doi: 10.1111/obr.12037

Obesity Treatment

Bariatric surgery for obese children and adolescents: a systematic review and meta-analysis

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Received 19 December 2012; revised 14 March 2013; accepted 14 March 2013

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Summary

The number of obese young people continues to rise, with a corresponding increase in extreme obesity and paediatric-adolescent bariatric surgery. We aimed to (i) systematically review the literature on bariatric surgery in children and adolescents; (ii) meta-analyse change in body mass index (BMI) 1-year post-surgery and (iii) report complications, co-morbidity resolution and health-related quality of life (HRQoL).

A systematic literature search (1955–2013) was performed to examine adjustable gastric band, sleeve gastrectomy, Roux-en-Y gastric bypass or biliopancreatic diversions operations among obese children and adolescents. Change in BMI a year after surgery was meta-analysed using a random effects model.

In total, 637 patients from 23 studies were included in the meta-analysis. There were significant decreases in BMI at 1 year (average weighted mean BMI difference: −13.5 kg m^{-2}; 95% confidence interval [CI] −14.1 to −11.9). Complications were inconsistently reported. There was some evidence of co-morbidity resolution and improvements in HRQol post-surgery.

Bariatric surgery leads to significant short-term weight loss in obese children and adolescents. However, the risks of complications are not well defined in the literature. Long-term, prospectively designed studies, with clear reporting of complications and co-morbidity resolution, alongside measures of HRQol, are needed to firmly establish the harms and benefits of bariatric surgery in children and adolescents.

Keywords: Adolescents, bariatric surgery, children, meta-analysis, obesity, systematic review.

obesity reviews (2013) **14**, 634–644

Introduction

The global prevalence of obesity is rising in children and adolescents (1). In the United Kingdom, e.g. among individuals aged 11–15 years, the prevalence was 14.7% in 1995 and 18.3% in the 2010 round of the National Child Measurement Programme (2). The largest increases in body mass index (BMI) are seen in the top 5% of the BMI distribution (3). Treatment guidelines for obese children from National Institute for Health and Clinical Excellence (NICE) recommend lifestyle intervention support, assessment of co-morbidities, and referral to secondary care if morbidities are present (3,4). Children and adolescents in whom lifestyle change and standard clinical care are ineffective in reducing BMI are increasingly being considered for bariatric surgery, which encompasses a number of different surgical procedures (4).

In 1967, Mason *et al*. performed the first gastric bypass (5). This technique was the precursor of the modern Roux-en-Y gastric bypass (RYGB) (6), where a 30-mL pouch is created from the upper stomach and anastomosed with the dissected jejunum, bypassing the remaining stomach and upper part of the small intestine. The bypassed stomach and small intestine are subsequently re-anastomosed (Y-shaped) with the jejunum, allowing biliopancreatic secretions to digest food intake. Weight loss was initially assumed to be due to the restriction of food intake and malabsorption (6,7). Although the emerging acknowledgement of the role of hormonal and autonomic changes after surgery indicate the true mechanisms are more complex (8,9). The adjustable gastric banding (AGB) procedure (10) is relatively simple and involves the placement of an adjustable silicon band around the stomach, 1–2 cm from the gastrosophageal junction to form a gastric pouch of approximately 30 mL. The sleeve gastrectomy (SG) procedure (11) involves resection of the greater curvature of stomach, resulting in a tubular stomach approximately 10–15% of its original size. Biliopancreatic diversion (BPD) combines elements of the SG and RYGB, with the removal of the greater curvature of the stomach (SG) and subsequent bypassing of the proximal small intestine with distal anastomosis of the common channel. All four procedures are usually carried out laparascopically. The exact underlying mechanisms of weight loss for each procedure remain unclear and vary by procedure; greater understanding of gut physiology and gut–brain communication have shown that the benefits of bariatric surgery extend beyond food restriction and malabsorption (7,9,12). Both RYGB and AGB have been used in obese children and adolescents in the United Kingdom and the United States (13).

