Bariatric Surgery in Morbidly Obese Adolescents: a Systematic Review and Meta-analysis

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Abstract Pubmed, Embase, and Cochrane were systematically reviewed for available evidence on bariatric surgery in adolescents. Thirty-seven included studies evaluated the effect of laparoscopic adjustable gastric banding (LAGB), Roux-en-Y gastric bypass (RYGB), or laparoscopic sleeve gastrectomy (LSG) in patients ≤18 years old. Fifteen of 37 studies were prospective, including one RCT. Mean body mass index (BMI) loss after LAGB was 11.6 kg/m² (95 % CI 9.8–13.4), versus 16.6 kg/m² (95 % CI 13.4–19.8) after RYGB and 14.1 kg/m² (95 % CI 10.8–17.5) after LSG. Two unrelated deaths were reported after 495 RYGB procedures. All three bariatric procedures result in substantial weight loss and improvement of comorbidity with an acceptable complication rate, indicating that surgical intervention is applicable in appropriately selected morbidly obese adolescents.

Keywords Adolescents · RYGB · LAGB · LSG · Bariatric surgery · Meta-analysis · Review · Weight loss · Quality of life

Introduction

Obesity is an emerging pandemic phenomenon [1]. Over the past three decades, the prevalence of adult obesity in the USA has doubled, while that of adolescent obesity has tripled [2]. Current estimates classify 33.6 % of adolescents living in the USA as overweight, 18.4 % as obese, and 13.0 % as being extremely obese, defined as body mass index (BMI) ≥85th, 95th, and 97th percentile, respectively [3]. Individual, social, environmental, and economic factors contribute to the development and persistence of morbid obesity.

Adolescent obesity is associated with preventable chronic health conditions like type two diabetes mellitus (T2DM), hypertension, obstructive sleep apnea syndrome (OSAS), dyslipidemia, nonalcoholic steatohepatitis, polycystic ovary syndrome, and various musculoskeletal diseases [4, 5]. Obese adolescents are likely to suffer from psychological morbidity, loss of self-esteem, and social exclusion which has the potential to scar them for life [6]. The risk of dying from any obesity-related cause increases by 6–7 % for every 2 years lived with obesity [7]. These findings urge us to find ways to treat obesity early in life.

Presently, adolescent obesity is mostly managed by combined lifestyle interventions focusing on behavioral and dietary modifications. These treatments are typically initiated and evaluated by a multidisciplinary team including a pediatrician, dietician, psychologist, and a physiotherapist. While often effective in short term, long-term effects are relatively disappointing. A recent Cochrane review shows a maximum of 1.7 kg/m² BMI loss after 12 months of lifestyle intervention [8].

In adults, bariatric surgery is extremely effective compared to conservative treatment, resulting in adequate long-term weight loss and reduction of mortality [9]. The last decades, various bariatric procedures have been performed in adolescents, including laparoscopic adjustable gastric banding...
LAGB), Roux-en-Y gastric bypass (RYGB), vertical banded gastroplasty, biliopancreatic diversion, and more recently laparoscopic sleeve gastrectomy (LSG). Potential adverse effects on growth and development in prepubertal patients who have not reached full maturity raise concerns. However, bariatric surgery relatively early in life intervenes before comorbidities become irreversible and reduces the risk of surgical complications.

Currently, the guidelines from the International Pediatric Endosurgery Group (IPEG) state that adolescents with a BMI >40 kg/m² or a BMI >35 kg/m² combined with severe comorbidities should be considered for surgical intervention, if they have (nearly) attained adult stature [10]. These guidelines are largely based upon a systematic review and meta-analysis by Treadwell et al. [11], reviewing studies up to December 2007. The last few years, indication criteria for bariatric surgery have expanded, and surgical techniques have improved. However, the outcome and best techniques to treat morbidly obese adolescents remain relatively unknown.

In this review, we evaluate and compare the efficacy, safety, and (psychosocial) health benefits of various bariatric surgical techniques as a treatment for morbid obesity in adolescents. Our data are obtained with help of supplemental data from several authors and strengthened by inclusion of the most recent high-quality studies.

Methods

Protocol and Registration

This review was conducted according to the PRISMA [12] and MOOSE [13] statements.

Eligibility Criteria

Prospective clinical trials and observational studies on LAGB, RYGB, and LSG were included with the following inclusion criteria: ≥10 patients, mean follow-up ≥12 months, age ≤18 years at time of operation (and less than 20 % >18 years), majority of procedures <25 years ago, and English full-text available. Meta-analysis of BMI loss was done when BMI loss was either reported or could be calculated.

Search

Pubmed, Embase, and Cochrane databases were searched on the 20 January 2014 with relevant search terms and Medical Subject Headings (MeSH) on LAGB, RYGB, and LSG in children and adolescents. Full electronic Pubmed search is presented in Fig. 1.

Study Selection

After electronically removing duplicates using EndNote X6.0.1 (Thomson Reuters), all remaining duplicate entries and aberrant records were manually removed. Two independent researchers (GP and LdV) screened the remaining abstracts and/or full-text version and collected the eligible citations. Clinical data and study properties were added to the citations by reviewing all full-text articles. Reviewing inclusion period, surgical center, authors, and population characteristics identified publications with data overlap; in which case, articles presenting the most complete and/or recent data were included.

Fig. 1 Search terms: full Pubmed search

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Pubmed search
(
  "[bantrian surgery"[MeSH Terms] OR "bantrian surgery"[All Fields]] OR
  "LAGB"[All Fields] OR
  "gastric bypass"[All Fields] OR
  \("stomach"[MeSH Terms] OR "stomach"[All Fields] OR "gastric"[All Fields] AND
  \("band"[All Fields] OR sleeve[All Fields]) OR
  "banded gastroplasty"[All Fields] OR
  \("sleeve"[All Fields] AND \("gastrectomy"[MeSH Terms] OR "gastrectomy"[All Fields]) OR
  \("anastomosis, roux-en-y"[MeSH Terms] OR \("anastomosis"[All Fields] AND \("roux-en-y"[All Fields]) OR
  \("roux-en-y anastomosis"[All Fields] OR \("roux en y"[All Fields])
)
AND
\("[bantrian surgery"[MeSH Terms] OR "[child"[All Fields] OR "adolescent"[All Fields] OR "pediatric"[All Fields]]
NOT
\("[lungectomy"[MeSH Terms] OR "Esophageal and Gastric Varices"[MeSH]
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Data Collection Process

Data relevant for our systematic review and meta-analysis were collected in a datasheet and completed with data from referenced articles or previous publications or by contacting the corresponding author.

Data Items

BMI before and after the procedure or BMI loss with reported variance, complications, and change in comorbidity was extracted from each article. When individual patient data were available, mean BMI and variance were calculated for those patients younger than 19 years. Mean BMI at follow-up was only used to calculate BMI loss if more than 50% of the baseline population had reached that moment.

Risk of Bias in Individual Studies

Study characteristics that influence risk of bias (e.g., prospective/retrospective) were assessed and collected in a table. Additionally, two independent reviewers carefully assessed details on the in- and exclusion process, preoperative lifestyle treatment, postoperative lifestyle support and loss to follow-up.

Summary Measures

Mean BMI loss was used for meta-analysis. Corresponding authors were contacted if variance of BMI loss was not reported. Complications and comorbidity resolution were summarized if follow-up was at least 6 months. Minor complications, reported in less than three studies, were omitted from the results.

Synthesis of Results

Summary effect measure of BMI loss and forest plots were produced with 95% CI for each surgical method using STATA (StataCorp. 2013. *Stata Statistical Software: Release 13.* College Station, TX, USA). Differences between operative techniques were tested in a random effect model. For missing variances, the square root of the average sample-size-weighted variance from all available variances was used. Data on complications or comorbidities were summarized when they were specifically mentioned. Results from large multicenter database studies were not summarized, while for short-term studies (~6-month follow-up), only perioperative results were summarized.

