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ORIGINAL CONTRIBUTIONS

Perioperative Course, Weight Loss and Resolution of Comorbidities After Primary Sleeve Gastrectomy for Morbid Obesity: Are There Differences Between Adolescents and Adults?

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Abstract
Background Morbid obesity in both adolescents and adults has risen in an alarming rate. Bariatric surgery is playing an increasing role in pediatric surgery. However, current evidence is limited regarding its safety and outcome.
Methods Since 2005, data from obese patients that undergo bariatric procedures in Germany are prospectively registered. For the current analysis, all adolescent and adult subjects that had undergone laparoscopic sleeve gastrectomy (LSG) from 2005 to 2014 were considered.
Results LSG represents the most common bariatric procedure in Germany with a proportion of 48.1% in adolescent and 48.7% in adult obese in 2014. LSG was performed in 362 adolescent and 15,428 adult subjects. Pre-operative BMI was comparable between the two populations. However, adult obese had more frequently coexisting comorbidities ($p < 0.01$). Complication rates and mortality (0 vs. 0.2%) did not differ significantly. Adolescents achieved a BMI reduction of 16.8 and 18.0 kg/m^2 at 12 and 24 months compared with 15.4 and 16.6 kg/m^2 in the adult group. There was a significantly higher BMI reduction in late adolescents (19–21 years) compared with patients ≤18 years at 24 months (19.8 vs. 13.6 kg/m^2). Resolution rate of hypertension was significantly higher in adolescents.
Conclusion LSG is a safe therapeutic option that can be performed in adolescents without mortality. Late adolescents experienced the highest weight loss; resolution rate of comorbidities was lower in adults. All future efforts should now be focused on the evaluation of the long-term outcomes of LSG in the pediatric population.

Keywords Sleeve gastrectomy · Obesity · Adolescents · Adults · German multicenter trial

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Introduction

Morbid obesity among adults is steadily increasing in nearly all parts of the world and has become one of the global major health problems. It promotes the development of various diseases, such as cardiovascular disease and type-2 diabetes (T2DM), which greatly increase mortality. Obesity among children and adolescents has also increased dramatically during the last decades. The nationwide "German Health Interview and Examination Survey for Children and Adolescents" (KiGGS), conducted in 2003–2006, showed a significant increase in the prevalence rates of overweight and obesity (18.8%) compared with the early 1990s. The prevalence of overweight, including obesity, in adolescents aged 11 to 17 years had almost doubled, and the prevalence of obesity had nearly tripled [1]. In the follow-up survey (2009–2012)—KiGGS Wave 1—it was shown that the rate has not further increased (18.9%) but still remains on a very high level [2].

Multiple comorbid conditions are associated with obesity in this age group. Pediatricians are now facing children and adolescents with comorbidities previously only seen in adults, including T2DM, obstructive sleep apnea, fatty liver disease, and hypertension [3]. In addition, obese adolescents are likely

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to suffer from psychological morbidity, loss of self-esteem, and social exclusion which has the potential to scar them for life [4]. This emphasizes the significance of this health issue and the need for both prevention and effective treatment measures of overweight and obesity in children and adolescents.

Obesity treatment comprises a multidisciplinary approach that intends to reduce weight, resolve comorbidities, and improve quality of life [5]. Unfortunately, non-surgical weight management programs, including lifestyle changes, increase in physical activity, and dietary modifications, have produced poor results [6]. Bariatric surgery has been proven to be the most effective treatment in morbidly obese adults with significant and sustained weight loss and a high rate of comorbidity resolution. However—despite encouraging results—pediatric bariatric surgery is still a controversial topic. There are still concerns about safety, effectiveness, the possibility of long-term complications, and adverse effects on growth and maturation that may be associated with bariatric surgery [7, 8].

Laparoscopic sleeve gastrectomy (LSG) has become a very popular surgical procedure and is increasingly being done as a stand-alone bariatric operation in adults. It has been shown to produce excellent excess weight loss in the short and mid-term comparable with Roux-Y-gastric bypass and superior to gastric banding with a low incidence of major complications and death [9]. There is only limited evidence regarding the safety and effectiveness of LSG in morbidly obese adolescent. Therefore, the aim of this study was a comparison of LSG outcomes in adolescent and adult obese subjects.

Methods

Since January 2005, data for obese patients undergoing a bariatric procedure are prospectively acquired in an online database ("German Bariatric Surgery Registry" (GBSR)) and analyzed by the *Institute for Quality Assurance in Operative Medicine* at the Otto-von-Guericke University of Magdeburg, Germany. This German multicentered observational study was conducted in accordance to the principles of the Declaration of Helsinki for Biomedical Research. Participation was voluntary, evaluation was based on anonymous data, and the study involved observation only—i.e., it had no influence upon the choice or course of therapy. All participants provided written informed consent for data collection.