Data from the US National Inpatient Sample suggest that 2,744 adolescent bariatric operations were performed in the US from 1996 to 2003 (14), and many more have been undertaken since this time. In general, data on the number and outcomes (including weight loss, health-related quality of life [HRQol], and co-morbidity resolution) of bariatric procedures carried out in children and adolescents are scarce. Most evidence comes from individual case studies, which do not provide reliable estimates of the true benefits and risks of undergoing bariatric surgery. The paucity of evidence in the literature, along with a lack of authoritative clinical guidelines, means that patient selection for surgical treatment is largely decided on by a multidisciplinary team using a case-by-case approach (15). There is a need for an up-to-date review of the literature to inform clinical guidelines. Two previous systematic reviews of the literature showed that sustained weight loss could be achieved after bariatric surgery, but reporting on related co-morbidities and complications was sparse, and surgery types were poorly differentiated (16,17). Given the rapid rise in the number of obese children and adolescents in the past 5 years, and the reported increase in bariatric surgery in these groups (14), we aimed to extend and update the previous reviews by (i) systematically reviewing the literature on bariatric surgery in children and adolescents; (ii) meta-analysing change in BMI separately by surgery type and (iii) reporting peri-operative complications, co-morbidity resolution and HRQoL.

Methods

Search strategy

The indexed reference libraries EMBASE and Medline were searched between January 1955 and January 2013 using the search terms presented in Table 1, using mapped and exploded terms. Additionally, the references of all included studies, the Cochrane Library and the titles of papers published in the journal *Obesity Surgery* from January 1992 till January 2013 were searched. Only papers written in English were retrieved.

Study selection

Studies were included if (i) they assessed BMI before and a minimum of six months after individuals predominately received AGB, RYGB, BPD or SG and (ii) the mean age of the population was between 6 and 18 years at study entry (18). Examination of other gastric procedures, including VBG and jejeunoileal bypass methods, were excluded as they are not currently recommended for use in paediatric populations (7,19). Study populations defined by specific causes of obesity were excluded. Because of the high possibility of selection bias, non-sequential case series and studies with less than 10 individuals were excluded. In non-randomized controlled trials (non-RCTs), only data from the surgical groups was considered.

We used a standard data extraction method to collect the following information on each study: years during which the surgery was performed, authors, country, study design, mean age and variance of study participants, type of surgery, gender distribution, complications, co-morbidities, pre-/post-surgery BMI with variance, number of participants, length of follow-up and loss to follow-up. Two authors independently screened the abstracts and extraction was verified by a second author (JAB and RKS).

Table 1 Search strategy for indexed reference libraries

Search terms for EMBASE and Medline via Ovid SP
1. child/ or adolescent/ or paediatric/
2. (child$ or 'young person?' or adolescent or paediatric).ab,ti.
3. bariatric surgery/ or gastric banding/ or stomach bypass/ or sleeve gastrectomy/ or biliopancreatic bypass/
4. ('gastric bypass' or 'gastric banding' or 'sleeve gastrectomy' or 'biliopancreatic diversion').ab,ti.
5. (1 or 2) and (3 or 4)

Meta-analysis statistical methods

Formulas outlined in the Cochrane Guidelines were used to derive necessary statistics or process individual data from each of the studies included in the meta-analysis (20). Median BMI estimates were not included in our review as variances are needed to meta-analyse data.

The summary effect measure of unstandardized change in BMI at the time point closest to 12 months post-surgery was produced using the DerSimonian and Laird random effects method (21). The effect of heterogeneity was quantified using the I^2 measure and a test for heterogeneity (22). As the vast majority of studies examining bariatric surgery in obese children and adolescents are uncontrolled before and after studies, which are sensitive to bias (23), potential confounding effects were hypothesized before undertaking the meta-analysis and explored by stratifying by surgery type. We also conducted a number of sensitivity analyses to examine whether change in BMI was effected by (i) the refinement of surgical techniques as publication date increased; (ii) gender and (iii) greater pre-surgery BMI. Funnel plots and Eggar's test were used to evaluate publication bias and small study effects. Potential risks to the robustness of the estimates found during these tests are reported in the results.

Results

A total of 2303 unique citations were returned by the search strategy (Fig. 1). Of these, 2185 were excluded based on abstract review. Two additional papers were retrieved during full text screening. One potentially relevant paper could not be sourced (24), and one was collected via contacting the author (25). A total of 54 papers met the inclusion criteria, representing 23 unique study populations. One controlled trial and 22 uncontrolled before and after studies meeting the inclusion criteria were retrieved.