Risk of Bias Across Studies

A funnel plot for standard error of BMI loss against BMI loss was used to assess publication bias for each technique. The straight lines indicate the region within which 95% of points should lie in the absence of both heterogeneity and publication bias (Fig. 4).

Additional Analyses

A meta-regression analysis was performed to assess if BMI loss was affected by follow-up duration after the first 12 months or by different surgical gastric banding techniques (perigastric vs. pars flaccida). Authors were contacted when technical details were not provided. Additionally, differences in baseline BMI of different surgical procedures were tested in a random effect model.

Results

Study Selection

The search in Pubmed, Embase, and Cochrane provided a total of 4575 citations. After removing duplicates and screening abstracts, 4468 records were excluded and 107 remained for full-text analysis. Seventy full-text articles did not meet the inclusion criteria. Therefore, a total of 37 articles were included, including one article reporting on both LAGB and LSG. Eleven of 18 LAGB studies, 6 of 13 RYGB studies, and 5 of 7 LSG studies were eligible for meta-analysis of BMI loss (Table 1, Fig. 2). No additional studies were identified through cross-referencing.

Risk of Bias Within Studies

The study design (randomized control trial (RCT), prospective, and retrospective) and study characteristics are presented in Table 1. Potential introducers of bias, other than design, are reported in Table 2. Of 18 LAGB studies, seven were prospective, including the only RCT in this review. Five of 13 RYGB studies were prospective and three of seven LSG studies.

Results of Individual Studies

In 15 of the 22 included datasets, SD of BMI loss was not reported or available. Nine of the contacted research groups were willing to supply data on BMI loss with SD at one or more follow-up moments to complete the dataset. Finally, 14 SDs were available and 8 were derived as stated in the methods.
| Authors                      | Operation period | Location                                      | N  | Follow-up (months) | Age (years; mean/range) | Operative technique details                                                                 | Design                   | Included for                  |
|-----------------------------|------------------|-----------------------------------------------|----|--------------------|-------------------------|-------------------------------------------------------------------------------------------|--------------------------|-------------------------------|
| **Studies on LAGB**         |                  |                                               |    |                    |                         |                                                                                           |                          |                               |
| Abu-Abied et al. [27]       | NR               | Tel-Aviv, Israel                               | 11 | 6–36               | 15.7                    | Perigastric                                                            | Retrospective            | M – CO – CM                   |
| Al-Qahtani [28]             | Jan, 2003–2005   | Riyadh, Saudi Arabia                          | 51 | 3–34               | 16.8                    | Pars flaccida                                                        | Retrospective            | CM                            |
| Alqahtani [29]              | 6/2004–2007      | Riyadh, Saudi Arabia                          | 50 | NR–60              | 17                      | Pars flaccida                                                        | Retrospective            | CO                            |
| Angrissani et al. [30]      | 1/1996–12/2003   | Naples, Italy                                 | 58 | 0–84               | 18.0                    | 55 perigastric; 3 pars flaccida                                      | Retrospective            | M – CO – CM                   |
| Dolan et al. [31]           | 1996–NR          | Brisbane, Australia—Royal Brisbane Hospital   | 17 | 12–46              | 16.7                    | Since 1999 pars flaccida                                            | Prospective              | M                             |
| Fickling et al. [32]        | 1998–2003        | Brisbane, Australia—Wesley Hospital           | 41 | 1–70               | 15.6                    | Since 1999 pars flaccida                                            | Retrospective            | CO – CM                       |
| Holterman et al. [14]       | 2005–6/2007      | Chicago, IL, USA                              | 20 | 15–42              | 16                      | Perigastric                                                          | Prospective              | M – CO – CM – QOL             |
| Inge et al. [33]            | 2002–2011        | Five centers, USA                             | 14 | 1                  | 17.1                    | Pars flaccida                                                        | Prospective              | CO                            |
| Lee et al. [34]             | 2002–2011        | New York, NY, USA—St. Luke’s-Roosevelt Hospital Center | 23 | 1–24              | 17.2                    | Pars flaccida                                                        | Retrospective            | CO – CM                       |
| Lennerz et al. [35]         | 1/2005–12/2010   | 23 centers, Germany                           | 10 | 0 to >30           | 16.7                    | NA                                                                     | Prospective              | M                             |
| Messiah et al. [36]         | 2004–10/2010     | 360 facilities, USA                          | 436| 0–12              | 18.5                    | NA                                                                     | Prospective database    | CM                            |
| Nadler et al. [37]          | 9/2001–1/2007    | New York, NY, USA—NY University School of Medicine | 73 | 12–24              | 15.8                    | Pars flaccida                                                        | Prospective              | M – CO – CM                   |
| O’Brien et al. [15]         | 2005–9/2008      | Melbourne, Australia                          | 25 | 24                 | 16.5                    | Pars flaccida                                                        | Retrospective            | M – CO – QOL                   |
| Silberhumer et al. [17]     | 1998–2004        | Salzburg/Vienna, Austria                     | 50 | 63–138             | 17.1                    | Pars flaccida                                                        | Retrospective multcenter | M – CO – CM – QOL             |
| Silva et al. [38]           | 7/2001–6/2010    | Oporto, Portugal                              | 14 | 12–36              | 16.3                    | Pars flaccida                                                        | Retrospective            | M – CO – CM                   |
| Varela et al. [39]          | 2002–2006        | 59 university centers, USA                   | 90 | 1                  | 12–18                   | NA                                                                     | Retrospective            | CO                            |
| Yitzhak et al. [18]         | 2000–2003        | Beer Sheva, Israel                            | 60 | 25–65              | 16                      | Two pars flaccida techniques                                         | Retrospective            | M – CO – CM – QOL             |
| Zitsman et al. [40]         | 8/2006–NR        | New York, NY, USA—Columbia University Medical Center |100| 12                 | 14–19                   | Pars flaccida                                                        | NR                       | M – CO – CM                   |
| **Studies on RYGB**         |                  |                                               |    |                    |                         |                                                                                           |                          |                               |
| De la Cruz-Munoz et al. [41]| 2001–2010        | Miami, FL, USA                                | 71 | 9–15               | 18.3                    | NR                                                                     | Retrospective            | M – CO                        |
| Inge et al. [42]            | 2001–2003        | Cincinnati, OH, USA                           | 10 | 1–24               | NR                      | Two open/Eight laparoscopic, hand-sewn gastrojejunostomy               | Retrospective            | CO – CM                       |
| Inge et al. [33]            | 2007–12/2011     | Five centers, USA                             | 161| 1                 | 17.1                    | NA                                                                     | Prospective              | CO                            |
| Lee et al. [34]             | 2002–2011        | New York, NY, USA—St. Luke’s-Roosevelt Hospital Center |32 | 1–24              | 18.6                    | Pouch 50 mL/40-cm biliopancreatic limb, 100-cm alimentary limb         | Retrospective            | CO – CM                       |
| Messiah et al. [36]         | 2004–10/2010     | 360 facilities, USA                          | 454| 12                | 18.5                    | NA                                                                     | Prospective database    | CM                            |
| Miyano et al. [43]          | 8/2002–5/2007    | Cincinnati, OH, USA                           | 77 | 3                 | 16.8                    | Biliopancreatic limb 75–150 cm/15–30 cm from Treitz/30–45 mL pouch    | Retrospective            | CO – CM                       |
| Nijhawan et al. [44]        | 2001–2007        | San Diego, CA, USA                            | 20 | 60–120             | 16.9                    | Pouch 15 mL/Roux limb 75 cm                                          | Retrospective            | M – CO – CM                   |
| Authors                  | Operation period       | Location                  | N  | Follow-up (months) | Age (years; mean/range) | Operative technique details                        | Design          | Included for               |
|-------------------------|------------------------|---------------------------|----|--------------------|-------------------------|----------------------------------------------------|-----------------|---------------------------|
| Olbers et al. [22]      | 2/2006–6/2009          | Gothenburg, Sweden        | 81 | 24                 | 16.5                    | Pouch <20 mL/Roux limb 80 cm                       | Prospective     | M – CO – CM – QOL         |
| Strauss et al. [45]     | 4/1985–5/1999          | New Brunswick, NJ, USA    | 10 | 8–156              | 16.2                    | Pouch 20±5 mL/Roux limb 50–150 cm or to distal jejenum | Retrospective   | M – CO – CM               |
| Sugerman et al. [19]    | 1981–1/2002            | Richmond, VA, USA         | 33 | 1–14               | 16                      | Standard, long-limb, and distal gastric bypass     | Retrospective   | M – CO – CM               |
| Varela et al. [39]      | 2002–2006              | 59 university centers, USA| 191| 1                  | 12–18                   | NA                                                 | Retrospective   | CO                        |
| Zeller et al. [20]      | 5/2004–1/2007          | Cincinnati, OH, USA       | 31 | 12                 | 16.4                    | Pouch 20 mL 5–10 cm from Treitz/Roux limb 100–150 cm [46] | Prospective     | QOL                       |
| Zeller et al. [21]      | 5/2004–9/2005          | Cincinnati, OH, USA       | 16/14 | 24               | 16.2                    | Pouch 20 mL 5–10 cm from Treitz/Roux limb 100–150 cm [46] | Prospective     | M – QOL                   |
| Aldaqal et al. [23]     | 11/2009–2/2012         | Jeddah, Saudi Arabia      | 32 | 12                 | 15.2                    | 50–80-mL lumen                                     | Prospective     | M – CO – CM – QOL         |
| Alqahtani et al. [47]   | 3/2006–2/2011          | Riyadh, Saudi Arabia      | 99 | 6–24               | 14                      | NR                                                | Retrospective   | M – CO – CM               |
| Boza et al. [48]        | 1/2006–10/2009         | Santiago, Chile           | 51 | 6–24               | 18                      | 60-F calibration catheter                          | Retrospective   | M – CO – CM               |
| Inge et al. [33]        | 2/2007–12/2011         | Five centers, USA         | 67 | 1                  | 17.1                    | NA                                                | Prospective     | CO                        |
| Lennerz et al. [35]     | 1/2005–12/2010         | 23 centers, Germany       | 11 | 12                 | 15.4                    | NA                                                | Prospective     | M – CM                    |
| Nadler et al. [49]      | 1/2010–12/2011         | Washington, DC, USA       | 23 | 9–15               | 17.3                    | 40-F bougie                                       | Retrospective   | M – CO – CM               |
| Varela et al. [39]      | 2002–2006              | 59 university centers, USA| 28 | 1                  | 12–18                   | NA                                                | Retrospective   | CO                        |