For the current investigation, we enrolled all obese subjects who were undergoing primary sleeve gastrectomy for morbid obesity within a 10-year period (1st January 2005 until 31st December 2014). Patients that underwent LSG as a revisional or redo operation were excluded. The main focus of this study was to compare the perioperative course, weight loss, and resolution of comorbidities between adolescent (group A) and adult obese subjects (group B). Group A comprised all adolescents (≤18 years) and late adolescents (19–21 years). In a second analysis, patients aged 18 years or less at the time of the operation were evaluated separately and compared with late adolescents/adults. Two patients with Prader-Willi syndrome were excluded from analysis.

The following variables were considered for analysis of the perioperative course:

- Patient demographics/clinical data: gender, initial height and weight, pre-operative BMI, comorbid conditions, and ASA stage.
- Operative data: operation time, surgical approach, conversion rate, antibiotic and thromboembolism prophylaxis, management of staple line, bougie size, sleeve volume, and hospital stay.
- Perioperative complications: intraoperative, general and surgical complications, re-operation, and mortality.

For the analysis of weight change and resolution of comorbidities at 12 and 24 months after primary LSG, all patients with available follow-up information at these time points were considered. In order to evaluate the influence of age at baseline on the postoperative weight loss in adolescents, we additionally compared adolescents (age ≤18 years) and late adolescents (19–21 years). All analyses included absolute weight loss, percentage of excess weight loss (% EWL), and BMI reduction.

The comorbidities analyzed were hypertension, type-2 diabetes, and sleep apnea. Resolution/improvement was defined according to the current medical treatment at the time of follow-up compared with baseline: *improvement*—reduction of medication/medical treatment; *resolution*—discontinuation of all medication/no current therapy. Furthermore, incidence of late complications (gastroesophageal reflux, recurrent vomiting, and incisional hernia) were analyzed for both populations at 12 and 24 months after the primary procedure.

Statistical Analysis

Statistical analysis was performed using SAS® 9.2 (SAS Institute Inc., Cary, NY, USA). In descriptive statistical analyses, absolute/relative frequencies are given for nominal values. Continuous data is expressed as mean and standard deviation or median and range, if appropriate. Differences in categorical variables are tested using Pearson's χ^2 test. Continuous variables were compared via robust *t* tests, where non-normally distributed data have been transformed using a square root function. As different populations and time points were analyzed, a Bonferroni correction (factor 6) was performed and thus, significance is indicated for $p \leq 0.05$.

Results

Within the study period (from 2005 to 2014), 362 adolescents (group A) and 15,428 adults (group B) underwent LSG as a primary procedure for morbid obesity. Of the 362 adolescents, 88 (24.3%) were 18 years or less at the time of surgery. There was a steady increase of LSG procedures per year in both groups. Since 2013, sleeve gastrectomy represents the most frequently performed bariatric procedure in Germany with a proportion of 48.1% in group A and 48.7% in group B in 2014.

Demographic Data

There was a higher proportion of female patients, both in adolescent (66.6%) and adult obese (64.7%, $p = 1.0$). Mean age at the time of surgery was 19.5 ± 1.5 in group A and 44.2 ± 11 years in group B. Mean height (172.8 ± 9.4 vs. 171.5 ± 9.9 cm, $p = 0.08$), weight (155.7 ± 33.2 vs. 152.5 ± 32.9 kg, $p = 0.43$), and mean BMI (52.0 ± 9.5 vs. 51.7 ± 9.5 kg/m^2, $p = 1.0$) were comparable between the two populations. Mean age of adolescents ≤18 years was 17.4 ± 1.1 years with the youngest patients being 12 years. Mean BMI did not differ significantly when compared with late adolescents/adults (51.3 ± 8.1 vs. 51.7 ± 9.5 kg/m^2, $p = 1.0$) (Table 3).

The vast majority of obese adolescent and adults presented with at least one comorbidity at baseline with a significantly higher proportion in the latter group (77.1 vs. 90.7%, $p < 0.01$). This difference was confirmed for every pre-existing comorbid condition except for the gastro-esophageal reflux disease (9.4 vs. 11.3%, $p = 1.0$). Hypertension was the most frequent comorbidity (34.8 vs. 63.9%, $p < 0.01$) followed by type-2 diabetes mellitus (insulin-dependent, 1.3 vs. 13.2%, $p < 0.01$; non-insulin-dependent, 9.0 vs. 20.7%, $p < 0.01$) and sleep apnea (8.3 vs. 26.7%, $p < 0.01$) (Table 1). In adolescents ≤18 years, 73.9% had comorbidities at baseline. Presence of non-insulin-dependent T2DM and gastro-esophageal reflux disease was not significantly different when compared with late adolescents/adults ($p = 0.7$ and $p = 1.0$) (Table 3).

Operative Data

Median operative time differed significantly between both groups (74 vs. 80 min, $p < 0.01$). LSG was completed by laparoscopy in 98.3% in group A and 98.5% in group B. Primary laparotomy was performed in 1.7 and 0.9%, respectively ($p = 0.83$). A conversion to the open approach became necessary only in the adult population in 0.6%. Perioperative antibiotic prophylaxis can be regarded as a standard of care and was routinely given in nearly all documented procedures without difference between both groups (96.7 vs. 93.8%, $p = 0.15$). The same was true for the thromboembolism prophylaxis (99.2 vs. 98.5%, $p = 1.0$).