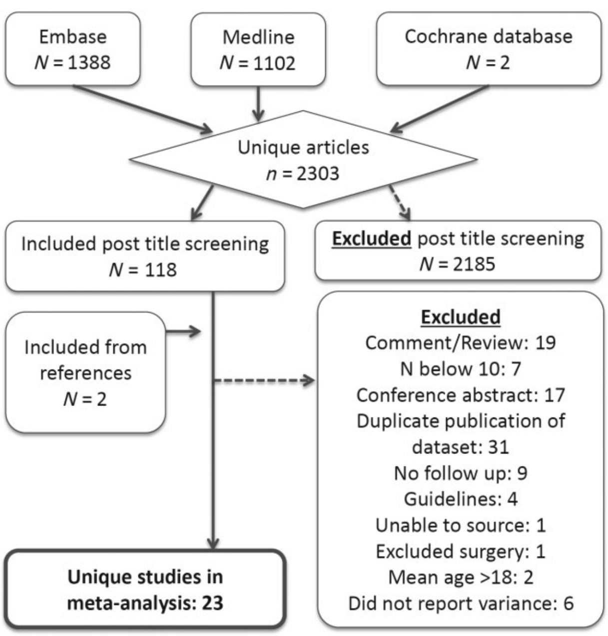

Figure 1 Paper retrieval schematic.

Patient characteristics

The median number of patients at baseline in each study was 24 (range 10–108). In total, 637 patients were analysed at post-surgery follow-up. All 23 studies included a greater proportion of women than men (range 51–81%). Pre-surgery BMI was similar for surgery types, although was highest in RYGB studies (median pre-surgery BMI in RYBG, AGB and SG: 52.4, 46.1 and 49.6, respectively). Seven RYGB, 11 AGB studies and 3 SG studies were sourced. One study employed BPD, and one employed Sanotoro III, a novel surgical procedure. Estimates from these studies were included in the main summary estimate, tables and figures, but should not be considered representative of these types of surgery as only 10 adolescents were included in each study. Age was broadly comparable across the remaining three surgery types, with the age at surgery within studies ranging from 5 to 23 years. The majority of patients were operated on between 1996 and 2012 (Table 2), although two studies using the RYGB method included operations from before 1986 (26,27).

Surgical techniques differed among the RYGB group (Supporting Information Supplementary Digital Content 1). Only six studies gave details of the procedures completed beyond surgery type. Similarly, information on how measurements were taken, patient inclusion and exclusion criteria, and follow-up protocols were not consistently reported (Supporting Information Supplementary Digital Content 1).

Change in BMI

Mean BMI at baseline ranged from 38.5 to 60.2 kg m^{-2} (mean 47.9 kg m^{-2}), and at follow-up from 25.2 to 41.5 kg m^{-2} (mean 34.7 kg m^{-2}). All studies reported decreases in BMI (Table 2). Findings from the meta-analysis of change in BMI at 12 months post-operatively are shown in Fig. 2. The average weighted mean BMI difference from baseline to 1 year was −13.5 kg m^{-2} (95% confidence interval [CI] −15.1, −11.9). There was strong evidence of heterogeneity among the studies ($I^2 = 76.1\%$ and $P < 0.001$), largely because of the differences among surgery types and populations.

When examined by operation type, heterogeneity was substantially lower within each group. Mean BMI loss

