of lithogenesis due to elevated urinary excretion of oxalates, uric acid, and calcium. Calcium, magnesium, or potassium intake may reduce lithogenesis. Similarly, the high consumption of animal proteins, sodium, or sugar can cause stones[3–6].

The association between BMI and urolithiasis is reported with a prevalence of obesity among patients with kidney stone disease ranging from 10 to 35%. The correlation between obesity and kidney stones is demonstrated by epidemiological study, with urolithiasis higher in obese (11.2%) and overweight (9.1%) patients[7].

Obesity is associated with increased excretion of solutes (mainly calcium, oxalates, and sodium) and a lower urinary pH, all factors contributing to stone formation. Calcium oxalate and uric acid stones are common types of stones diagnosed in obese patients, and improper diet plays a major role in their pathophysiology[7,8].

Bariatric surgery (BS) is highly effective for the prolonged treatment of morbid obesity, leading to substantial weight loss, reducing mortality, and a lower incidence of obesity-related comorbidities, including diabetes, HNT, cardiovascular disease, and obstructive sleep apnea. Surgical treatment may lead to long-term complications such as nutritional deficiencies, biliary lithiasis, abnormal bone and mineral metabolism, and nephrolithiasis[9,10].

This risk of developing urolithiasis in bariatric patients increases by 7.6% for 5 years post-surgery and higher after malabsorptive procedures. Stones typically develop around 1.5 years post-surgery. Hypo- and malabsorptive procedures predispose to fat malabsorption, enhancing free oxalate absorption by sequestration of calcium in fat. Hyperoxaluria is the most common disorder in patients receiving BS. The underlying mechanism is not understood but is linked to nutrition imbalances, fat malabsorption, and alteration of the intestinal microbiota[11–13].

The study aimed to evaluate the incidence of urolithiasis for 2 years in patients who underwent BS in an Italian center of excellence, focusing on the impact of different procedures and the role of nutritional counseling as a reducing risk factor.

Methods

The study was prospectively conducted by two Academic Center (General Surgery and Urology Division) part of the same Institution between January 2020 and September 2022. All methods were carried out in accordance with relevant guidelines and regulations. All experimental protocols were approved by the Department of Medico-Surgical Sciences and Biotechnologies with protocol n 0001612 of December 16, 2019. Informed consent was obtained from all subjects.

Patients attending consecutive follow-up visits up to the second year following primary BS were included.

Nutritional counseling

Was performed, and anthropometric parameters (weight, height, BMI, and %EWL) were measured pre- and post-surgery. After overnight fasting, patients were weighed barefoot and in light clothing to the nearest 0.1 kg. Height was measured using a fixed wall stadiometer; height and weight were recorded, and BMI (kg/m^2) was calculated. Fluid intake and supplementation were assessed during follow-up visits.

All patients followed our post-operative nutritional protocol: liquid (up to 1 week), pureed (2 or 3 weeks), soft solid (progress as tolerated), and firmer, regular food.

After the first post-operative month, patients were advised to meet minimal carbohydrates (130 g/day) and fat (20 g/day) needs. The dietitian aimed to advise a balanced diet, including adequate servings from all food groups, with protein of 1.1 g/kg ideal body weight, and to limit or exclude added sugar, concentrated sweets, fruit juice, fried foods, carbonated drinks, caffeine, and alcohol. Daily intake of a minimum of 1.5 L of water was recommended.

Urological counseling

Pre-operative urinary stone disease was excluded by evaluating the upper urinary tract through an abdominal ultrasound performed one month before surgery and urine analysis. Patients with a history of urinary stone disease, caliectasis, hydroureteronephrosis, and/or kidney stones discovered at the pre-operative ultrasound evaluation were excluded from the study. Patients with urine analysis positive for urinary crystals were also excluded from the study.

Follow-up period

BS patients attended ambulatory visits every 1st, 3rd, 6th, and 12 months for the first year and then every six months, receiving surgical/nutritional and psychological assessment. At 2 years follow-up, all the patients underwent urine analysis. All patients positive for urinary crystals were referred to the Division of Urology to evaluate the possible presence of urinary stones. According to the European Association of Urology (EAU) guidelines, patients receive a complete urological evaluation. Urolithiasis (in case of urine analysis positivity) was evaluated by an abdominal computed tomography (CT) without contrast (Fig. 1).