Studies included for meta-analysis and systematic review, marked gray if only eligible for semiquantitative analysis

NR not reported, NA not applicable, M meta-analysis, CO complications, CM comorbidity, QOL quality of life assessment
Synthesis of Results

Per procedure, a short summary is provided of weight loss, complications, comorbidity reduction, and quality of life assessment (QOL). An overview is provided in Tables 3, 4, and 5 and in Fig. 3.

Laparoscopic Adjustable Gastric Band

Weight Loss  Summary BMI measure at baseline was 45.8 kg/m² (44.0–47.7). The summary effect measure of BMI loss in nine studies was 11.6 kg/m² (9.8–13.4) (Fig. 3). After the first 12 months, there was no association between length of follow-up and excess BMI loss ($\beta=0.06$, $p=0.51$). Clustering datasets by banding technique showed no differences in BMI loss (pars flaccida vs. perigastric, 11.0 vs. 10.1 kg/m², $p=0.61$).

Complications  Thirteen studies report unique data on complications after gastric banding in a total of 538 patients (Table 4). No deaths occurred in any of the studies. Perioperative complications including intra-abdominal bleeding and conversion to laparotomy were reported in 0.8 % and surgical site infection in 1.4 %. Late complications including bowel obstruction and abdominal wall hernia were reported in 1.1 % of cases. During the total follow-up period (0 to 138 months), 10.5 % of subjects experienced band-related complications (55/524) and 9.9 % (17/172) gastrointestinal complaints (nausea, vomiting, GERD, diarrhea, and gallstones). There were 77 reinterventions (14.7 %), including 3 cholecystectomies. The majority were band-related procedures like replacement or repositioning ($n=28$), removal ($n=12$), and port-revision ($n=16$). Vitamin deficiencies were reported in 5 of 18 studies; oral supplements for iron, vitamin D, folic acid, and zinc deficiencies were prescribed in 0.5 to 36 % of patients, but criteria for deficiencies were poorly defined. Only 2 of 18 studies report standard postoperative vitamin supplementation, while 13 do not mention a standard policy.

Resolution of Comorbidities  Out of the 18 LAGB studies included in this review, 11 report data on comorbidity resolution (Table 5). The definitions and cutoff values for comorbidities were specified in 5 of 11 studies and varied between studies. Resolution rates for hypertension, reported in nine studies, range from 22.9 to 100 %; six studies showed complete resolution in all patients. Nine studies report prevalence of dyslipidemia in 8 to 86 %, with eight reporting resolution in 0 to 100 % (median 50 %) of all cases. Six out of seven studies that report on diabetes prevalence in 0 to 33 %, all showed 100 % resolution after surgery. Resolution of prediabetes (three studies, prevalence 24–93 %) ranged from 72 to 100 %.

