ORIGINAL ARTICLE

Successful surgical weight loss with laparoscopic sleeve gastrectomy for morbid obesity prior to kidney transplantation

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SUMMARY

Morbid obesity in kidney transplant (KT) candidates is associated with increased complications and graft failure. Multiple series have demonstrated rapid and significant weight loss after laparoscopic sleeve gastrectomy (LSG) in this population. Long-term and post-transplant weight evolutions are still largely unknown. A retrospective review was performed in eighty patients with end-stage kidney disease (ESKD) who underwent LSG in preparation for KT. From a median initial BMI of 43.7 kg/m^2, the median change at 1-year was -10.0 kg/m^2. Successful surgical weight loss (achieving a BMI $<$ 35 kg/m^2 or an excess body weight loss $>$50%) was attained in 76.3% and was associated with male gender, predialysis status, lower obesity class and lack of coronary artery disease. Thirty-one patients subsequently received a KT with a median delay of 16.7 months. Weight regain (increase in BMI of 5 kg/m^2 postnadir) and recurrent obesity (weight regain + BMI $>$ 35) remain a concern, occurring post-KT in 35.7% and 17.9%, respectively. Early LSG should be considered for morbidly obese patients with ESKD for improved weight loss outcomes. Early KT after LSG does not appear to affect short-term surgical weight loss. Candidates with a BMI of up to 45 kg/m^2 can have a reasonable expectation to achieve the limit within 1 year.

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Key words
bariatric surgery, chronic kidney disease, kidney transplantation, laparoscopic sleeve gastrectomy, morbid obesity

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Introduction

Morbid obesity, diabetes and hypertension are tangled together as risk factors for cardiovascular disease affecting the long-term survival and quality of life of kidney transplant (KT) patients. National guidelines have only suggested a need for weight loss [1–3]. The eligibility of morbidly obese candidates can vary depending on local policy of the transplant programme. Each programme must decide whether morbid obesity is a relative or

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absolute contra-indication, how to measure obesity, whether it should be treated surgically and when this should be done relative to a potential KT.

One approach would be to treat the morbid obesity with bariatric surgery, then proceed to listing for transplantation once the necessary weight loss has been achieved. Numerous case series have demonstrated the relative safety and efficacy of bariatric surgery in KT candidates [4–15]. The most common operations have been laparoscopic sleeve gastrectomy (LSG) [4,6–10] or laparoscopic Roux-en-Y gastric bypass (LRYGB) [11–13]. In general, a rapid and significant weight loss has been demonstrated. However, in the published series, heterogeneity of the operations performed, varying lengths of surveillance, small study sizes and different measures of weight loss used have rendered comparisons difficult. The objectives of this multi-centric study are to perform a comprehensive anthropometric evaluation of the evolution of the body mass index (BMI) after LSG and the impact of a subsequent KT.

Materials and methods

This retrospective study was designed to evaluate the treatment of obesity using LSG in the context of kidney transplantation. The primary endpoint was the evolution of BMI. The inclusion criteria were age >18 years and stage IV and V end-stage kidney disease (ESKD) with a glomerular filtration rate <30 ml/min/1.73 m^2 and an indication for bariatric surgery (BMI > 40 kg/m^2, or >35 with at least one comorbidity such as hypertension, dyslipidaemia or diabetes) [16]. The exclusion criteria included a previous bariatric or gastric surgery, or a contra-indication to transplantation. The study was approved by the Research Ethics Committee at the Hôpital Maisonneuve-Rosemont (study number: 13022) and the Research Ethics Board of the McGill University Health Centre (study number: 2017-3316).