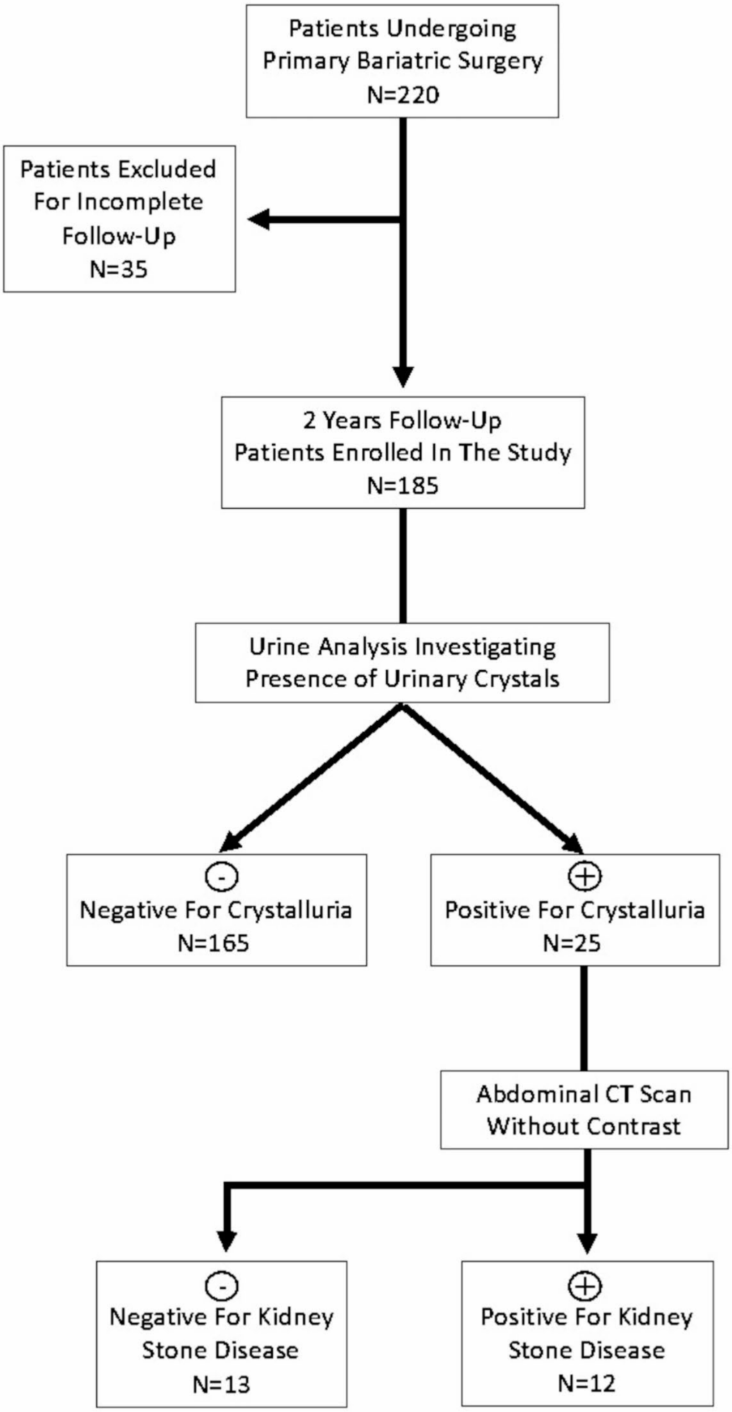

Fig. 1. Flowchart of the study.

Statistical methods

Continuous variables assuming normal distribution are expressed as mean ± standard deviation (SD), while categorical variables are presented as numbers (n) and proportions (%). Kidney stone formation risk was evaluated using Cox regression, presenting hazard ratios (HRs) and 95% confidence intervals (CIs) as measures of association. Preoperative variables were assessed as risk factors for postoperative kidney stones among the operative group using unadjusted Cox regression and further in a multivariable model including all preoperative variables. A second Cox regression model, including postoperative weight reduction at 2 years after surgery, was