Table 2 Study characteristics and BMI before and after surgery, by surgery type

Study	Surgery dates	n*	Mean age in years (range)	Female (%)	Mean follow-up in months (range)	Mean BMI baseline (SD)	Mean BMI at follow-up (SD)
Laproscopic adjustable gastric banding							
Dolan, 2004 (52)	1996–†	17/17	† (12–19)	82	~12	43.1 (9.6)	33 (7.0)
Angrisani, 2005 (53)	1996–2003	48/58	18.0	81	~12	46.1 (6.31)	35.9 (8.4)
Fielding, 2005 (29)	1998–2005	18/41	15.6 (12–19)	73	~36	42.4 (8.2)	29 (6)
Silberhumer, 2006 (28)	1998–2004	50/50	17 (9–19)	62	35 (4–85)	45.2 (7.6)	32.6 (6.8)
Dillard, 2007 (54)	2001–2006	14/24	18 (14–20)	75	~12	49 (10)	40 (13)
Holterman, 2010 (34)	2005–2007	20/20	16 (14–17)	75	~12	50 (10)	41.5 (~10†)
Nadler, 2009 (45)	2005–2007	45/45	16	67	~12	48.1 (6.4)	36.3 (7.5)
O'Brien, 2005 (31)	2005–2008	24/25	16.5	64	~24	42.3 (6.1)	29.6 (6.8)
Dabbas-Tyan, 2011 (55)	2008–†	9/15	17 (13–18)	†	15 (6 –30)	46.1 (5.0)	40.1 (7.9)
Silva, 2012 (56)	2001–2010	14/14	16 (14–17)	71	~12	46.1 (3.2)	37.3 (3.9)
De Filippo, 2012 (57)	†	12/14	16 (12–18.6)	71	~12	39.0 (3.5)	31.2 (4.4)
Roux-en-Y gastric bypass							
Sugerman, 2003 (26)	1981–2002	31/33	16 (12–19)	58	~12	52 (11)	36 (10)
Strauss, 2001 (27)	1985–1999	10/10	16 (15–17)	70	† (12–15)	52.4 (10.1)	36.2 (9.7)
Loux, 2008 (30)	2000–2005	16/16	18.6 (14–20)	69	17 (1–39)	54.1 (7.6)	35.1 (9.3)
Cruz-Muñoz, 2010 (25)	2002–2007	45/78	(16–17)	77	~12	45.8 (5.6)	32.5 (9.8)
Inge, 2010 (46)	2002–2007	59/61	17 (12–23)	67	~12	60.2 (11.8)	37.7 (8.6)
Teeple, 2012 (58)	2004–2009	14/15	†	67	~12	58.8 (10.7)	37.6 (9.0)
Olbers, 2012 (33)	2006–2009	81/81	16.5 (13–18)	65	~12	45.5 (6.1)	30.8 (4.6)
Laproscopic sleeve gastrectomy							
Alqahtani, 2012 (32)	2008–2011	41/108	14 (5–21)	51	~12	49.6 (11.5)	32.4 (8.5)
Nadler, 2012 (44)	2010–2011	9/23	17 (14–19)	78	~10	52 (9)	39 (8)
Boza, 2012 (35)	2006–2009	40/51	18 (15–19)	80	~12	38.5 (3.7)	25.2 (~3.7†)
Other							
Velhote, 2010 (59)	2003–2006	10/10	16 (14–19)	70	~12	51.7 (8.4)	32.8 (6.7)
Marceau, 2010 (60)	1993–2009	10/10	16.8 (16–17)	60	~120	55.9 (14.0)	28.8 (3.7)

*Population at follow-up/population receiving surgery; †Information not reported.
BMI, body mass index; SD, standard deviation.