Patients were identified from their respective institutional kidney transplant databases. The baseline demographic, medical and anthropometric characteristics were summarized using median and interquartile range for age, weight and BMI (non-normally distributed variables), and proportions for categorical variables. The baseline BMI was set at the time of LSG. Annual BMI measurements were considered within one month of the anniversary date of LSG. BMI calculations were adjusted as required for lower limb amputations. The ideal BMI of 25 kg/m^2 was used for the calculation of excess body weight and excess body weight loss (EBWL). The BMI limit for listing was 35 kg/m^2 and a relative contra-indication. Weight regain was defined as an increase in BMI greater than 5 kg/m^2 after the nadir post-LSG. A recurrence of obesity was a weight regain above 35 kg/m^2. Coronary atherosclerotic disease (CAD) was defined as having had a revascularization procedure, either percutaneously or surgically. Diabetes included treatment with oral hypoglycaemic medications or insulin, measured in units per day. Sleep apnoea was considered present regardless of compliance with positive pressure ventilation treatment. Follow-up visits with anthropometric measurements and a review of medications were continued every three to four months after LSG. An improvement in diabetes, hypertension or dyslipidaemia was noted if there was a 50% or greater decrease in the total daily dose of medication (s). Sleep apnoea was considered resolved if positive pressure ventilation support was no longer necessary. The surveillance time of the ‘Post-LSG’ group ended with a kidney transplantation, a second bariatric surgery or death. The surveillance time in the ‘Post-KT’ group began at KT and ended with a second bariatric surgery or death. Successful surgical weight loss (SSWL) was achieved with a BMI under 35 kg/m^2 or an EBWL of greater than 50%. The decisions for listing and for transplantation were made on a case-by-case basis by the local transplant committee. The two kidney transplant programmes involved in this study used similar but slightly different listing habits. In one programme, there is a strict limit of <36.0 kg/m^2 prior to listing, while the other uses a BMI < 40 kg/m^2 with ongoing surgical weight loss. Patients who had a BMI already under 35 at LSG were not counted in the calculation of successful weight loss, nor in the excess weight loss to the limit.

Time to transplantation was calculated from the date of LSG to the date of KT. Early KT was defined as a KT within 1 year of LSG. Perioperative data were collected, including extended criteria donors (ECD), donation after cardiovascular death (DCD), living donor (LD), donor/recipient weight ratio (using a hypothetical ratio with the pre-LSG weight and an actual ratio with the weight at KT), delayed graft function (DGF), biopsy-proven acute rejection (BPAR) within the first transplant year, serum creatinine and creatinine clearance by CKD-Epi, at 3 and 12 months. Outcomes of graft loss, death and re-do bariatric surgery were also noted.

The change of mean BMI over time was analysed using a linear mixed-effect model accounting for multiple measures and adjusted for demographic characteristics (age and gender) and comorbidities (hypertension, diabetes, dyslipidaemia, CAD and sleep apnoea). The variables with a P-value < 0.2 were kept in the adjusted final model. Analysis for the clinical factors associated with a SSWL was performed initially by Chi-square or Fisher's exact test for categorical variables and Wilcoxon for continuous variables as appropriate, then by adjusted odds ratio estimates. A mixed linear spline model was used to identify inflection points of change of BMI over time. Multiple candidate nodes were tested, and we selected the best model using AIC, BIC and −2 Res Log Likelihood. The analysis of timing of KT after LSG with subgroups divided between KT < 12 months and KT > 12 months was performed with a mixed linear spline model adjusted for the time of kidney transplant.

Results

Baseline demographic, medical and anthropometric characteristics

In total, eighty KT candidates were identified who had an LSG during the period from January 2013 until January 2020. The baseline characteristics are summarized in Table 1. A slight majority were males (58.8%) with a median age of 50 years. One fifth were older than 60 years. The majority were on haemodialysis (81.8%) with a median time from initiation of dialysis to LSG of 2.7 years. Only one subject was on peritoneal dialysis. There was a mean of 2.7 diseases of the metabolic syndrome per subject. Hypertension was the most common (88.8%), followed by dyslipidaemia (62.5%), diabetes (60.0%) and sleep apnoea (58.8%). A previous history of CAD was reported in 18.8%. The median BMI at LSG was 43.7 kg/m^2, which translated to an excess body weight of 51.6 kg, or an excess weight to the BMI limit of 23.4 kg. There were 65 patients (82.3%) with a BMI > 40 kg/m^2 and 12 (15.2%) with a BMI > 50 kg/m^2. Three subjects had an initial BMI < 35 kg/m^2.