Quality of Life  Holterman et al. [14] showed that 75 % of the children had abnormal scores on the Pediatric Quality of Life Inventory (Peds-QL) at baseline, which improved at 12 and 18 months after surgery. The RCT by O’Brien et al. [15] showed improvements in reported physical functioning, general health, self-esteem, family activities, and change in health with the Child Health Questionnaire (CHQ CF-50) after gastric banding, while the lifestyle group improved only in general health perception. Silberhumer et al. [16, 17] found significant improvement after 35 months by using the BAROS and Moorehead-Ardelt Quality of Life questionnaires (both
| Study                          | Inclusion and exclusion criteria                                                                 | Intervention before surgery                                                                 | Support after surgery                                                   | Loss to follow-up                                      |
|-------------------------------|---------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|--------------------------------------------------------|
| **Gastric banding**           |                                                                                                   |                                                                                             |                                                                         |                                                        |
| Abu-Abeid et al. [27]         | NIH criteria                                                                                      | ≥1-year dietician                                                                          | Emotional support                                                        | NR                                                     |
| Al-Qahtani [28]               | NIH criteria                                                                                      | Failure to lose weight for ≥6 months with conservative treatment                            | Flexible follow-up, reinforcement of the importance of diet and exercise | NR                                                     |
| Alqahtani [29]                | NIH criteria                                                                                      | Failure to lose weight for ≥6 months with conservative treatment                            | Flexible follow-up, reinforcement of the importance of diet and exercise | NR                                                     |
| Angrisani et al. [30]         | BMI ≥40 or ≥35 kg/m² with comorbidities, psychiatric and genetic disorders excluded                 | ≥1 year of conservative medical treatment                                                   | NR                                                                      | 8–12–24 % (12–36–60 months)                           |
| De la Cruz-Munoz et al. [41]  | NIH criteria                                                                                      |                                                                                             |                                                                         |                                                        |
| Dolan et al. [31]             | NR (2/17 patients BMI < 35)                                                                      |                                                                                             |                                                                         |                                                        |
| Fielding et al. [32]          | BMI ≥40 or ≥35 kg/m² with comorbidities                                                           | “Appropriate pediatric care”                                                                 | Surgeon alone                                                           |                                                        |
| Holtermann et al. [14]        | NIH criteria                                                                                      | 4–6-month multidisciplinary program                                                          | Behavioral, nutritional, and activity monitoring and monthly counseling  | 20 %                                                   |
| Inge et al. [33]              | Pratt [50], BMI ≥35 with major comorbidities and BMI ≥40 with other comorbidities, no binge-purge eating disorders |                                                                                             |                                                                         |                                                        |
| Lee et al. [34]               | NIH criteria, procedure choice on individual basis                                                | Exercise and diet with nutritionist, educational sessions, and psychological and nutritional evaluations | NR                                                                      | 70 % (24 months)                                       |
| Lennerz et al. [35]           | CAADIP 2010 and IFSO guidelines, procedure choice on individual basis                              |                                                                                             |                                                                         |                                                        |
| Messiah et al. [36]           | NA (national database)                                                                            |                                                                                             |                                                                         |                                                        |
| Nadler et al. [37]            | NIH criteria                                                                                      |                                                                                             |                                                                         |                                                        |
| O’Brien et al. [15]           | BMI ≥35 kg/m², identifiable medical complications, physical limitations, or psychosocial difficulties | >3 years of attempts to lose weight by lifestyle means                                       | Participants were encouraged to do exercise and maintain a high level of activity | 4 %                                                    |
| Silberhumer et al. [17]       | >99.5th age- and gender-adjusted growing percentile, adolescents < 14 years old at least one comorbidity | Diet camps, behavioral therapy, and drug therapy                                             |                                                                         |                                                        |
| Silva et al. [38]             | IPEG guidelines                                                                                    |                                                                                             |                                                                         |                                                        |
| Varela et al. [39]            | NA (national database)                                                                            |                                                                                             |                                                                         |                                                        |
| Yitzhak et al. [18]           | NIH criteria                                                                                      | Failed conservative treatment                                                              |                                                                         |                                                        |
| Zitsman et al. [40]           | Pratt [50], BMI ≥35 with major comorbidities and BMI ≥40 with other comorbidities, no binge-purge eating disorders |                                                                                             |                                                                         |                                                        |
| **Gastric bypass**            |                                                                                                   |                                                                                             |                                                                         |                                                        |
| Study                        | Inclusion and exclusion criteria                                                                 | Intervention before surgery                                      | Support after surgery                                                                 | Loss to follow-up                  |
|-----------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------------------------|-----------------------------------|
| De la Cruz-Munoz et al. [41]| NIH criteria                                                                                   | NR                                                               | NR                                                                                   | 9 % for LAGB+RYGB                  |
| Inge et al. [42]            | BMI ≥40 kg/m² with serious obesity-related comorbidities or BMI ≥50 kg/m² with other comorbidities | ≥6 months of organized attempts at weight management             | Regular visits with the surgeon, psychologist, and dietician                         | NR                                |
| Inge et al. [33]            | Pratt [50], BMI ≥55 with major comorbidities and BMI ≥40 with other comorbidities; no binge-purge eating disorders | NR                                                               | NR                                                                                   | NR                                |
| Lee et al. [34]             | NIH criteria, procedure choice on individual basis                                             | Exercise and diet with nutritionist, educational sessions, and psychological and nutritional evaluations | NR                                                                                   | 84 % (24 months)                  |
| Messiah et al. [36]         | NA (national database)                                                                         | NA                                                               | NA                                                                                   | 12–34–63 % (3–6–12 months)        |
| Miyano et al. [51]          | 2002–2006, BMI ≥40 kg/m² with serious obesity-related comorbidities or BMI ≥50 kg/m² with other comorbidities 2006–2007, BMI ≥35 kg/m² with serious obesity-related comorbidities or BMI ≥40 kg/m² with other comorbidities | ≥6 months of organized attempts at weight management             | Regular visits with the surgeon, psychologist, and dietician                         | NR                                |
| Nijhawan et al. [44]        | NR                                                                                             | NR                                                               | Follow-up visits, encourage support groups                                           | 20 %                              |
| Obers et al. [22]           | BMI >40 or BMI >35 kg/m² with comorbidity, pubertal Tanner stage >III and passed peak height growth velocity, no untreated psychiatric disorder | Multidisciplinary lifestyle intervention                         | Follow-up visits, no support program                                                  | 0 %                               |
| Strauss et al. [45]         | NR                                                                                             | Serious attempts at weight loss in diet and behavior modification programs | NR                                                                                   | 10 %                              |
| Sugerman et al. [19]        | NIH criteria                                                                                   | NR                                                               | NR                                                                                   | 3.1–6.7–22.2–33.3 % (1–5–10–14 years)                                      |
| Varela et al. [39]          | NA (national database)                                                                         | NA                                                               | NA                                                                                   | NA                                |
| Zeller et al. [20]          | Inge: BMI ≥40 with comorbidity or ≥50 [52]                                                    | Inge: ≥6 months of organized attempts at weight management       | NR                                                                                   | 10 % (12 months)                  |
| Zeller et al. [21]          | Inge: BMI ≥40 with comorbidity or ≥50 [52]                                                    | Inge: ≥6 months of organized attempts at weight management       | NR                                                                                   | 12 %                              |
| Sleeve gastrectomy          | Aldaqal et al. [23]                                                                            | ≥6 months of recognized, medically supervised weight loss attempts | NR                                                                                   | NR                                |
|                            | BMI ≥40 kg/m² with serious obesity-related comorbidities or BMI ≥50 kg/m² with other comorbidities |                                                                  |                                                                                      |                                   |
|                            | Alqahtani et al. [47]                                                                          | 6 months in a formal weight loss program                         | Follow-up visits                                                                     | 17–14 % (12–24 months)            |
|                            | BMI ≥40 or ≥35 kg/m² with comorbidities (five patients with BMI <35)                           |                                                                  |                                                                                      |                                   |
|                            | Boza et al. [48]                                                                               |                                                                  |                                                                                      |                                   |
|                            | NIH criteria, evaluation by multidisciplinary team                                             |                                                                  |                                                                                      |                                   |
|                            | Inge et al. [33]                                                                               |                                                                  |                                                                                      |                                   |
|                            | Pratt [50], BMI ≥55 with major comorbidities and BMI ≥40 with other comorbidities, no binge-purge eating disorders |                                                                  |                                                                                      |                                   |
|                            | Lee et al. [34]                                                                                |                                                                  |                                                                                      | 70 % (24 months)                  |
tests are not specifically validated in children) but no further changes between 3 and 5 years after surgery. Yitzhak et al. [18] report 93% improvement in physical activity and 72% improvement in social- and self-esteem with non-validated questionnaires.

**Pars Flaccida Versus Perigastric Technique**

The LAGB-related problems including slippage, pouch dilatation, and migration—after a follow-up period of 0–7 years—do not appear to occur more in patients who were operated before the surgeons updated their techniques to the currently used pars flaccida technique (11.2% (10/89) vs. 10.3% (45/435)).

**Roux-en-Y Gastric Bypass**

**Weight Loss** The studies reporting on laparoscopic Roux-en-Y gastric bypass have a summary BMI loss of 16.6 kg/m² (13.4–19.8) after 12 to 86 months (Table 3, Fig. 2). A follow-up period exceeding 12 months was not correlated to BMI loss ($\beta=0.04$, $p=0.51$). BMI loss after RYGB was significantly higher than that after LAGB ($p=0.008$). Mean preoperative BMI was 49.6 kg/m² (46.4–52.7) and did not differ from LAGB ($p=0.11$).

**Complications**Nine studies present summarizable complication rates in a total of 495 patients. Two sudden deaths were reported in one study, 2 and 6 years after surgery, respectively, which were probably unrelated to the procedure. However, no autopsies were performed to determine the cause of death [19]. Perioperative complications including anastomotic leakage, bleeding, and conversion occurred in 5.1% and infection of the surgical site in 6.2% of patients. Late complications including obstruction, internal herniation, ulcers, and abdominal wall hernia occurred in 20.2% of patients.

Gastrointestinal complaints like nausea, vomiting, dumping, and GERD were reported in 9.3%; nine patients in five studies (5.6%) suffered from nutritional deficiencies or dehydration requiring hospitalization. Less severe vitamin deficiencies were reported in 6 of 13 studies; oral supplements for iron, vitamin A, vitamin B1, vitamin B12, vitamin D, folic acid, and zinc deficiencies were used in an estimated 4–56% of patients, but criteria for deficiencies and exact numbers were poorly described. In 5 of 13 studies, postoperative vitamin supplementation was standard policy, while in seven no details are provided. The highest percentage of deficiencies occurred in the study in which no supplements were supplied.