Management of the staple line was nearly identical between LSG performed in adolescent and adult obese ($p = 1.0$). Oversewing of the staple line was applied in 43.9 and 42.2%, and staple line buttressing materials were used in 21.5 and 21.8%, respectively. In 2.2 and 2.0%, staple line buttressing and oversewing was performed simultaneously.

The mean Bougie size used in this study and the sleeve volume were comparable in both adolescent and adult obese (36.4 vs. 36.0 Charriere, $p = 0.46$; 108.7 vs. 109.8 ml, $p = 1.0$). Median hospital stay was 5.0 days in both groups (Table 2).

When adolescent ≤18 years were analyzed separately, no significant differences were found for every parameter except for the laparotomy rate. Primary laparotomy was more frequently performed in this group (4.6 vs. 0.9%, $p = 0.01$) (Table 3).

Perioperative Complications

Intraoperative complications occurred in only 2 (0.6%) adolescent and 267 (1.7%) adult obese ($p = 0.52$), with injuries to the spleen (0.28 vs. 0.34%) and the liver (0.0 vs. 0.1%) and bleeding (0.0 vs. 0.1%) being the most frequent events. During the postoperative course, 6.4% of the adolescent and 5.5% of the adult population developed general complications ($p = 1.0$). Surgical complications were observed in 17 (4.7%) adolescent and 688 adult patients (4.5%; $p = 1.0$). There were no significant differences for the most relevant surgical complications: staple line leak (1.9 vs. 1.4%, $p = 1.0$) and postoperative hemorrhage (0.8 vs. 1.3%, $p = 1.0$). A re-operation became necessary in 17 (4.7%) adolescent and 549 (3.6%) adult obese ($p = 1.0$). There were no reported mortalities in group A, and mortality rate in the adult population was 0.2% (Table 2). When adolescent ≤18 years were analyzed separately, again, no significant differences were found for all complications evaluated in this study. However, there was a trend towards a higher rate of general complications (9.1 vs. 5.5%, $p = 0.88$) and staple line leaks in this group (3.4 vs. 1.4%, $p = 0.72$) (Table 3).

Weight Loss

Follow-up information were available for 168/61 (46.4/16.8%) adolescent and 6939/2930 (45.0/19.0%) adult obese subjects at 12 and 24 months. Follow-up rate for adolescents ≤18 years was 51.1% ($n = 45$) and 19.3% ($n = 17$) at both time points. Demographic, operative data, and complication rate did not differ significantly between patients with follow-up information and the entire patient cohort in all groups. At 12 months, adolescent obese had lost 50.1 ± 18.2 kg compared with 45.4 ± 18.2 kg in the adult group ($p < 0.01$). BMI reduction also differed significantly between both groups (16.8 ± 5.9 vs. 15.4 ± 6.0 kg/m^2, $p = 0.02$). The weight loss in the second year was much less pronounced compared with

Table 1 Demographic data and comorbidities at baseline of adolescent and adult obese

	Adolescent (n = 362)	Adult (n = 15,428)	p value
Age (years; mean ± SD)	19.5 ± 1.5	44.2 ± 11	<0.01
Gender (female; %)	66.6%	64.7%	1.0
Height (cm; mean ± SD)	172.8 ± 9.4	171.5 ± 9.9	0.08
Weight (kg; mean ± SD)	155.7 ± 33.2	152.5 ± 32.9	0.43
BMI (kg/m^2; mean ± SD)	52.0 ± 9.5	51.7 ± 9.5	1.0
Comorbidity (%)			
Total	77.1	90.7	<0.01
Hypertension	34.8	63.9	<0.01
T2DM	10.3	33.9	<0.01
Sleep apnea	8.3	26.7	<0.01
Reflux	9.4	11.3	1.0
ASA I/II (%)	63.1	44.3	<0.01

Adolescents (≤18 years) and late adolescents (age, 19–21 years) are considered one group

the first 12 months postoperatively. At 24 months, absolute weight loss was 54.4 ± 24.9 vs. 48.9 ± 22.6 kg and BMI reduction was 18.0 ± 8.2 vs. 16.6 ± 7.4 kg/m^2 for groups A and B, respectively. These differences were no longer significant (p = 0.58; p = 1.0). % EWL for both time points is presented in Fig. 1. When adolescents ≤18 years were analyzed separately, no significant differences were found for both 12 (% EWL, 59.9 ± 22.6 vs. 60.9 ± 22.5, p = 1.0; BMI reduction. 15.6 ± 5.6 vs. 15.4 ± 6.0 kg/m^2, p = 1.0) and 24 months (% EWL, 53.5 ± 25.8 vs. 64.1 ± 24.6, p = 0.67; BMI reduction, 13.6 ± 7.6 vs. 16.6 ± 7.4 kg/m^2, p = 0.72). However, 2 years after the procedure, weight change was less pronounced in adolescents aged ≤18 years compared with late adolescents/adult subjects (Table 3).