Bariatric surgery and perioperative outcomes

The bariatric operations were performed at two university-affiliated hospitals by nine different bariatric surgeons using linear cutting endoscopic staplers and an endoscopic bougie to prevent stenosis. No overswing was performed. The median length of hospitalization was two days. Postoperative complications occurred in nine patients (11.3%). One grade IV Clavien-Dindo complication occurred and consisted of pulmonary oedema requiring mechanical ventilation. There was one grade III stroke requiring anticoagulation with residual partial left hemiplegia. The grade II complications included transient atrial fibrillation (n = 1), postoperative haemorrhage (n = 3), dehydration (n = 3) and urinary retention (n = 1). Gastro-oesophageal reflux requiring proton pump inhibitor therapy occurred in five patients (6.4%). No cases of gastric leak, fistula, axial deviation or stenosis have been reported to date. The median time of surveillance post-LSG was 30.3 months. The number of candidates completing the first year of clinical surveillance was 67, followed by 46, 29, 19 and 11 annually thereafter. Post-LSG, there was an improvement or complete resolution of hypertension, diabetes, dyslipidaemia and sleep apnoea of 38.0 %, 54.2 %, 8% and 21.3%, respectively.

The 5-year evolution of anthropometric measurements is summarized by year of surveillance in Table 2. The median BMI at year 1 was 33.7 kg/m^2 and was relatively stable to year 5, at 34.8 kg/m^2 with a nadir of 32.0 kg/m^2. The percentage of patients achieving a BMI < 35 kg/m^2 varied between 60.0% and 67.9% over the span of 5 years of observation. The median time to reach the limit was 6.5 months. The annual median EBWL spanned 49.0–60.7%. The percentage with an EBWL > 50% was between 70.1% and 57.9%. Post-LSG, six subjects have had a weight regain, of whom three had recurrent obesity (3.7%). The median time to weight regain was 32 months. Two subjects with weight regain have had a kidney transplantation as their BMI had remained below the limit.

In the evaluation of weight loss by obesity class, patients in the lowest class, with an initial BMI between 35.0 and 39.9 kg/m^2, had a significantly higher EBWL at 1-year (69.0%) versus other higher obesity classes: 40.0–44.9, 45.0–49.9 and >50.0 kg/m^2 who had 55.5%, 54.2% and 44.1%, respectively. Whereas the change in BMI at 1 year statistically favoured the heaviest obesity class (BMI > 50 kg/m^2), with a ΔBMI of −12.6 kg/m^2, the lower BMI classes had −12.4 kg/m^2, −9.69 kg/m^2 and −9.05 kg/m^2 (Table S1).

A linear spline regression fit of the BMI evolution demonstrated two significant inflection points in the post-LSG phase, at 3 and 12 months (Fig. 1). The first inflection point represents the end of the immediate drastic weight loss, and the second point, the nadir. These inflection points define three phases, *Immediate Post-LSG* with a ΔBMI of −2.4 kg/m^2/month. The second phase until month 12 is the *Short-Term Post-LSG*, with a slower rate of −0.43 kg/m^2/month. The final phase, *Long-term Post-LSG*, has a slight rise by +0.05 kg/m^2/month.

A summary of post-LSG outcomes is found in Table 3. The proportion of SSWL at year 1 was 76.3%,

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Table 1. Baseline demographic, medical and anthropometric characteristics of transplant candidates undergoing laparoscopic sleeve gastrectomy and subsequent kidney transplant.

	LSG	LSG → KT	*P*-value*
Number, *n* (%)	80	31 (38.8)	
Age, median years [IQR]	50.0 [42.0, 56.3]	48.0 [43.0, 54.5]	0.5856
Male gender, *n* (%)	47 (58.8)	19 (61.3)	0.7399
Terminal renal failure, *n* (%)	63 (81.8)	27 (87.1)	0.7607
Comorbid disease, *n* (%)			
Hypertension	71 (88.8)	28 (90.3)	0.4796
Diabetes	48 (60.0)	20 (64.5)	0.4185
Dyslipidaemia	50 (62.5)	18 (58.1)	0.8588
Sleep apnoea	47 (58.8)	16 (51.6)	0.2364
Coronary artery disease	15 (18.8)	5 (16.1)	0.8495
Baseline anthropometric characteristics, median [IQR]			
Height, m	1.70 [1.63, 1.78]	1.72 [1.63, 1.75]	
Initial weight, kg	125.7 [113.5, 141.2]	118.5 [105.8, 130.0]	
Initial body mass index (pre-LSG), kg/m^2	43.7 [40.7, 47.6]	42.1 [39.4, 44.2]	0.0001
Initial excess body weight, kg	51.6 [44.9, 65.9]	47.0 [40.0, 52.5]	
Initial excess body weight to BMI limit, kg	23.4 [18.1, 36.9]	19.7 [14.3, 25.4]	
Initial BMI > 40, *n* (%)	65 (82.3)	22 (71.0)	0.0728
Initial BMI > 50, *n* (%)	12 (15.2)	0	

*Chi-squared or Fisher exact test for categorical variables, and *t*-test or Wilcoxon test for continuous variables.