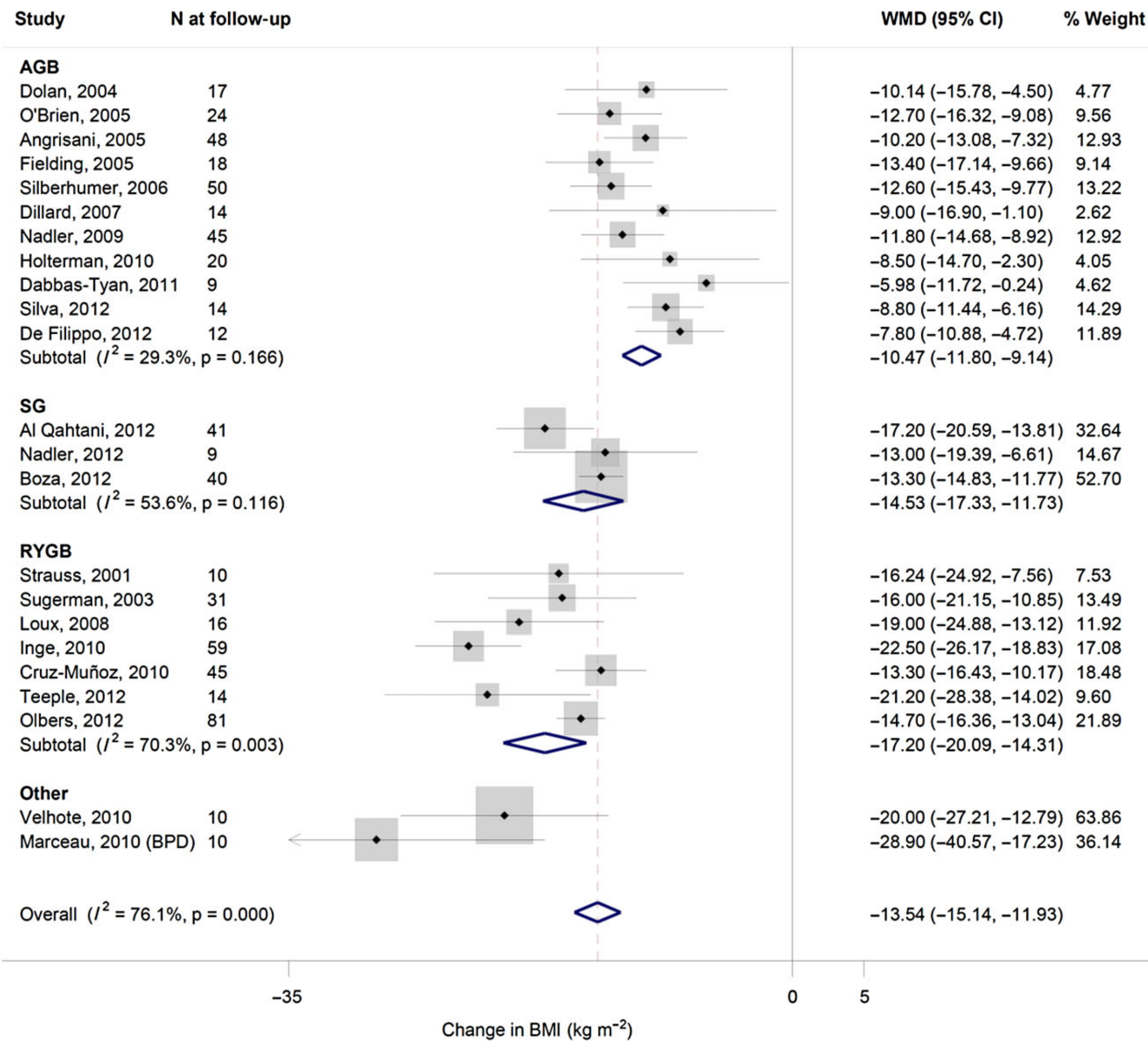

Figure 2 Meta-analysis of BMI change after bariatric surgery for adolescent obesity, by surgery type and overall. AGB, adjustable gastric banding; BMI, body mass index; BPD, biliopancreatic diversion; CI, confidence interval; RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy.

at approximately 12 months was greatest for RYGB (−17.2 kg m^{-2} [95% CI −20.1, −14.3]; eight studies; $n = 256$) and smallest for AGB (−10.5 kg m^{-2}; [95% CI −11.8, −9.1]; 11 studies; $n = 271$ patients). Removal of the two AGB studies with an average follow-up of around 36 months after surgery (28,29) had minimal effects on the summary estimate (−10.5 to −9.8 kg m^{-2}). BMI loss after SG resulted in a mean BMI reduction of −14.5 kg m^{-2}; 95%CI −17.3, 11.7; three studies; $n = 90$ patients).

There was no conclusive evidence of bias identified visually, or through hypothesis testing during the sensitivity analysis.

Peri-operative complications

It was not possible to provide a summary estimate of the number of complications as studies defined complications in different ways and expressed complications as a count of events or described case-specific complications (Table 3).