To further investigate the influence of age on weight loss in the adolescent group, we additionally compared adolescents aged ≤18 years and late adolescents (19–21 years). Mean initial BMI (51.3 vs. 52.0 kg/m^2) and frequency of pre-existing comorbidities (73.9 vs. 77.1%) at baseline were comparable between both adolescent groups. At 12 months, the absolute weight loss (47.4 ± 17.6 vs. 51.1 ± 18.4 kg), % EWL (59.9 ± 22.6 vs. 65.9 ± 22.0), and BMI reduction (15.6 ± 5.6 vs. 17.2 ± 6.0 kg/m^2) were higher in late adolescents (p = 0.48; p = 0.26; p = 0.24). At 24 months, all these differences were more pronounced and became statistically significant: absolute weight loss (39.6 ± 23.6 vs. 60.1 ± 23.3 kg, p = 0.01), % EWL (53.5 ± 25.8 vs. 72.8 ± 24.5, p = 0.03), and BMI reduction (13.6 ± 7.6 vs. 19.8 ± 7.8 kg/m^2, p = 0.02) (Fig. 2).

Table 2 Perioperative parameter and complications for primary LSG in adolescent and adult obese

	Adolescent (n = 362)	Adult (n = 15,428)	p value
Operative time (min; median (range))	74 (26–350)	80 (20–394)	<0.01
Bougie size (French; mean)	36.4	36.0	0.46
Sleeve volume (mL; mean ± SD)	108.7 ± 35.9	109.8 ± 37.6	1.0
Conversion (%)	0	0.6	0.94
Management of staple line (%)			
Reinforcement	21.5	21.8	1.0
Oversewing	43.9	42.2	
Intraoperative complications (%)	0.6	1.7	0.52
General complications (%)	6.4	5.5	1.0
Surgical complications (%)	4.7	4.5	1.0
Staple line leak	1.9	1.4	1.0
Hemorrhage	0.8	1.3	1.0
Re-operation (%)	4.7	3.6	1.0
Hospital stay (day; median (range))	5 (1–69)	5 (1–253)	1.0
Mortality (%)	0	0.23	1.0

Adolescents (≤18 years) and late adolescents (age, 19–21 years) are considered one group

Table 3 Demographic and perioperative parameter and weight loss: comparison between adolescents (≤18 years) and late adolescents/adults

	Adolescents (n = 88)	Late adolescents/adults (n = 15,702)	p value
Age (years; mean ± SD)	17.4 ± 1.1	43.8 ± 11.3	<0.01
BMI (kg/m^2; mean ± SD)	51.3 ± 8.1	51.7 ± 9.5	1.0
Comorbidity (%)			
Total	73.9	90.5	<0.01
Primary laparotomy (n/%)	4/4.6	146/0.9	0.01
Operative time (min; mean (range))	84 (26–350)	87.8 (20–394)	1.0
Intraoperative complications (%)	1.1	1.7	1.0
General complications (%)	9.1	5.5	0.88
Surgical complications (%)	3.4	4.5	1.0
Staple line leak	3.4	1.4	0.73
Hemorrhage	0	2.2	1.0
BMI reduction (kg/m^2; mean ± SD)			
At 12 months	15.6 ± 5.6	15.4 ± 6.0	1.0
at 24 months	13.6 ± 7.6	16.6 ± 7.4	0.72
% EWL (mean ± SD)			
At 12 months	59.9 ± 22.6	60.9 ± 22.5	1.0
At 24 months	53.5 ± 25.8	64.1 ± 24.6	0.67

Resolution of Comorbidities

Following LSG, a remarkable resolution rate of pre-existing comorbid conditions was reported in both adolescents and adults. However, resolution rate was much higher in adolescent obese. This was confirmed for every comorbidity analyzed in this study. One year after LSG, complete resolution or improvement of type-2 diabetes was observed in 90.9% in the adolescent population compared with 81.6% in obese adults (p = 0.28). Hypertension resolved or improved in 78.7% of adolescent and 66.7% of adult subjects, respectively, with anti-hypertensive medication at baseline (p < 0.01). Likewise, sleep apnea resolved or improved in a higher proportion of adolescent obese (81.3 vs. 71.1%, p = 0.13). Twenty-four months after the procedure, resolution rate was 100% in adolescent patients for type-2 diabetes and hypertension compared with 74.7 and 62.8% for adult obese. This difference was less pronounced for sleep apnea (75.0 vs. 68.1%) (Table 4). Due to the small number of patients and the low follow-up rate, no additional analysis for the resolution of comorbidities could be performed for adolescents aged ≤18 years.

Late Complications

Gastro-esophageal reflux was reported by 14.9% of the adolescent and 17.2% of the adult obese at 12 months after LSG (p = 1.0). Two years after surgery, a slight increase of patients with symptomatic reflux was observed in both groups (16.4 vs. 18.7%, p = 1.0); 10.7/8.6% of the adolescent and 8.2 /7.9% (p = 1.0) of the adult patients, respectively, complained about recurrent vomiting at 12/24 months after LSG. Incisional hernias were diagnosed in 3 adolescent (1.8%) and 110 (1.6%) adult subjects 1 year after the primary procedure. At 24 months, no further increase of the hernia rate was noted in both groups. Likewise, the separate analysis of adolescents aged ≤18 years revealed no significant differences for all late complications. However, there was only one patient (5.9%) in this group with symptomatic reflux at 24 months compared with a reflux rate of 18.7% in the late adolescent/adult group (p = 1.0).