Table 2. Anthropometric evolution after laparoscopic sleeve gastrectomy and after kidney transplant.

	Post-LSG		Post-KT	
Surveillance time, months median [IQR]	30.3 [17.0, 44.0]		24.0 [14.8, 48.0]	
BMI, kg/m^2 median [IQR]	*n*		*n*	
Preoperative	80	43.7 [40.7, 47.6]	31	31.9 [28.1, 34.2]
1-year	67	33.7 [31.2, 37.1]	28	29.3 [24.9, 33.1]
2 years	46	33.0 [30.5, 36.0]	15	30.1 [27.5, 33.2]
3 years	29	33.1 [32.3, 38.5]	12	31.2 [27.2, 32.1]
4 years	19	33.1 [31.7, 35.2]	8	33.6 [31.7, 36.0]
5 years	11	34.8 [31.9, 38.1]	3	36.2 [30.7, 37.6]
EBWL*, % median [IQR]				
Preoperative	0		60.4 [49.0, 73.5]	
1-year	55.5 [43.2, 64.4]		61.9 [49.4, 101.6]	
2 years	60.7 [45.7, 68.8]		55.5 [50.1, 83.9]	
3 years	53.8 [38.7, 65.3]		61.0 [50.5, 87.0]	
4 years	53.0 [40.2, 68.0]		43.1 [33.4, 58.3]	
5 years	49.9 [40.4, 67.8]		29.9 [29.3, 64.2]	
Weight regain, *n* (%)	6 (7.5)		10 (35.7)	
Recurrent obesity, *n* (%)	3 (3.8)		5 (17.9)	

*EBWL relative to the initial pre-LSG excess weight.

followed annually by 70.0%, 72.7%, 75.0% and 50.0%, respectively. The majority of KT were performed in the first 2 years post-LSG with nine during the first year, and thirteen during the second. Nine KTs have been performed thereafter. Seven patients have died post-LSG, prior to receiving a kidney transplant. The aetiologies of mortality included cardiovascular disease ($n = 4$), palliation/compliance with haemodialysis ($n = 2$) and sepsis ($n = 1$). Two patients have had a revision bariatric surgery after 2 and 3 years.