	OAGB	RYGB	SG	Total
No. of patients (%)	30 (16.2%)	41 (22.2%)	114 (61.6%)	185 (100.0%)
Sex (F/M)	18/12	36/5	93/21	147/38
Age, yy Mean (SD)	50.18 (10.36)	51.12 (9.99)	45.25 (12.25)	47.27 (11.77)
BMI, kg/m^2 Mean (SD)	29.36 (4.52)	28.18 (4.43)	26.78 (3.70)	27.47 (4.09)
EWL, % Mean (SD)	70.36 (17.65)	70.17 (17.46)	73.88 (14.51)	72.53 (15.69)
Urinary crystals, F/M (%)	3/0 (1,62%)	6/0 (3,24%)	14/2 (8,64%)	23/2 (13.5%)
Urinary stone, F/M (%)	2/0 (1,08%)	2/0 (1,08%)	8/0 (4,33%)	12/0 (6.49%)
Comorbidities				
HTN N (%)	16 (8,65%)	20 (10,81%)	37 (20,00%)	73 (39,46%)
DLP N (%)	10 (5,41%)	11 (5,95%)	17 (9,18%)	38 (20,54%)
OSAS N (%)	10 (5,41%)	9 (4,86%)	3 (1,62%)	22 (11,89%)
T2DM N (%)	7 (3,78%)	15 (8,11%)	28 (15,14%)	50 (27,03%)

Table 1. Study population characteristics. OAGB: one anastomosis gastric bypass; RYGB: roux en y gastric bypass; SG: sleeve gastrectomy; HTN: hypertension; DLP: dyslipidemia; OSAS: Obstructive sleep apnea syndrome; T2DM: type II diabetes; BMI: body mass index; EWL: excess weight loss.

	OAGB (*N* = 30)	RYGB (*N* = 41)	SG (*N* = 114)	Total	*P* value
Ph Pre-op Mean (SD)	6.232 (0.602)	6.400 (0.657)	6.188 (0.977)	6.241 (0.868)	**0.405**
Ph Post-op Mean (SD)	5.927 (0.527)	6.032 (0.455)	5.897 (0.613)	5.943 (0.570)	**0.347**
Comparative *P* value (pre-post)	**0.31**	**0.45**	**0.38**	**0.48**	

Table 2. Urinary Ph modification for each bariatric procedure. P significance was set at $p < 0.05$.

performed and adjusted for all preoperative variables. Med Calc (version 22.013, Medcalc Software Ltd) was used for statistical analysis[14].

Results

Primary bariatric surgery was performed on 253 patients between January 2020 and September 2022; 35 patients were excluded due to incomplete follow-up, 18 for specific urological contraindications (see urological counseling session). After two years of follow-up, 185 patients (47 ± 12 years, 38 males, and 147 females) were included in the study; 114 of them received Sleeve Gastrectomy (SG), 30 received One-Anastomosis Gastric Bypass (OAGB), and 41 underwent Roux-n-Y Gastric Bypass (RYGB) (Table 1).

Patients underwent urine analysis and provided early morning urine samples before the nutritional assessment. 25 patients (13.5%) found crystalluria in their samples, evaluated for the presence of urinary stones. Most of the urine crystals were found as calcium oxalate ($n = 19$) followed by uric acid ($n = 4$) and amorphous phosphate/urate ($n = 2$). Urinary ph modification was assessed for each bariatric procedure reporting a slightly statistically not significant acidification (Table 2). None of these 25 patients resulted symptomatic during the urological examination, referring to no episode of fever nor flank pain. Subsequently, all those patients were invited to perform a low-dose abdominal CT scan without contrast. Kidney stone disease was described in 12 patients (6.49%. HU range + 400 + 1100) out of the 25 with crystalluria (Fig. 1).Most of the patients ($n = 10$) showed a monolateral single kidney stone located in the inferior calyces with a maximum diameter inferior to 6 mm and no caliectasis nor hydroureteronephrosis. Only two patients showed monolateral multiple kidney stone disease affecting both middle and inferior calices without any alteration of the urinary tracts and with a maximum stone diameter inferior to 7 mm. No simultaneous cases of ureteral stones were reported. These 12 patients belonged to the group where calcium oxalate crystals were discovered during the urine analysis.

These patients were all female and had a mean age, BMI, and %EWL of 46.7 years, 28.14 (kg/m2), and 63.5%, respectively. The average water intake was 1.12 L/day and each patient assumed supplementation. Out of these, 12 patients, 2 underwent RYGB, 2 OAGB, and 8 SG. These findings highlight variations in the occurrence of crystals and stones across different surgical interventions, suggesting differential effectiveness or patient characteristics between groups.