Discussion

Morbid obesity in both, adolescents and adults, has risen in an alarming rate and can be regarded as one of the greatest health problems facing the world today. Furthermore, obesity is strongly associated with several comorbidities that increase mortality. Conservative treatment often fails to result in significant and sustained weight loss. Bariatric surgery in adults is now widely accepted as a safe and effective treatment for morbid obese subjects after unsuccessful conservative therapy. In adolescents, bariatric surgery is clearly playing an increasing role. However, there are still concerns about safety, effectiveness, the possibility of long-term complications, and adverse effects on growth and maturation. Furthermore, there are only a limited number of studies that analyzed the safety and outcome of bariatric surgery in children and adolescent [5, 10–15]. In addition, there is no agreement which procedure should be applied. Therefore, it is of great importance to analyze the results of pediatric bariatric surgery in large

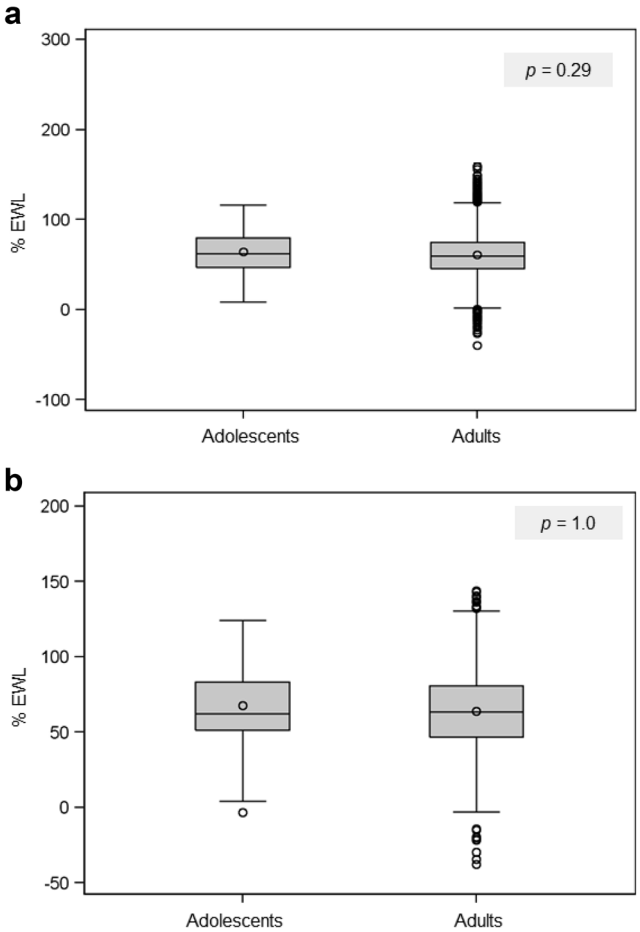

Fig. 1 **a** Percentage of excess weight loss at 12 months after primary LSG for adolescent (64.3 ± 22.3) and adult obese subjects (60.8 ± 22.5); follow-up rate, 46.4 and 45.0%; adolescents (≤18 years) and late adolescents (age, 19–21 years) are considered one group. **b** Percentage of excess weight loss at 24 months after primary LSG for adolescent (67.4 ± 26.1) and adult obese subjects (63.9 ± 24.6); follow-up rate, 16.8 and 19.0%; adolescents (≤18 years) and late adolescents (age, 19–21 years) are considered one group