Fifty-seven reinterventions (17.1%) were performed including cholecystectomy in seven, endoscopic procedures (mainly balloon dilatation for stricture of the anastomosis) in 18, surgery for gastrointestinal obstruction in 13, and for leak or fistula repair in six.
Resolution of Comorbidities  Eight of the 13 studies on RYGB report data on comorbidity resolution and/or improvement (Table 5). The definitions and cutoff values for comorbidities were specified in five of eight studies and varied between studies. The studies reporting on hypertension (n=4) show 61 to 100 % improvement or resolution. Six to 62 % of the subjects had dyslipidemia, resolving in 56 to 100 %. Diabetes resolved in 79 to 100 %, with resolution in all subjects in five out of six studies.

Quality of Life  Quality of life, reported in two studies, showed significant improvement in seven of the eight health domains on the Short Form-36 Health Survey (SF-36) at 1-year follow-up and significantly increased quality of life scores after 6 months, but not after 12 (assessed with the Peds-QL and IWQOL-Kids). Depression scores were significantly less, 6 and 12 months after surgery, than before surgery [20–22].

Laparoscopic Sleeve Gastrectomy  

Weight Loss  Five studies present the results of the relatively new LSG technique with a follow-up between 6 and 24 months. BMI before surgery was 48.1 kg/m² (41.8–54.5), which does not differ from LAGB or RYGB patients (p=0.42 and p=0.50, respectively). BMI loss in these studies is 14.1 kg/m² (10.8–17.5) and does not differ from LAGB and RYGB (p=0.17 and p=0.24, respectively).

Complications  Five studies including 272 patients reported two perioperative complications (0.7 %) and no mortality.

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| Authors          | N     | FU         | Death | Perioperative complications | Surgical site infection | Late complications | Hiatal hernia | Band-specific complaints | Gastrointestinal complaints | Nutritional deficiency / dehydration | DVT | Pulmonary system (pneumonia, pulmonary embolism) |
|------------------|-------|------------|-------|-----------------------------|-------------------------|-------------------|---------------|-------------------------|---------------------------------|----------------------------------|-----|-----------------------------------------------|
| **LAGB**         |       |            |       |                             |                         |                   |               |                         |                                 |                                  |     |                                               |
| Perigastric      |       |            |       |                             |                         |                   |               |                         |                                 |                                  |     |                                               |
| Abu-Abid et al. | 11    | 6-36 months| *     | 0                            | *                       | 0                 | *             | 0                       | 0                               | *                                | *  | *                                             |
| Angrisani et al. | 58    | 0-7 years  | 0     | 1                            | *                       | *                 | 6             | *                       | *                                | *                                | *  | *                                             |
| Holterman et al. | 20    | 15-42 months| *     | *                            | *                       | 1                 | 4             | *                       | *                                | *                                | *  | *                                             |
| Pars flaccida    |       |            |       |                             |                         |                   |               |                         |                                 |                                  |     |                                               |
| Alqahtani        | 50    | NR-5 years | *     | 0                            | *                       | 2                 | 9             | 1                       | *                                | *                                | *  | *                                             |
| Fielding et al.  | 41    | 1-70 months| 0     | 0                            | *                       | 2                 | *             | *                       | *                                | *                                | *  | *                                             |
| Lee et al.       | 23    | 1-24 months| *     | *                            | *                       | 2                 | *             | *                       | *                                | *                                | *  | *                                             |
| Nadler et al.    | 73    | 12-24 months| 0    | *                            | 1                       | 3                 | 7             | 5                       | *                                | *                                | *  | *                                             |
| O'Brien et al.   | 24    | 24 months  | *     | 0                            | *                       | 8                 | 1             | *                       | *                                | *                                | *  | *                                             |
| Silberhumer et al.| 50    | 63-138 months| *   | *                            | *                       | 6                 | *             | *                       | *                                | *                                | *  | *                                             |
| Silva et al.     | 14    | 12-36 months| 0     | 0                            | *                       | 2                 | 2             | *                       | *                                | *                                | *  | *                                             |
| Yitzhak et al.   | 60    | 25-65 months| 0     | 0                            | *                       | 10                | *             | *                       | *                                | *                                | *  | *                                             |
| Zitsman et al.   | 100   | 12 months  | 0     | 1                            | *                       | 1                 | 6             | *                       | *                                | *                                | *  | *                                             |
| Inge et al.      | 14    | 30 days    | 0†    | 1                            | 0†                      | 0†                | *†           | *†                     | 1†                               | *†                               | 0† | 1†                                           |
| **TOTAL**        | 538   |            |       | 0.0% (0/346)                 | 0.8% (3/372)            | 1.4% (1/73)       | 1.1% (2/184)  | 2.6% (5/193)            | 10.5% (55/524)                  | 9.9% (17/172)                    | 2% (1/50) |                                               |
| Short-term perioperative outcome |       |            |       |                             |                         |                   |               |                         |                                 |                                  |     |                                               |
| Varela et al.    | 90    | 30 days    | 0     | *                            | *                       | *                 | *             | *                       | *                                | *                                | *  | *                                             |
| **RYGB**         |       |            |       |                             |                         |                   |               |                         |                                 |                                  |     |                                               |
| De la Cruz-Munoz et al. | 71 | 9-1 months  | *     | 0                            | *                       | 2                 | *             | *                       | *                                | *                                | *  | *                                             |
| Inge et al.      | 10    | 1 month-2 years| *   | 1                            | *                       | 1                 | 1             | 1                       | 1                                | 1                                | *  | *                                             |
| Lee et al.       | 32    | 1-24 months| *     | *                            | *                       | *                 | *             | *                       | *                                | *                                | *  | *                                             |
| Miyano et al.    | 77    | 90 days    | 0     | 2                            | 2                       | 24                | *             | *                       | *                                | 5                                | 1  | 0                                             |
| Nijhawan et al.  | 20    | 60-120 months| 0    | 0                            | 1                       | 3                 | *             | *                       | *                                | *                                | *  | *                                             |
| Obeys et al.     | 81    | 24 months  | 0     | 2                            | *                       | 6                 | *             | *                       | *                                | *                                | 1  | *                                             |
| Strauss et al.   | 10    | 8-156 months| *    | 0                            | 2                       | *                 | 2             | 1                       | *                                | *                                | *  | *                                             |
| Sugerman et al.  | 33    | 1-14 years | 2     | *                            | 5                       | 14                | *             | *                       | *                                | *                                | 1  | 1                                             |
| Inge et al.      | 161   | 30 days    | 0†    | 17                           | *†                      | 9†                | *†            | *†                     | 1†                               | *†                               | 1† | 2†                                           |
| **TOTAL**        | 495   |            |       | 0.9% (2/211)                 | 5.1% (22/430)           | 6.2% (8/130)      | 20.2% (53/263)| *                    | *                                | 9.3% (16/172)                   | 5.6% (9/162) | 2.3% (2/87)                     | 1.5% (2/130) |
| Short-term perioperative outcome |       |            |       |                             |                         |                   |               |                         |                                 |                                  |     |                                               |
| Varela et al.    | 191   | 30 days    | 0     | *                            | *                       | *                 | *             | *                       | *                                | *                                | *  | *                                             |
| **LSG**          |       |            |       |                             |                         |                   |               |                         |                                 |                                  |     |                                               |
| Alqaqal et al.   | 32    | 12 months  | *     | 0                            | *                       | *                 | *             | *                       | *                                | *                                | *  | *                                             |
| Alqahtani et al. | 99    | 6-24 months| 0     | 0                            | 2                       | 1                 | *             | *                       | 3                                | *                                | *  | *                                             |
| Boza et al.      | 51    | 6-24 months| 0     | 0                            | *                       | 1                 | *             | *                       | *                                | *                                | *  | *                                             |
| Nadler et al.    | 23    | 9-15 months| *     | 0                            | *                       | 0                 | *             | *                       | 3                                | *                                | *  | *                                             |
| Inge et al.      | 67    | 30 days    | 0†    | 2                            | 2†                      | 3†                | *†           | *†                     | 2†                               | 1†                               | 0† | 1†                                           |
Table 4 (continued)