A comprehensive statistical analysis did not show any statistically significant association between the incidence of stones and crystals and the type of surgical intervention ($P > 0.05$ for all correlations). The results are explained by the small number of stones and crystals accounted for in our population study. The analysis of incidences of conditions such as HTN, Dyslipidemia (DLP), Obstructive Sleep Apnea Syndrome (OSAS), and T2DM across three surgical intervention groups revealed significant differences in the incidence rates of HTN, DLP, and OSAS among the groups, as evidenced by p-values of 0.0144, 0.0207, and approximately 0.00000016, respectively. These findings indicate a variation in health condition prevalence after surgical intervention, highlighting potentially differential health impacts of the interventions. Conversely, T2DM did not show a significant difference in incidence rates across the groups, with a p-value of 0.2733, suggesting a consistent prevalence regardless of surgical intervention type (Table 3).

Analyzing the incidence of crystals and stones development according to BMI post-treatment, with a new threshold of < 30 and > = 30 kg/m^2, provides the following insights:

For Crystals Post-Bariatric Surgery:

- Proportion with Condition: Of the group < 30 BMI, approximately 12.14% of individuals developed crystals post-treatment, compared to 17.02% in the > = 30 BMI group.
- Confidence Intervals: For the group < 30, the confidence interval ranges from 6.73 to 17.55%, and 6.28–27.77% for the > = 30 group.
- P-Value: 0.547 indicates that the difference in the proportion of individuals developing crystals between the two BMI post-treatment categories is not statistically significant.

For Stones Post- Bariatric Surgery:

- Proportion with Condition: Approximately 3.57% of individuals in the < 30 BMI group developed stones post-treatment, compared to 14.89% in the > = 30 group.
- Confidence Intervals: For the < 30 group, the confidence interval ranges from 0.50 to 6.65%, and 4.72–25.07% for the > = 30 group.
- P-Value: 0.017 indicates a statistically significant difference in the incidence of stone development between the two BMI post-treatment categories. This suggests a higher occurrence in individuals with a BMI > = 30 post-treatment.

The analysis shows a significant difference in the incidence of stone development based on BMI post-treatment, with a higher incidence observed in individuals with a BMI > = 30. For crystals, the difference doesn't achieve statistical significance (Fig. 2).

Discussion

BS is an effective treatment for morbid obesity. It results in rapid, pronounced, and sustained weight loss, improved quality of life, and prolonged life expectancy. Obesity-related diseases, such as T2DM, HTN, OSAS, and DLP, typically improve or even resolve after BS.

Despite benefits, some proportion of operated patients experiences long-term complications, post-bariatric procedure, such as nutritional deficiencies, gallbladder lithiasis, recurrent calcium oxalate urolithiasis, and osteoporosis[9,10].

The literature shows the highest risk of developing kidney stones is reported in malabsorptive procedures, the intermediate in RYGB, and the lowest in restrictive techniques[11,12]. However, Laurens et al., in their study, indicate that the incidence of kidney stones after primary BS procedures was increased more than six-fold compared to matched controls from the normal population. The highest incidence was observed after malabsorptive procedures, while RYGB and SG had similar incidences[13]. Recently, Ghanem et al. in a comprehensive review about BS impact on organ transplant, stated that RYGB portends up to a threefold increase in calcium oxalate stone formation postoperatively affecting graft survival[15]. In our study, kidney stone disease was described in 12 patients (6.49%), and most of them underwent SG without statistical significance compared with the other bariatric procedures, probably for unbalanced group analysis (114 SG vs. 30 OAGB vs. 41 RYGB).

Nephrolithiasis develops from urinary metabolic changes in these patients, such as low urinary volume, hypocitraturia, and hyperoxaluria. Our study found calcium oxalate stones in every patient. The underlying mechanisms for increased urinary oxalates in post-BS patients have not been completely elucidated but may be related to dietary factors, intestinal fat malabsorption, and changes in intestinal oxalate transport. A diet rich in oxalate and/or poor in calcium decreases the generation of unabsorbable calcium oxalate complexes, resulting in a higher amount of free oxalate in the intestinal lumen. Vitamin C supplements are metabolized to oxalate contributing to hyperoxaluria.