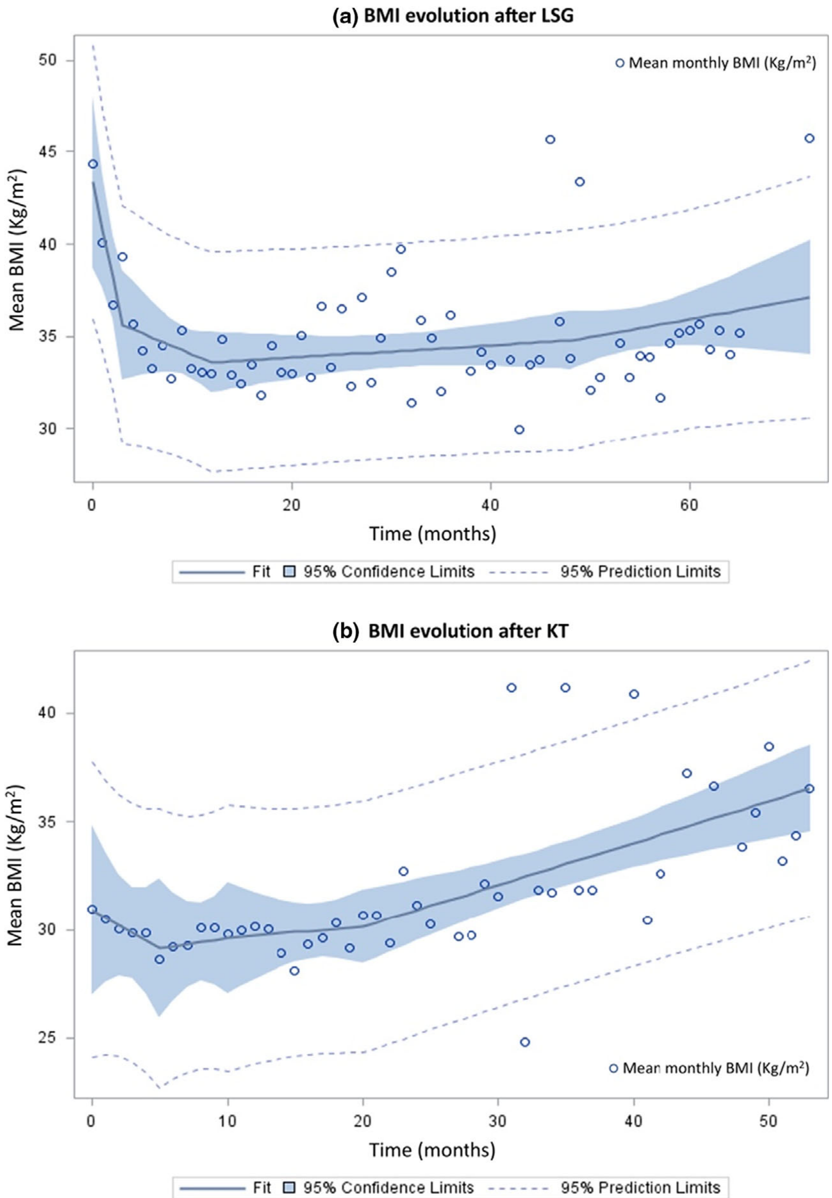

Figure 1 Spline regression of the evolution of body mass index after a laparoscopic sleeve gastrectomy (a) and after a subsequent kidney transplant (b). BMI, body mass index; LSG, laparoscopic sleeve gastrectomy; KT, kidney transplant.

Kidney transplantation after LSG

Thirty-one subjects in the cohort have received a KT after LSG. The baseline demographic characteristics and medical profile of KT+ (Table 1) were not statistically different from KT− group, except for a significantly lower mean initial BMI (41.4 KT+ vs. 46.1 KT−, by Wilcoxon rank test, *P*-value = 0.0001). Data on perioperative characteristics and short-term outcomes after KT in candidates with previous LSG are depicted in Table 4. The median time to KT was 16.7 months after a median weight loss of 31.7 kg. Three subjects have been transplanted with a BMI > 35 kg/m^2. No candidate with an initial BMI > 50 kg/m^2 has received a KT yet. No patient was guaranteed listing by undergoing bariatric surgery, and eight were refused listing post-LSG. The reasons noted included severity of cardiovascular comorbidities ($n = 4$), compliance ($n = 2$), advanced cancer ($n = 1$) and unspecified ($n = 1$). An ECD graft was used in seven recipients (22.6 %) and a DCD graft in nine (29.0 %). There was only one living donor KT. The DGF rate was 32.1%. One year of observation after KT was available in 28 patients. BPAR occurred in six recipients (19.4%) within the first year.

Table 3. Outcomes post-LSG during each successive year of surveillance.

Year of surveillance	1	2	3	4	5
Subjects completing year, *n*	67	46	29	19	11
Event occurring during surveillance year					
Successful surgical weight loss, %	76.3	70.0	72.7	75.0	50.0
Kidney transplantation, *n*	9	13	2	3	4
Death, *n*	1	3	1	1	1
Re-do bariatric surgery, *n*	0	1	1	0	0

Recovery of graft function was completed by the third month and essentially stable at 1 year. There have been no graft losses reported. There has been one death, more than 5 years after KT.