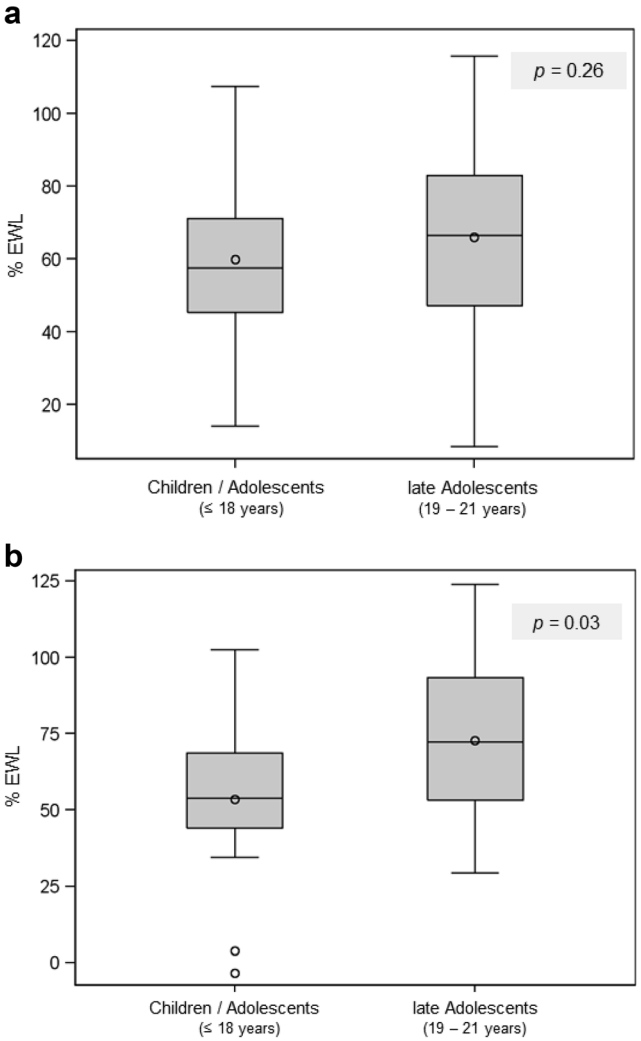

Fig. 2 **a** Percentage of excess weight loss at 12 months after primary LSG: comparison between children/adolescents (59.9 ± 22.6) and late adolescents (65.9 ± 22.0); follow-up rate, 51.1 and 44.9%. **b** Percentage of excess weight loss at 24 months after primary LSG: comparison between children/adolescents (53.5 ± 25.8) and late adolescents (72.8 ± 24.5); follow-up rate, 19.3 and 16.1%

populations and to compare the outcomes with those achieved in adult surgery.

Within the German multicentered observational study (GBSR), data of patients undergoing a bariatric procedure are prospectively acquired. Since 2005, 46,259 obese subjects that had undergone an operation could be enrolled. For the current analysis, all patients with primary LSG for morbid obesity performed within a 10-year period were considered for analysis. The main focus of this study was to investigate the perioperative course, weight loss, and resolution of comorbidities in adolescent obese and to compare these results with adults undergoing the same procedure.

Currently, LSG represents the most common bariatric procedure in Germany and was performed in 362 adolescent and 15,428 adult obese. In 2014, 77 hospitals performed LSG in adolescent obese, with only one hospital with >10 procedures/year. When children and adolescent ≤18 years were analyzed separately for the same time period (2005–2014), only 230/88 (all procedures/LSG) subjects could be identified. These findings reveal that pediatric bariatric surgery is not commonly being performed in Germany. This is reflected by the recommendations of the current national guidelines. Here, bariatric surgery is only advised in strictly selected cases and as the last alternative after repeated failure of multimodal conservative therapies in extremely obese adolescents with significant comorbidity [16].

The results of the current study demonstrated that the frequency of coexisting comorbidities is significantly lower in adolescent obese subjects but already on very high level. This is in line with the results of the Teen-LABS study, which demonstrated that a relevant proportion of adolescent obese has concomitant comorbid conditions. In their study, 49% presented with three or fewer and 39% with four or five

Table 4 Resolution/improvement of comorbid conditions in adolescent and adult obese after primary LSG

	Adolescent *n* (%)	Adult *n* (%)	*p* value
T2DM			
Incidence (baseline)	32/310 (10.3)	4625/13,653 (33.9)	<0.01
Resolution/improvement			
At 12 months	11/12 (90.9)	1674/2052 (81.6)	0.28
At 24 months	4/4 (100.0)	618/827 (74.7)	1.0
Hypertension			
Incidence (baseline)	126/362 (34.8)	9852/15,428 (63.9)	<0.01
Resolution/improvement			
At 12 months	48/61 (78.7)	2968/4449 (66.7)	<0.01
At 24 months	20/20 (100.0)	1147/1826 (62.8)	<0.01
Sleep apnea			
Incidence (baseline)	30/362 (8.3)	4116/15,428 (26.7)	<0.01
Resolution/improvement			
At 12 months	13/16 (81.3)	1360/1913 (71.1)	0.13
At 24 months	3/4 (75.0)	537/789 (68.1)	1.0

Adolescents (≤18 years) and late adolescents (age, 19–21 years) are considered one group