| Authors          | N   | FU | Complication                      | Death | Perioperative complications | Surgical site infection | Late complications | Hiatal hernia | Band-specific complications | Gastrointestinal complaints | Nutritional deficiency / dehydration | DVT | Pulmonary system (pneumonia, pulmonary embolism) |
|------------------|-----|----|-----------------------------------|-------|-----------------------------|-------------------------|-------------------|--------------|----------------------------|-----------------------------|--------------------------------------|-----|-----------------------------------------|
|                  |     |    |                                   | 272   | 0 % (0/150)                 | 0.7 % (2/272)           | 2.0 % (2/99)      | *            | *                          | *                           | *                                    | *   | *                                        |
| Short-term perioperative outcome |     |    |                                   |       |                             |                         |                   |              |                            |                             |                                      |     |                                          |
| Varela et al.    | 28  | 30 days | 0                                   | *     | *                           | *                       | *                 | *            | *                          | *                           | *                                    | *   |                                          |

| Authors          | Total | Intervention | Conversion to malabsorptive anatomy | Band, removal | Band replacement/repositioning | Band, port revision | Gastrointestinal obstruction | Leak/fistula repair | Cholecystectomy | Abdominal hernia repair | EGD |
|------------------|-------|--------------|------------------------------------|---------------|--------------------------------|---------------------|--------------------------|---------------------|-----------------|--------------------------|-----|
|                  |       |              |                                     |               |                                |                      |                          |                     |                 |                          |     |
| LAGB             |       |              |                                     |               |                                |                      |                          |                     |                 |                          |     |
| Perigastric      |       |              |                                     |               |                                |                      |                          |                     |                 |                          |     |
| Abu-Abeid et al. | 0    | *            | *                                   | *             | *                             | *                    | *                        | *                   | *               | 0                        |     |
| Angrisani et al. | 7    | 3            | 5                                   | 3             | *                             | *                    | *                        | *                   | *               | 11                       |     |
| Holzman et al.   | 5    | *            | *                                   | 1             | *                             | *                    | *                        | *                   | *               | 2                        |     |
| Pars flaccida    |       |              |                                     |               |                                |                      |                          |                     |                 |                          |     |
| Alqahtani        | 12   | *            | 2                                   | *             | *                             | *                    | *                        | *                   | 0               | 2                        |     |
| Fielding et al.  | 2    | *            | *                                   | 1             | 1                             | *                    | *                        | *                   | *               | 2                        |     |
| Lee et al.       | 2    | *            | 1                                   | 1             | *                             | *                    | *                        | *                   | *               | 2                        |     |
| Nadler et al.    | 17   | *            | 2                                   | 5             | 1                             | *                    | 1                        | *                   | 3               | 12                       |     |
| O’Brien et al.   | 9    | *            | *                                   | 6             | 2                             | *                    | 1                        | *                   | *               | 9                        |     |
| Silberhumer et al.| 6    | 8            | *                                   | 2             | 2                             | *                    | *                        | *                   | *               | 12                       |     |
| Silva et al.     | 4    | *            | *                                   | *             | *                             | *                    | *                        | *                   | *               | 3                        |     |
| Yitzhak et al.   | 10   | *            | 2                                   | 6             | 2                             | *                    | *                        | *                   | *               | *                        | 10  |
| Zisman et al.    | 9    | *            | *                                   | 3             | 3                             | 2                    | *                        | *                   | 1               | 2                        |     |
| Inge et al.      | 3†   | *            | *                                   | *             | 0                             | *                    | *                        | 0                   | 0†              | 0†                       |     |
| TOTAL            | 83   | 11           | 12                                  | 28            | 16                            | 2                    | 0                        | 3                   | 5               | 0                        | 14.7 % (77/524) |
| Short-term perioperative outcome |       |              |                                     |               |                                |                      |                          |                     |                 |                          |     |
| Varela et al.    | 0    | *            | *                                   | *             | *                             | *                    | *                        | *                   | *               | 0                        |     |
| RYGB             |       |              |                                     |               |                                |                      |                          |                     |                 |                          |     |
| De la Cruz-Manor et al. | 2 | * | * | * | * | * | * | * | * | * | 0 |
| Inge et al.      | 7    | *            | *                                   | *             | *                             | 1                    | *                        | *                   | 1               | 2                        |     |
| Lee et al.       | 2    | *            | *                                   | *             | 1                             | *                    | *                        | *                   | *               | 1                        |     |
| Miyano et al.    | 34   | *            | *                                   | *             | 4                             | 4                    | *                        | 2                   | 13              | 23                       |     |
Table 4 (continued)

| Authors          | Total | Conversion to malabsorptive anatomy | Band, removal | Band replacement/repositioning | Band, port revision | Gastrointestinal obstruction | Leak/fistula repair | Cholecystectomy | Abdominal hernia repair | EGD |
|------------------|-------|-------------------------------------|---------------|--------------------------------|---------------------|-----------------------------|---------------------|------------------|------------------------|------|
| Nijhawan et al.  | 5     | *                                   | *             | *                              | *                   | 2                           | 0                   | *                | *                       | 1    |
| Olbers et al.    | 19    | *                                   | *             | *                              | *                   | 5                           | 0                   | 5                | *                       | *    |
| Strauss et al.   | 5     | *                                   | *             | *                              | *                   | 1                           | *                   | 2                | *                       | 1    |
| Sugerman et al.  | 22    | 2                                   | *             | *                              | *                   | 1                           | *                   | *                | 6                       | 3    |
| Inge et al.      | 17†   | *                                   | *             | *                              | *                   | 3                           | 4                   | *                | 3                       | 10†  |
| TOTAL            | 96    | 2                                   | 0             | 0                              | 0                   | 13                          | 6                   | 7                | 11                      | 18   |

Short-term perioperative outcome

| Varela et al.    | 4.3–7.6 % | * | * | * | * | * | * | * | 0 |

LSG

| Aldaqal et al.   | 0     | * | * | * | * | * | * | * | 0 |
| Akhahtani et al.| 6     | * | * | * | * | * | * | * | 0 |
| Boza et al.      | 1     | * | * | * | * | * | * | * | 1 |
| Nadler et al.    | 3     | * | * | * | * | * | * | * | 0 |
| Inge et al.      | 11†   | * | * | * | * | * | 0 | 2 | 0 |
| TOTAL            | 10    | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

Short-term perioperative outcome

| Varela et al.    | 0     | * | * | * | * | * | * | * | 0 |

Complications: death (all cause), perioperative (conversion, bleeding, or organ laceration), surgical site infection, late complications (obstruction, abscess, internal hernia, leak, or incisional hernia), hiatal hernia, band-specific (port revision, slippage, dilated pouch, and band migration), gastrointestinal complaints (nausea, vomiting, intestinal blood loss, diarrhea, GERD, gallstones, and dumping), nutritional deficiency/dehydration, DVT, and pneumonia/pulmonary embolus