Evolution of BMI after KT in patients with a previous LSG

The median surveillance time post-KT was 24.0 months. The evolution of BMI after KT is summarized in Table 1. The median BMI at KT was 31.9 kg/m^2 and stable until the fourth year at 33.8 kg/m^2. The percentage of EBWL after KT, relative to the initial pre-LSG weight was 60.4% at KT, essentially stable until the fourth year, where it decreased to 43.1% and by the fifth year, 29.9%. Post-KT, ten patients had weight regain, while five (17.9%) had recurrent obesity. One of the patients has had a second bariatric surgery, a conversion to Roux-en-Y gastric bypass to treat the recurrent obesity. A linear spline regression fit of the evolution of mean BMI, found one significant inflection point after KT, at 5 months, which represents the nadir of the BMI post-KT. In the immediate phase following KT, the BMI declined by −0.31 kg/m^2. Postnadir, there is a slow increase in mean BMI, at 0.15 kg/m^2. Beyond 20 months, a low number of data points does not allow for reliable measure of the trend.

Table 4. Perioperative characteristics and short-term outcomes after kidney transplant in candidates with previous laparoscopic sleeve gastrectomy.

Median time from LSG to BMI limit, months [IQR]	6.5 [3.0–11.0]
Median time from LSG to KT, months [IQR]	16.7 [7.0, 23.7]
ECD, *n* (%)	7 (22.6)
DCD, *n* (%)	9 (29.0)
LD, *n* (%)	1 (3.2)
Actual donor/recipient (post-LSG) weight ratio [IQR]	0.84 [0.72, 0.99]
Hypothetical donor/recipient (pre-LSG) weight ratio [IQR]	0.66 [0.52, 0.75]
DGF, *n* (%)	9 (32.1)
BPAR within 1 year, *n* (%)	6 (21.4)
Creatinine, µmol/l [IQR]	
3 months	113 [103, 127]
1 year	116 [96, 126]
Creatinine clearance, ml/min [IQR]	
3 months	59 [50.5, 68.5]
1 year	63 [47.5, 71]
Graft loss, *n*	0
Death, *n*	1
Re-do bariatric surgery, *n*	1

Early and late kidney transplantation after LSG

In a post hoc analysis, the impact of the KT event on the evolution of BMI was assessed. The monthly BMI of a 24-month period centred on the KT were compared between the Early KT and Late KT subgroups with Wilcoxon-signed rank test. There was a statistically significant change in the slope of BMI in the early KT group (n = 11; mean change of post-KT slope versus pre-KT slope was +0.90 kg/m^2/month; P-value = 0.002), whereas no significant difference was found in the late group (n = 16; P-value = 0.9562). In the linear spline with random effect model, the interaction between month and KT in the early KT subgroup is significant (estimate = 0.11, P-value = 0.0432), which means that weight loss slows down by 0.11 units per month after KT in the early KT group. No interaction was found in the late KT group. A subsequent analysis of observed versus predicted BMI post-LSG found no significant difference after the KT in either group (Fig. S1). Finally, the mixed-effect model found no difference in the evolution of BMI after LSG, including the post-KT period, between early KT (within 1 year of the LSG) and late KT (more than 1-year post-LSG) subgroups (Fig. S2).

Predictive clinical factors for successful surgical weight loss

The predictive clinical factors associated with SSWL were evaluated. The baseline clinical variables included in the analysis were gender, BMI (5-unit) weight class,

Table 5. Factors associated with successful surgical weight loss by adjusted odds ratio estimates.

Factor	Odds ratio	95% Confidence interval	*P*-value
Male gender	6.74	1.05–43.39	0.0445
Age	1.02	0.95–1.09	0.6341
Hypertension	2.06	0.22–19.47	0.5281
Diabetes	1.84	0.28–12.13	0.5275
Dyslipidaemia	0.35	0.06–2.06	0.2406
Sleep apnoea	1.19	0.22–6.32	0.8381
Coronary artery disease	0.10	0.01–0.99	0.0486
Hospital site for LSG (A vs. B)	1.38	0.26–7.41	0.7075
Initial BMI (5 kg/m^2 units)*	0.34	0.17–0.69	0.0028

*Reported as unadjusted OR, as the model did not converge for this factor in the adjusted odds ratio estimates.

age, hypertension, haemodialysis, diabetes, dyslipidaemia, CAD and hospital site of LSG. In the unadjusted odds ratio estimates model, there was a complete separation of data for the factor of HD, where all predialysis patients had a SSWL. Furthermore, each increase of pre-LSG BMI by five units decreased the chance of SSWL by 66% (OR = 0.34; 95%CI = 0.17–0.69). For neither of these factors did the model converge for the adjusted odds ratio estimate model, and as such, they were not included in the final adjusted model. The adjusted odds ratio estimates for SSWL were significant for the female gender and a previous history of CAD as risk factors of non-SSWL. Male patients were 6.74 times more likely to achieve SSWL (OR = 6.74; 95% CI = 1.05–43.39), and patients with history of CAD had a 90% less chance to achieve SSWL (OR = 0.10; 95% CI = 0.01–0.99; Table 5).