comorbidities [10]. In our study, the initial weight and BMI at baseline were comparable in both groups. This agrees only in part with the results of a study by Alqahtani et al., who compared 108 pediatric and 114 adult patients. Although preoperative BMI was comparable in both groups, the pediatric subjects suffered more frequently from hypertension and obstructive sleep apnea at baseline [5]. There were no significant differences in our study for all procedural variables except for the operation time, which was longer in adults. However, when adolescents aged ≤18 years were analyzed separately, operation time did not differ significantly and there was a significantly higher rate of primary laparotomy. The reason for this remains unclear. It can be speculated that few of the procedures have been performed by pediatric surgeon with little expertise in bariatric surgery. Complication rates were also comparable between the populations. This was also true for the most frequent surgical complications, i.e., staple line leak and hemorrhage. There were no mortalities in adolescents compared with a mortality rate of 0.2% in adult obese. However, in the separate analysis of adolescents aged ≤18 years, there was a non-significant trend towards a higher rate of general complications and staple line leaks for this group. These results mainly agree with the results of other studies. In a retrospective single-center study including 135 adolescents that had undergone LSG, no mortalities were reported. Overall complication rate was 4.4%. There were no intraoperative complications compared with a 0.2% ($n = 2$) complication rate in our study [11]. Nocca et al. reviewed 61 late adolescents with LSG. Intraoperatively, no complications were observed and no mortalities were recorded. Major complications occurred in 6.5%, with leak rate comparable with our results (1.6 vs. 1.9%) and a higher rate of bleeding complications (3.3 vs. 0.8%) [12]. In the Teen-LABS study including 277 adolescents that were treated with Roux-Y-gastric bypass (RYGB; 66%) and LSG (28%), major/minor complication experienced 7.9/14.9% of the patients, no deaths were observed. The re-operation rate was 2.5% compared with 4.7% in our study [10]. The only study that compared the outcome after LSG between adolescent and adult obese reported no major complications in the pediatric group compared with 3.5% in the adult group [5]. Thus, all these results including the findings of our study demonstrate that LSG in adolescents is a safe procedure with a risk for perioperative complications at least comparable with adults. None of the studies reported mortalities. This is an important finding, especially due to the fact that a potential selection bias can be assumed. Indication for surgery is more restrictive in adolescents. Hence, bariatric procedures are only performed in highly selected cases.

In our study, LSG resulted in a significant weight loss in adolescent obese subjects with a mean % EWL of 64.4 and 67.4% and a mean BMI reduction of 16.8 and 18.0 kg/m^2 at 12 and 24 months after the procedure. Compared with the adult population, % EWL and BMI reductions were more pronounced at both time points. However, the differences were no longer statistically significant at 24 months which possibly may have been influenced by the low follow-up rate. Interestingly, we found different results when adolescents aged ≤18 years were analyzed separately and compared with late adolescents/adults. Two years after LSG, % EWL and BMI reduction were more pronounced in the latter group.

The weight change in obese adolescents at 12 and 24 months after LSG observed in our cohort is within the range reported by other studies [11–13]. Raziel et al. studied 32 adolescent who underwent LSG during a 6-year period. They demonstrated that weight loss is increasing over time

with a remarkable mean % EWL of 101.6% at 60 months post-surgery [14]. In a prospective multicentre study by Inge et al., 242 adolescent obese underwent either RYGB (161) or LSG (67). At the 3 years after surgery, mean weight had decreased by 27% with comparable results between both procedures [15]. Serrano et al. reviewed 45 obese adolescents that had undergone bariatric surgery in a single institution. They also demonstrated that weight loss after LSG and RYGB is comparable with a mean % EWL at 24 months of 60.3 vs. 58.1% [17]. In retrospective analysis by Pedroso et al., 174 adolescent obese underwent gastric banding (LAGB) or LSG. At 24 months after the procedure, patients who had undergone LSG displayed a significantly greater % EWL (70.9 vs. 35.5%) [18]. There is only one study which compared the outcome after LSG between adult (n = 114) and pediatric (108) obese patients. In contrast with our results, it showed no statistically significant differences for all weight loss outcome measures at 12 and 24 months [5]. However, the number of patients was considerably lower in this study with an available follow-up data for 41 vs. 44 and 8 vs. 13 pediatric and adult patients, respectively, at both time points.

Interestingly, we found that LSG is more effective in late adolescents compared with children/adolescent ≤18 years. Late adolescents (19–21 years) experienced a greater mean % EWL and BMI reduction. This difference became statistically significant at 24 months and could be an explanation for our finding that weight loss in adolescent ≤18 years was also less pronounced when compared with obese subjects >18 years. This finding agrees with results of a study by Alqahtani et al. who evaluated the outcome of LSG in 116 children (≤14 years) and 158 adolescents. They further divided the cohort into subgroups based on their age (5–8.9, 9–12.9, 13–16.9, and 17–21 years). The latter group exhibited the highest weight loss at 1, 2, and 3 years after the procedure [19]. We are not able to explain this finding. However, if this can be confirmed in further studies, one could consider recommending bariatric surgery preferably in the late adolescence in order to improve the weight loss after LSG. Another argument for this recommendation could be the non-significant trend towards a higher rate of general complications and staple line leaks in obese adolescents ≤18 years in our study.