** indicates not reported, * denotes not summarized due to short follow-up
Table 5  Comorbidity prevalence and reduction

| Author          | Baseline N (%) | HT       | Dyslipidemia | T2DM   | Prediabetes/Insulin resistance | OSAS | Musculoskeletal complaints | Asthma | Menstrual problems | GERD |
|-----------------|----------------|----------|--------------|--------|-------------------------------|------|---------------------------|--------|--------------------|------|
| Abu-Abeid et al. [27] | Baseline N (%) | NR       | 2/11 (18.2 %)†, 1/11 (9.1 %)‡ | NR     | NR                            | NR   | NR                        | NR     | NR                 | NR   |
|                 | Resolved N (%) | NR       | 2/2 (100 %)‡ | NR     | NR                            | NR   | NR                        | NR     | NR                 | NR   |
| Al-Qahtani et al. [28] | Baseline N (%) | 6/51 (11.8 %) | NR       | 7/51 (13.7 %) | NR                            | 10/51 (19.6 %) | 7/51 (13.7 %)† | NR     | NR                 | NR   |
|                 | Resolved, N (%) | 6/6 (100 %) | NR       | 7/7 (100 %)  | NR                            | 10/10 (100 %) | 7/7 (100 %)† | NR     | NR                 | NR   |
| Angrisani [30]   | Baseline N (%) | 8/58 (13.4 %) | 6/58 (10.3 %) | 8/58 (13.4 %) | NR                            | 10/58 (17.2 %) | 12/58 (20.7 %)† | NR     | 4/58 (69 %)† | NR   |
|                 | Resolved N (%) | NR       | NR          | NR     | NR                            | NR   | NR                        | NR     | NR                 | NR   |
| Fielding et al. [32] | Baseline N (%) | 2/41 (4.9 %) | NR       | 2/41 (4.9 %)  | NR                            | 1/41 (2.4 %) | 1/41 (2.4 %)‡ | NR     | NR                 | NR   |
|                 | Resolved N (%) | 2/2 (100 %) | NR       | 2/2 (100 %)  | NR                            | 1/1 (100 %) | 1/1 (100 %)‡ | NR     | NR                 | NR   |
| Holterman et al. [14] | Baseline N (%) | 9/20 (45 %) | 16/20 (80 %) | NR     | 18/20 (90 %)† | NR                            | NR     | NR                 | NR   |
|                 | Resolved N (%) | 9/9 (100 %) | 11/16 (67 %) | NR     | 13/18 (72 %)† | NR                            | NR     | NR                 | NR   |
| Lee et al. [34]  | Baseline N (%) | 2/23 (9 %) | 2/23 (9 %)‡ | 0/23 (0 %) | NR                            | 3/23 (13 %) | NR                       | NR     | NR                 | NR   |
|                 | Resolved N (%) | NR       | 1/2 (50 %)  | 0/0     | NR                            | NR   | NR                       | NR     | NR                 | NR   |
| Messiah et al. [36] | Baseline N (%) | 80 (18 %) | 61 (14 %)  | 65 (15 %) | NR                            | 80 (18 %) | 113 (25 %)¥ | 90 (21 %) # | 84 (19 %) | 50 (11 %)‡ | 109 (25 %) |
|                 | Improved N (%) | 54 %     | 23 %        | 59 %    | NR                            | 46 % | 50 % ¥44 % # | 23 % | 38 % ¥51 % ¥ | 45 % |
| Nadler et al. [37] | Baseline N (%) | 4/21 (19 %) | 7/21 (33 %) | NR     | 5/21 (24 %)‡ | 4/21 (19 %) | 10/21 (48 %)¥ | 5/21 (24 %)† | NR     | 1/1 (5 %) |
|                 | Resolved N (%) | 4/4 (100 %) | 3/7 (43 %)  | NR     | 5/5 (100 %)‡ | 3/4 (75 %) | 7/10 (70 %)¥ | 3/5 (60 %)† | NR     | 1/1 (100 %) |
| Silberhumer et al. [17] | Baseline N (%) | 12/50 (24 %) | 4/50 (8 %)  | 5/50 (10 %) | NR                            | 8/50 (16 %)§ | 3/5 (6 %) | NR     | 1/50 (2 %) |
|                 | Resolved, N (%) | 11/12 (91.7 %) | 4/4 (100 %) | 5/5 (100 %) | NR                            | 7/8 (87.5 %)§ | 3/3 (100 %) | NR     | 1/1 (100 %) |
| Silva et al. [38] | Baseline N (%) | 13/14 (92 %) | 12/14 (85.7 %) | NR     | 13/14 (92.8 %)† | NR                            | NR     | NR                 | NR   |
|                 | Resolved, N (%) | 13/13 (100 %) | 8/12 (66.7 %) | NR     | 13/13 (100 %)† | NR                            | NR     | NR                 | NR   |
| Yitzhak et al. [18] | Baseline N (%) | 3/60 (5 %)  | NR          | 2/60 (33.3 %) | NR                            | 10/60 (16.7 %) | 3/60 (%) | NR     | NR                 | NR   |
|                 | Resolved, N (%) | 3/3 (100 %) | NR          | 2/2 (100 %) | NR                            | 10/10 (100 %) | 3/3 (100 %) | NR     | NR                 | NR   |
| Zitsman et al. [40] | Baseline N (%) | 35/85 (41.2 %) | 49/85 (57.6 %) | NR     | NR                            | NR    | 28/85 (32.9 %) | 26/85 (31 %)† | NR     | NR |
|                 | Resolved, N (%) | 8/35 (22.9 %) | 24/49 (49 %) | NR     | NR                            | NR    | 4/28 (14.3 %) | 21/26 (81 %)‡ | NR     | NR |
| Miyano et al. [51] | Baseline N (%) | 18 (29 %)  | 38 (62 %)   | 8 (13 %) | NR                            | 46 (69 %) | 11 (21 %) | 11 (24 %) ¥ | 15 (27 %) |
|                 | Resolved, N (%) | NR       | NR          | NR     | NR                            | NR    | NR                       | NR     | NR                 | NR   |
| Inge et al. [42]  | Baseline N (%) | NR       | NR          | 1/10 (10 %) | NR                            | 1/10 (10 %) | NR     | NR                 | NR   |
|                 | Resolved, N (%) | NR       | NR          | 1/1 (100 %) | NR                            | 1/1 (100 %) | NR     | NR                 | NR   |
| Lee et al. [34]  | Baseline N (%) | 6/32      | 2/32 (6 %)  | 3/32 (%) | NR                            | 5/32 | NR                       | NR     | NR                 | NR   |
|                 | Resolved, N (%) | NR       | 2/2 (100 %)‡ | 3/3 (100 %) | NR                            | NR    | NR                       | NR     | NR                 | NR   |
| Author          | Baseline N (%) | Dyslipidemia (%) | Prediabetes/Insulin resistance | OSAS (%) | Musculoskeletal complaints (%) | Asthma (%) | Menstrual problems (%) | GERD (%) |
|-----------------|----------------|-------------------|--------------------------------|----------|-------------------------------|------------|------------------------|----------|
| Messiah et al.  | 118 (26 %)     | 65 (14 %)         | 67 (15 %)                     | NR       | 117 (26 %)                    | 94 (21 %)  | 85 (18 %)              | 127 (28 %)|
| Improved (%)    | 61 %           | 59 %              | 79 %                          | NR       | 56 %                          | 50 %       | 44 %                   | 90 %     |
| Nijhawan et al. | 3/25 (12 %)    | 10/25 (40 %)      | 3/25 (12 %)                   | NR       | 4/25 (16 %)                   | 14/25 (56 %) | 6/25 (24 %)          | NR       |
| Resolved (%)    | 3/3 (100 %)    | 10/10 (100 %)     | 3/3 (100 %)                   | NR       | 4/4 (100 %)                   | 13/14 (92.9 %) | 6/6 (100 %)         | NR       |
| Olbers et al.   | 0/81 (0 %)     | 15/80 (19 %)      | 27/81 (33 %)                  | 0/81 (0 %)| NR                           | 17/78 (21 %) | 0/81 (0 %)           | 127 (28 %)|
| Resolved (%)    | N/A            | 14/15 (93.3 %)    | 1/1 (100 %)                   | N/A      | NR                           | 13/17 (76.5 %) | 3/3 (100 %)         | NR       |
| Strauss et al.  | 3/10 (30 %)    | NR                | NR                            | 2/10 (20 %)| 1/10 (10 %)       | NR         | NR                     | NR       |
| Resolved/improved (%) | 3/3 (100 %) | NR                | NR                            | 2/2 (100 %)| 1/1 (100 %)       | NR         | NR                     | NR       |
| Sugerman et al. | 11/33 (33 %)  | NR                | 2/33 (6 %)                    | 6/33 (18 %)| 11/33 (33 %)    | NR         | NR                     | 5/33 (15 %)|
| Resolved (%)    | 9/11 (82 %)    | NR                | 2/2 (100 %)                   | 6/6 (100 %)| 4/11 (36 %)     | NR         | NR                     | 3/5 (60 %)|
| Aldaql et al.   | 4/32 (13 %)    | NR                | 5/32 (16 %)                   | 1/32 (3 %) | NR                           | NR         | NR                     | NR       |
| Resolved (%)    | 3/4 (75 %)     | NR                | 4/5 (80 %)                    | 1/1 (100 %)| NR                          | NR         | NR                     | NR       |
| Alqahtani et al. | 39/108 (36.1 %)| 52/108 (48.1 %)  | 22/108 (20.4 %)               | 14/108 (13 %) | 36/108 (33.3 %) | NR         | NR                     | NR       |
| Resolved (%)    | 27/36 (75 %)   | 21/30 (70 %)      | 15/16 (93.8 %)                | 11/11 (100 %) | 20/22 (90.9 %) | NR         | NR                     | NR       |
| Boza et al.     | 4/51 (7.8 %)   | 12/51 (23.5 %)    | 2/51 (3.9 %)                  | 27/51 (52.9 %)| NR                       | 3/5 (5.9 %) | NR                     | NR       |
| Resolved (%)    | 44 (100 %)     | 7/12 (58 %)       | 1/2 (50 %)                    | 26/27 (96.2 %)| NR                       | N/A        | NR                     | NR       |
| Nadler et al.   | 1/7 (14.3 %)   | NR                | 3/7 (57 %)                    | 1/7 (14.3 %)| 1/7 (14.3 %)      | 1/7 (14.3 %) | 1/7 (14.3 %)        | 1/7 (14.3 %)|
| Resolved (%)    | 1/1 (100 %)    | NR                | 3/3 (100 %)                   | 4/4 (100 %) | 1/1 (100 %)       | 1/1 (100 %) | 1/1 (100 %)          | 1/1 (100 %)|