	OAGB	RYGB	SG	Total	P value
No. of patients	2 (16.7%)	2 (16.7%)	8 (66.7%)	12 (100%)	
Age, yy mean (SD)	41.50 (3.53)	54.50 (12.02)	46.00 (8.47)	46.67 (8.73)	0.8
BMI, kg/m^2 mean (SD)	26.00 (7.84)	27.65 (3.65)	29.80 (4.25)	28.14 (5.73)	0.65
EWL,% mean (SD)	62.35 (1.34)	66.95 (5.16)	62.90 (7.36)	63.48 (6.30)	0.9
Comorbidities					
HTN N (%)	0	1 (50%)	2 (25%)	3 (25%)	**< 0.0144**
DLP N (%)	0	1 (50%	2 (25%)	3 (25%)	**< 0.0207**
OSAS N (%)	0	1 (50%)	0 (0%)	1 (8,3%)	**< 0.00000016**
T2DM N (%)	0	1 (50%)	3 (37.5%)	4 (33,3%)	0.3

Table 3. Characteristics of patients with kidney stone disease. Significant values are in bold.

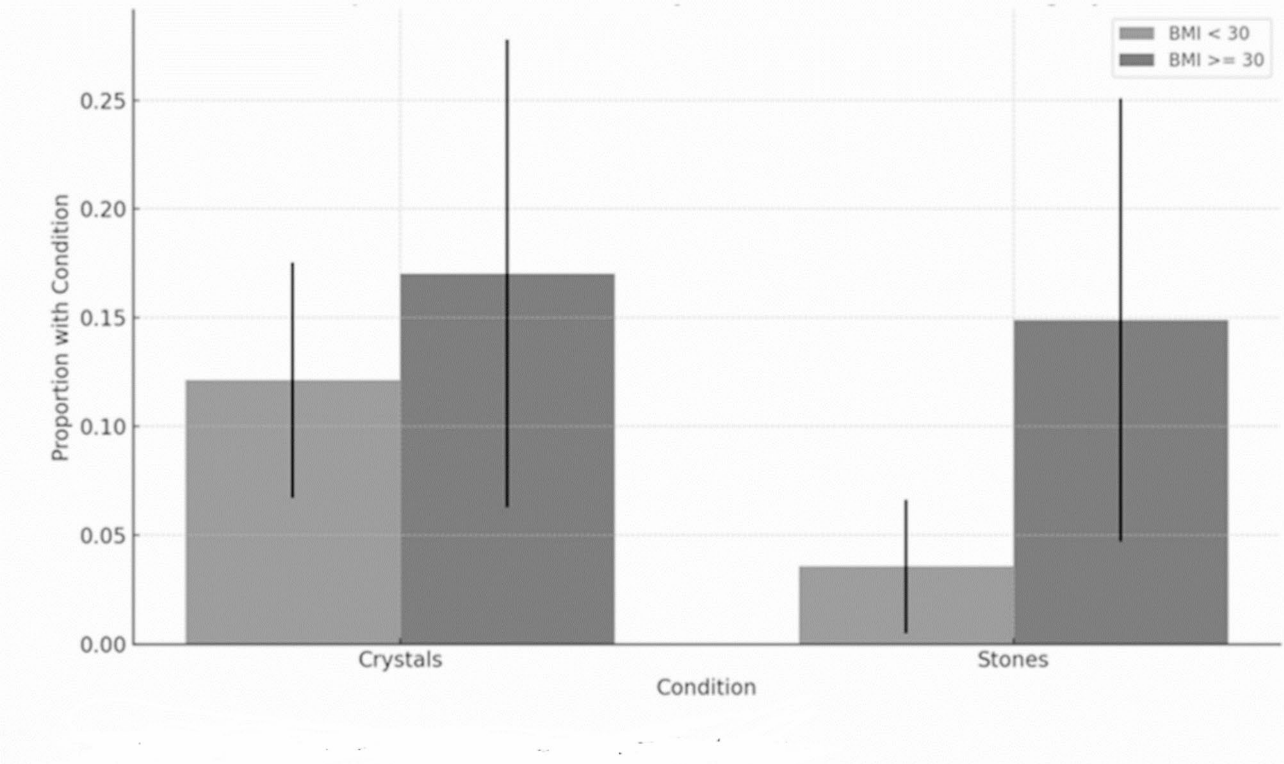

Fig. 2. Proportion of conditions by BMI post-treatment category.