In this study, we showed that LSG is not only effective in terms of weight loss. LSG also strongly improved coexisting comorbidities. This effect was more pronounced in adolescent obese compared with adult patients and was confirmed for every comorbidity. Resolution rate (complete resolution or improvement) at 12 and 24 months was 90.9 and 100% for T2DM, 78.7 and 100% for hypertension, and 81.3 and 75% for sleep apnea. Although our results are in line with the findings of other investigations, they have to be interpreted with caution. For the definition of remission, not all strict criteria (i.e., duration of remission, fasting blood glucose, HbA1c) were applied. In a study by Al-Sabah et al., all patients with T2DM and 75% of those with hypertension at baseline showed a complete resolution of the disease at 2 years after LSG [11]. Complete resolution or amelioration of comorbidities including T2DM, hypertension, and sleep apnea was observed in all adolescent patients within 1 year after LSG in a study by Raziel et al. [14]. In a prospective study including 242 adolescent obese who underwent RYGB and LSG, remission of T2DM occurred in 95% of participants who had the condition at baseline, remission of elevated blood pressure in 74%, and remission of dyslipidemia in 66% at 3 years after surgery [15]. These impressive results are not being achieved in adult obese. In an analysis of the Bariatric Outcomes Longitudinal Database (BOLD) including 186,576 patients, remission rates were 52% for T2DM, 35.2% for hypertension, and 34.2% for dyslipidemia 12 months after LSG [20]. This fact is confirmed by the results of our study. Here, the effect of LSG on comorbid conditions was more pronounced in adolescents obese. Therefore, it can be assumed that there is a higher potential for the reversal of obesity-related comorbidities in this age group. This might be related to the duration of the comorbid condition itself. For the T2DM in adult obese, it is known that there is a correlation between the duration of diabetes and the likelihood of remission. Furthermore, it can be speculated that bariatric surgery in the adolescence may avoid or postpone the development comorbidities in the adulthood as this was demonstrated for T2DM in adults [21]. However, this has to be confirmed in future studies. The positive impact of bariatric surgery on comorbidities should be taken into consideration when timing of surgery is being discussed. In morbidly obese adolescent with coexisting comorbidities and no response to non-surgical therapy, surgery should be offered early in life before these conditions become irreversible.

LSG may improve or aggravate existing gastro-esophageal reflux or may lead to “de novo” reflux. The mechanisms responsible for this are not fully understood. Reduction of the lower esophageal sphincter pressure, a reduced gastric compliance, an increased sleeve pressure, and a decreased sleeve volume are being discussed as causative factors [22]. In our study, symptomatic reflux was reported by 14.9% of the adolescent and 17.2% of the adult obese at 12 months after LSG. Two years after surgery, a further increase was noted in both groups. Interestingly, the lowest reflux rate (5.9%) was observed in adolescents ≤18 years at 24 months. However, this finding may be attributed to the low follow-up rate. The incidence of symptomatic reflux after LSG in our study is within the range reported in the literature. In adult series, symptomatic reflux was observed to occur in 7.8–20% of patients at 12–24 months after sleeve gastrectomy [23]. Little evidence exists regarding reflux following LSG in the adolescent population. In a retrospective multicenter review, 21.3% of the 61 adolescent patients developed reflux that responded favorably to proton pump inhibitor treatment [12]. These results illustrate that symptomatic gastro-esophageal reflux also represents a relevant late complication in adolescent that had

undergone LSG. In these patients, a lifelong follow-up and consequent treatment is necessary to avoid any progression to Barrett's esophagus and esophageal adenocarcinoma.

There are some limitations to our study that should be acknowledged. First, the data used for this study was collected from many hospitals. Thus, there are no effective means of establishing the reliability of the data recorded. As with any large database analysis, there are likely data entry inaccuracies. Second, the observational design without standardization of surgical technique and postoperative care may restrict interpretation of the data. In addition, a major criticism is the considerably low follow-up rate with available information in less than 50% and less than 20%, respectively, at 12 and 24 months in all groups. This may have strongly influenced the results regarding weight loss and resolution of comorbidities and questions our ability to generalize our findings. One reason for the poor follow-up rate is the multicentre nature of the study, collecting data from many hospitals throughout the country. Additionally, mid- and long-term complications after LSG are less frequent compared with RYGB and LAGB which may also impact the patient's adherence to follow-up instructions. Furthermore, it has been reported that the adolescent population has an important risk of impaired follow-up due to the increased mobility [12].

Conclusion

The current study analyzed a large cohort of adolescent and adult obese that underwent LSG for morbid obesity during a 10-year period. Currently, LSG represents the most common bariatric procedure in Germany. It was demonstrated that LSG is a safe therapeutic option that can be performed in adolescents with a very low morbidity. No mortalities were observed. The perioperative complication rates were at least comparable with those observed in the adult population. LSG resulted in a substantial weight loss in both adolescent and adult obese subjects with better results in the adolescent population. Interestingly, LSG resulted in a higher weight loss in late adolescents (19–21 years) compared with patients ≤18 years, suggesting that this age would be the preferable time period to perform bariatric surgery. LSG also strongly improved pre-existing comorbidities. This effect was more pronounced in adolescent obese compared with adult patients, suggesting that there is a higher potential for the reversal of obesity related comorbidities in this age group. This important finding provides a strong argument to offer bariatric surgery early in life before comorbid conditions become irreversible. Symptomatic gastro-esophageal reflux was shown to be a relevant late complication following LSG, both in adolescent and adult obese. This highlights the importance of a lifelong follow-up to avoid secondary complications. All future efforts should now be focused on the evaluation of the long-term outcomes of LSG in the pediatric population to confirm LSG surgery as a safe, highly effective, and durable therapeutic option in morbidly obese adolescents.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that there are no conflicts of interest.

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Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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