Dyslipidemia including “†” elevated triglycerides, “‡” elevated total cholesterol, or “§” elevated LDL

Prediabetes or insulin resistance defined as “†” HOMA insulin resistance, “§” impaired glucose tolerance, “¥” elevated fasting glucose, or “‡” elevated fasting insulin

Musculoskeletal problems defined as “†” osteoarthropathy, “‡” Perthes disease of the hip, “¥” back pain, “§” musculoskeletal disorder, “$” orthopedic comorbidities/pain, or “§” compression fracture of vertebrate

Menstrual problems including “†” menstrual irregularity, “‡” amenorrhea, or “¥” polycystic ovary syndrome

HT hypertension, T2DM type 2 diabetes mellitus, OSAS obstructive sleep apnea syndrome, GERD gastroesophageal reflux disease
The incidence of wound infection was 2.0%, and late complications occurred in 1.2%, gastrointestinal complaints in 4.9% (Table 4). Postoperative vitamin supplementation was described in one of seven studies; none of the studies report whether deficiencies occurred.

Resolution of Comorbidities In four out of five studies on LSG, comorbidities are reported (Table 5). The definitions and cutoff values for comorbidities were specified in two of four studies and varied between studies. Hypertension resolved in 75–100%. Dyslipidemia improved, with resolution rates of 58 to 70%, and diabetes, reported in three studies, resolved in 50 to 93.8%.

Fig. 3 Meta-analysis: forest plot for BMI loss with 95% confidence intervals and summarized means after LAGB, RYGB, and LSG

Fig. 4 Funnel plots: funnel plots of SEM of BMI loss versus BMI loss for the assessment of heterogeneity in outcome reporting. Dots outside the 95% pseudo confidence limits are indicative of heterogeneity.
Quality of Life  Aldaqal et al. [23] assessed self-esteem and quality of life at baseline and 1 year after LSG with the Rosenberg self-esteem scale (RSE) and the Peds-QL. Patients improved significantly on the RSE and all six scores of the Peds-QL (including the summary score) 1 year after the procedure.

Risk of Bias Across Studies

Figure 4 shows the funnel plots for standard error of BMI loss against BMI loss in each procedure. Eight of the studies reporting on LAGB outcome are within the expected range, while one study shows more and two show less than expected BMI loss. Four RYGB studies are in the expected range, while two are not (one more and one less), and three LSG studies are in the expected range, while two are not (one more and one less).

Discussion

Summary of Evidence

The 37 studies that were eligible for systematic reviewing represent the increasing interest in bariatric surgery in morbidly obese adolescents, although the studies were mainly observational and varied in quality. To ensure that the meta-analysis was based on valid data and solidly compares surgical methods, we reported only peer-reviewed published studies and obtained additional data from the authors of nine studies.

All three procedures lead to significant weight loss in morbidly obese adolescents, and similar to a large Swedish study in adults, weight loss is most pronounced after RYGB [9]. This seems to persist after both RYGB and LAGB. For LSG studies, long-term follow-up is not yet available. While adverse events are relatively mild and long-term complication rates are acceptable, they are more frequent and more serious after RYGB than after LAGB. In the currently available follow-up after LSG, the rate of adverse events appears to be similar to that after LAGB. Although a healthy nutritional status in adolescents is important to prevent developmental and growth deficiencies, standard postoperative vitamin supplementation regimens and the occurrence of deficiencies are not reported in most studies (not at all in LSG studies). However, more and more severe deficiencies occur after RYGB than after LAGB.

Reduction of comorbidity, which is pivotal for health gain, is impressive in all techniques, and QOL consistently showed improvement, although follow-up up to 24 months may not be enough to capture negative long-term effects in life after bariatric surgery. The difference in adults between adverse events of the old perigastric LAGB technique and the more recently adapted pars flaccida technique [24] is not reproduced reviewing young patients.

Limitations

Funnel plots show heterogeneity of the data but no indication of publication bias due to underreporting of poor outcomes. A limitation of the currently available literature is the lack of high-quality, prospective randomized controlled trials, which increases the risk of bias and therefore introduces heterogeneity. Assessment of the three fundamental domains in risk of bias in observational studies (appropriate selection of participants, appropriate measurement of variables, and appropriate control of confounding) shows that studies are heterogeneous in patient selection, in preoperative and postoperative treatment protocol and that loss-to follow-up is substantial. Furthermore, reduction of comorbidity receives sufficient attention in most studies, but varying and lacking definitions of comorbidity introduce another possible source of bias. The similarity in outcome in all studies, however, strengthens our conclusion that the current methods of summarizing BMI loss, complication rate, and reduction of comorbidity are indicative of the true outcome.

Conclusions

This review is the first that has retrieved sufficient data for meta-analysis of BMI loss by contacting all authors of included studies, to enable a solid statistical analysis. All three analyzed bariatric surgical techniques—laparoscopic adjustable gastric banding, Roux-en-Y gastric bypass, and laparoscopic sleeve gastrectomy—result in substantial weight loss and improvement of comorbidity in the short to medium term. This indicates that, considering the acceptable complication rate, surgical intervention is applicable in appropriately selected adolescents. While BMI loss after RYGB is superior, a higher rate of adverse events and reinterventions has to be taken into account. We recognize that RYGB is currently considered in the treatment of adolescents with a more extreme BMI (>50 kg/m²), while LAGB and LSG are applied when obesity is less extreme.

The quality of the available literature is limited. In the current climate where availability of bariatric surgery for morbidly obese children is already increasing, randomized controlled trials comparing bariatric surgery with standard conservative treatment are difficult to perform. Currently, seven active studies are registered in ClinicalTrials.gov assessing the effects of bariatric surgery in adolescents, including one randomized controlled trial. We recommend the involved researchers to use solid outcome reporting strategies and strongly support the pleas for standardized weight loss reporting [25, 26].
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Conflict of Interest The authors declare that they have no conflict of interest.

Statement of Informed Consent Does not apply.

Statement of Human and Animal Rights For this article, no studies with human participants or animals were performed by any of the authors.

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