Discussion

This multicentric study confirms the efficacy of surgical weight loss in the preparation for kidney transplantation. Qualitatively, the majority (76.6%) achieved the BMI limit in a median time of 6.5 months. Almost all of these successes (93%) were achieved within 2 years. Previous studies of LSG have reported success rates of 56% at a mean of 92 days to the same limit [14], and 100% success in a smaller cohort within three months, from a lower mean initial BMI (38.8 kg/m^2) [6]. The major complication rate (2.5%) in this cohort is lower than 7.06%, previously published for haemodialysis patients [17], and the overall complication rate of 11.3% is slightly lower than the combined surgical and medical complication rate of 6.2 + 8.3% for CKD patients from the MBSAQIP database [18]. This demonstrates the effectiveness, efficiency and relatively safety of LSG in helping patients become eligible for the kidney transplant waiting list. It should be acknowledged that a BMI limit may not be the best barometer of success, especially since success is dependent on the initial starting point.

Quantitative metrics for surgical weight loss should provide more objective and practical information for the transplant clinician. The median change in BMI at 1 year in this study was −10.0 kg/m^2 and is very close to previously published numbers (−9.8 kg/m^2) [8]. This should allow a clinical estimate and a timeline to plan for transplant evaluation, possible listing and, hopefully, scheduling of living-donation operations. Alternatively, the median EBWL could be used and was 55.5% at 1-year, with previous studies ranging from 33.6% to 56% [4,8,9]. The results of this study support the indication for LSG in candidates with a BMI of up to 45 kg/m^2 with a strong chance of achieving a BMI limit of 35 kg/m^2 within 2 years. The corollary, however, is that LSG may be inadequate for super-obese patients (BMI > 50 kg/m^2) who require greater weight loss. In this study, no super-obese patient has yet to receive a KT. LRYGB may be a better option and has been reported to have a greater EBWL, 60–70% over 9 months [11,13].

For this study, SSWL was defined to include both quantitative and qualitative criteria: a EBWL > 50% and a BMI under the limit. There was a significant association with the gender, CAD, haemodialysis and obesity class. This suggests that perhaps an earlier bariatric intervention, while still in the predialysis phase and before the development of cardiac complications, would be favourable toward a better weight loss outcome. Patients with a lower obesity class clearly have an advantage of starting with an initial BMI closer to the ideal. The threshold where LSG is less effective and a RYGB would be preferentially indicated could be determined by practical considerations. From this study, an expected median change in BMI of −10 kg/m^2 after

LSG would be a conservative clinical goal, so a patient with an initial BMI > 50 would be beyond the potential weight loss. Even if a higher limit, 40 kg/m^2 were to be employed, a large portion of the cohort would still have an insufficient result. The gender difference will have to be further investigated through more in-depth psychological, nutritional and physiological evaluations.

After surgical weight loss, to date, candidates received a KT in a median time of 16.7 months. Post-KT, there was another brief weight loss period measured from KT (−0.31 kg/m^2/month until 5 months), followed by a gradual weight gain (+0.15 kg/m^2/month). Whether the immediate weight loss is typical of the early post-transplant period or the continuation of the surgical weight loss remains to be determined. Further statistical analysis did not reveal any significant difference in the post-KT evolution of weight between Early KT and Late KT subgroups. Future studies with larger cohorts may be able to provide more statistical power to answer this question. It will also be interesting to determine whether there is a beneficial effect of pre-KT LSG on the risk of post-transplant weight gain [19].