Urine crystals are a marker indicating urine supersaturation, which may cause stone formation due to an imbalance in inhibitors and promoters of urolithiasis[16]. According to Daudon et al., crystalluria can monitor patients with metabolic disorders affected by urinary stone disease[17]. Based on the literature, calcium oxalate is the most common type of crystalluria[18]. Even though the type of urine crystals does not always correlate with that of the stones, several studies suggest that calcium oxalate crystals highly predict the presence of calcium oxalate stones[16,19]. Although in our study, patients affected by kidney stone diseases did not require surgical interventions, and so no stone analysis was performed, the presence of calcium oxalate crystals may suggest that the majority of the stone's composition may be made of calcium oxalate, which is the most common type of stone discovered in bariatric patients.

After bariatric surgery, a diet rich in oxalate and poor in calcium is very common and linked to a reduction in the assumption of milk and other dairy products because the intake of these foods is associated with gastrointestinal symptoms and "dumping syndrome" in some patients[9].

As known by the literature, changing solubility and supersaturation of the solutes is a crucial factor in lithogenesis. Most bariatric surgery patients have low fluid intake due to the small gastric pouch; although patients are advised to an appropriate fluid intake to achieve a urinary volume of approximately 2.5 L/day, patients in our study took 1.12 L/ day of water. These data suggest that an inadequate fluid and calcium intake, may have a crucial role in the pathogenesis of urinary stone disease. The results indicate that BC and different bariatric procedures, EWL, and comorbidities didn't represent a risk factor affecting the stone incidence (supporting nutritional counseling as crucial in risk prevention). However, patients BMI at the end of the procedure significantly affects stones appearance. Of the group, 3.57% of individuals in the BMI < 30 group developed stones post-treatment, compared to 14.89% in the > = 30 group, which confirmed that obesity is the central risk factor for stone development, while crystalluria depends more on dietary habits.

Specific guidelines to prevent nephrolithiasis after BS are lacking, but reducing oxalate intake, avoiding gram doses of vitamin C supplementation, and increasing calcium and fluid intake should be recommended.

Postoperative bariatric follow-up is crucial for weight loss support and early detection of nutritional deficiencies, urolithiasis, and osteoporosis. Medium-long follow-up can be used to observe relatively unknown long-term complications of bariatric surgery.

Despite several limitations, such as a short observation period, limited sample size, and no control group, our findings suggest that patients undergoing bariatric surgery may develop kidney stone disease regardless of surgical procedure, particularly in those remaining in the obesity BMI class. Pre- and post-operative counseling should include a discussion about the risk of developing this complication for patients who are considering bariatric surgery. After surgery, even in absence of symptoms, a 24-hour urinary calcium and oxalate measurements and an abdominal ultrasound to evaluate the upper urinary tract could be indicated as follow-up prevention strategy.

Conclusions

Despite its benefits, bariatric surgery may lead to long-term complications, including, in some experiences, an increased risk of kidney stones; in our survey, 6.49% of patients (% like those reported in worldwide population) presented with lithiasis without correlation with bariatric surgery (any operation).

Post-bariatric surgery, dietary evaluation is crucial in treating and preventing stone formation. Following surgery, monitoring urinary stones could be indicated particularly for patients who remain in the obesity category.

Data availability

All data analyzed during this study are included in this published article and are available from the corresponding author on reasonable request.