In the analysis of the weight evolution, recurrent obesity may not be evident in the median BMI. A direct accounting for recurrent obesity and weight regain could provide more meaningful insights. Numerous definitions have been suggested and used in the bariatric literature [20,21]. Two distinct metrics were chosen for this study. The definition of *weight regain* was a BMI increase of 5 kg/m^2 after the nadir, which implies a clinically significant weight gain and a worsening to the next obesity class. The definition of *recurrent obesity* was a weight regain to a BMI above 35 kg/m^2, which would put the patient above the clinical limit for listing. Post-LSG, weight regain was observed in a small percentage (7.5%) occurring over a span of 21–55 months. However, only half of the weight regain incidences were classified also a recurrence of obesity (3.8%). Highlighting the difference between regain and recurrence, two patients who had a regain but remained below the BMI limit were still transplanted. In the subsequent post-KT period, the ratio of weight regain to recurrent obesity remained the same, 2:1, but increased sevenfold to 35.7% and 17.9%, respectively. Whether these post-KT regains and recurrences occurred as a consequence of the KT, such as the addition of immunosuppression, the lifting of dietary restriction required of ESRD, or their occurrences are an inherent risk in the evolution post-LSG, remains to be determined. Only one previously published study has reported no recurrent obesity within the first year post-LSG to KT [7], though the definition of recurrence is not stated. In the general population, recurrent obesity after LSG, defined as a weight gain of 10 kg from the nadir, was been reported at 58.5% of patients after 10 years, with 13% suffering from an increase of 25 kg [22]. In another study, weight regain was noted in 75.6% of patients after 6 years [23,24]. Future long-term studies will be necessary to document the outcomes in the ESRD and KT populations.

The main limitations of this study stem from the complexity of analysing two major events in the evolution of BMI. The anthropometric outcomes reported in the post-LSG and post-KT evolutions are treated as distinct time periods and serially. Certainly, in real life, there is a significant interplay between the two events and periods, which was analysed with the comparison pre-/post-KT BMI slopes. A larger cohort in the future could certainly improve the power and reliability of statistical analyses. The goal for bariatric surgery in the transplant candidate is weight loss to qualify for the waiting list. A consensus for the definition of BMI limit, successful surgical weight loss, weight regain and recurrent obesity will certainly facilitate further discussion and comparisons of outcomes. The long-term maintenance of weight loss and its impact on comorbidities such as diabetes and cardiac conditions and on mortality, especially with the addition of immunosuppression, are the ultimate goals for future studies as they are not fully captured in this study. Nonetheless, the consistency of outcomes from different centres with the procedure being performed by nine surgeons makes the generalizability of the results possible.

Conclusion

Laparoscopic sleeve gastrectomy provides rapid, significant and safe weight loss for morbidly obese patients in end-stage kidney disease. This bariatric surgery offers a clear clinical pathway for access to the transplant waiting list. The kidney transplant event does not appear to alter the post-LSG BMI evolution significantly. Male patients, predialysis, lower obesity classes and those without coronary artery disease had increased chances for successful surgical weight loss. LSG should be considered as early as possible for candidates with BMI between 35 and 45 kg/m^2, given an expectation of at least six months to achieve the BMI limit of 35 kg/m^2.

Authorship

GC: participated in research design, writing of the paper, performance of the research and data analysis, and is the senior supervisor of the project. RH: participated in research design, performance of the research, writing of the paper and data analysis. J-PL: participated in research design, writing of the paper, performance of the research and data analysis. JT: participated in research design, writing of the paper, performance of the research and data analysis. SG: participated in the performance of the research. LB: participated in research design, and performance of the research. NE: participated in writing of the paper and data analysis. AA: participated in the performance of the research and data analysis. RP: participated in research design and performance of the research. PYG: participated in research design and performance of the research. All authors participated in the critical review of the manuscript and approved the submitted version.

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Conflicts of interest

The authors of this manuscript have no conflicts of interest to disclose.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Depiction of observed and predicted BMI evolution, as determined by fixed effects estimates, of patients who underwent LSG and subsequently had a KT. BMI, body mass index; KT, kidney transplant; LSG, laparoscopic sleeve gastrectomy.

Figure S2. BMI evolution using LOESS regression in patients having undergone KT early (<12 months) or late (>12 months) after LSG. BMI, body mass index; KT, kidney transplant; LSG, laparoscopic sleeve gastrectomy.

Table S1. Weight loss at 1-year post-LSG by obesity class.

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