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References

1. Siener, R.K. Nutrition stone disease. *Nutrients* **13**(6), 1917. https://doi.org/10.3390/nu13061917 (2021).
2. Kotsiris, D., Adamou, K. & Kallidonis, P. Diet and stone formation: A brief review of the literature. *Curr Opin Urol*. **28**(5), 408–413 https://doi.org/10.1097/MOU.0000000000000521 (2018).
3. Ferraro, P. M. et al. Dietary and lifestyle risk factors associated with incident kidney stones in men and women. *J. Urol.* **198** (4), 858–863. https://doi.org/10.1016/j.juro.2017.03.124 (2017).
4. Ferraro, P.M. & Bargagli, M. Dietetic and lifestyle recommendations for stone formers. *Arch. Esp. Urol.* **74** (1), 112–122 (2021) (English, Spanish. Erratum in: Arch Esp Urol. 2021;74(8):725–726).
5. Ferraro, P. M. et al. Risk of kidney stones: Influence of dietary factors, dietary patterns, and vegetarian-vegan diets. *Nutrients*. **12** (3), 779. https://doi.org/10.3390/nu12030779 (2020).
6. Prezioso, P., Strazzullo, D., Lotti, T., CLU Working Group & et al. Dietary treatment of urinary risk factors for renal stone formation. A review of CLU Working Group. *Arch. Ital. Urol. Androl.* **87** (2), 105–120. https://doi.org/10.4081/aiua.2015.2.105 (2015) (erratum in: Arch Ital Urol Androl. 2016;88(1):76. Ferraro, Manuel [added]).
7. Carbone, A. et al. Obesity and kidney stone disease: A systematic review. *Minerva Urol. Nefrol*. **70** (4), 393–400. https://doi.org/10.23736/S0393-2249.18.03113-2 (2018). Epub 2018 May 31. PMID: 29856171.
8. Poore, W. et al. Obesity and its impact on kidney stone formation. *Rev. Urol.* **22** (1), 17–23 (2020).
9. Ormanji, M. S., Rodrigues, F. G. & Heilberg, I. P. Dietary recommendations for bariatric patients to prevent kidney stone formation. *Nutrients*. **12** (5), 1442. https://doi.org/10.3390/nu12051442 (2020). PMID: 32429374; PMCID: PMC7284744.
10. Weiss, D. Long-term complications of bariatric surgery. *JAMA* **325**(2), 186 https://doi.org/10.1001/jama.2020.22478 (2021).
11. Gonzalez, R. D. & Canales, B. K. Kidney stone risk following modern bariatric surgery. *Curr. Urol. Rep.* **15** (5), 401. https://doi.org/10.1007/s11934-014-0401-x (2014). PMID: 24658828; PMCID: PMC4058764.
12. Prochaska, M. & Worcester, E. Risk factors for kidney stone formation following bariatric surgery. *Kidney360.* **1** (12), 1456–1461. https://doi.org/10.34067/kid.0004982020 (2020).
13. Laurenius, A. et al. Incidence of kidney stones after metabolic and bariatric surgery-data from the Scandinavian Obesity Surgery Registry. *Obes. Surg.* ;**33**(5):1564–1570. doi: https://doi.org/10.1007/s11695-023-06561-y. (2023).
14. https://www.medcalc.org/.
15. Ghanem, O. M. et al. Obesity, organ failure, and transplantation: A review of the role of metabolic and bariatric surgery in transplant candidates and recipients. *Surg. Endosc.* **38**(8), 4138–4151 https://doi.org/10.1007/s00464-024-11043-y (2024). (Erratum in: Surg Endosc. 2024;38(8):4764).
16. Almannie, R. M. et al. Neural network analysis of crystalluria content to predict urinary stone type. *Res. Rep. Urol.* **13**, 867–876. https://doi.org/10.2147/RRU.S322580 (2021).
17. Daudon, M., Jungers, P. & Lacour, B. Clinical value of crystalluria study. *Ann. Biol. Clin. (Paris)*. **62** (4), 379–393 (2004).
18. Verdesca, S. et al. Crystalluria: Prevalence, different types of crystals and the role of infrared spectroscopy. *Clin. Chem. Lab. Med.* **49** (3), 515–520 (2011).
19. Minnes, R. et al. Fiber-optic evanescent wave spectroscopy (FEWS) of crystals from a urine sample as a tool for evaluating the chemical composition of kidney stones. *Anal. Methods*. **11** (18), 2404–2409 (2019).

Author contributions

CRediT Contributors Roles 1.Conceptualization 2. Data Curation 3. Formal Analysis 4. Funding Acquisition 5. Investigation 6. Methodology 7. Project Administration 8. Resources 9. Software 10. Supervision 11. Validation 12. Visualization 13. Writing – Original Draft 14. Writing – Review & Editing A.I., I.C.: 1,2,3,5,6,7,9,13 A.L.P, F.DA, F.M.V., G.L.,D.B.:8,11,12,14 G.C.:10,14.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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