In RYGB studies, nutrient deficiencies, hernias, wound infections, small bowel obstructions, cholelithiasis and ulcers were reported most frequently (Table 3). One RYGB study did not report any complications (30). The low sample size in each study hampered efforts to understand which complications were specifically associated with

Table 3 Complications and adverse events

Study	Any mortality (%)	Conversions or reversal (%)	Hernia (%)	Wound infection (%)	Ulcer (%)	Nutrient deficiency (%)	Stenosis (%)	Leakage (%)	Pouch dilation (%)	Slippage (%)	Cholelithiasis (%)	Total affected (%)[†]
Adjustable gastric banding												
Dolan, 2004 (52)	0/17 (0)	*	*	*	*	*	*	1/17 (6)	*	1/17 (6)	*	2/17 (12)
O'Brien, 2010 (9)	0/25 (0)	*	*	*	*	*	*	*	6/25 (24)	*	1/25 (4)	12/25 (48)
Angrisani, 2005 (53)	0/58 (0)	6/58 (10)	*	*	*	*	*	*	2/58 (3)	1/58 (2)	*	6/58 (10)
Fielding, 2005 (29)	0/41 (0)	*	*	*	*	*	*	1/41 (2)	*	1/41 (2)	*	*
Silberhumer, 2006 (28)	0/50 (0)	0/50 (0)	*	*	*	*	*	*	*	0/50 (0)	*	*
Dillard, 2007 (54)	*	*	0/24 (0)	*	*	*	*	1/24 (4)	6/24 (25)	0/24 (0)	*	*
Nadler, 2009 (45)	*	2/47 (4)	*	*	*	*	*	*	*	*	*	*
Holterman, 2010 (34)	*	*	1/20 (5)	*	*	*	*	*	*	*	*	5/20 (25)
Dabbas-Tyan, 2011 (55)	0/15 (0)	1/15 (7)	*	*	*	0/15 (0)	*	*	1/15 (7)	*	1/15 (7)	*
Silva, 2012 (56)	0/14 (0)	0/14 (0)	*	*	*	2/14 (14)	*	2/14 (14)	*	*	1/14 (7)	*
De Filippo, 2012 (57)	0/10 (0)	*	*	*	*	*	*	*	*	*	1/10	*
Roux-en-Y gastric bypass												
Strauss, 2001 (27)	0/10 (0)	*	2/10 (20)	*	*	1/10 (10)	*	*	*	*	2/10 (20)	*
Sugerman, 2003 (26)	2/33 (6)	2/33 (6)	11/33 (33)	5/33 (15)	4/33 (12)	1/33 (3)	*	*	*	*	*	*
Loux, 2008 (30)	*	*	*	*	*	*	*	*	*	*	*	*
Inge, 2010 (46)	0/61 (0)	*	*	*	*	*	*	*	*	*	*	16/61 (26)
Cruz-Muñoz, 2010 (25)	*	*	*	*	*	3/60 (5)	*	*	*	*	*	5/60 (8)
Teeple, 2012 (58)	0/15 (0)	*	2/15 (13)	*	*	*	*	1/15 (7)	*	*	*	5/15 (33)
Olbers, 2012 (33)	0/81 (0)	*	5/81 (6)	1/81 (1)	*	*	*	*	*	*	5/81 (6)	*
Sleeve gastrectomy												
Alqahtani, 2012 (32)	0/108 (0)	0/108 (0)	*	2/108 (2)	*	*	*	1/108 (1)[‡]	*	*	*	*
Nadler, 2012 (44)	0/23 (0)	*	*	*	*	*	*	*	*	*	*	1/23 (4)
Boza, 2012 (35)	*	1/51 (2)	*	*	*	*	*	1/51 (2)	*	*	*	*
Other												
Velhote, 2010 (59)	0/10 (0)	*	*	*	*	1/10 (10)	*	*	*	*	3/10 (30)	*
Marceau, 2010 (60)	0/10 (0)	2/10 (20)	*	*	*	*	*	*	*	*	*	*

*Not stated [†]Definition of 'total affected' predominately absent in source papers [‡]Treated for leak, but further investigation showed no active leak present.

Table 4 Resolution of co-morbidities from baseline (pre-surgery) to follow-up

Study	Hypertension (%)	Sleep apnoea (%)	Type 2 diabetes (%)	Insulin resistance (%)	PCOS (%)	Dyslipidaemia (%)
Adjustable gastric banding						
Dolan, 2004 (52)	*	*	*	*	*	*
O'Brien, 2010 (9)	*	*	*	*	*	*
Angrisani, 2005 (53)	*	*	*	*	*	*
Fielding, 2005 (29)	2/2 (100)	1/1 (100)	2/2 (100)	*	*	*
Silberhumer, 2006 (28)	6/12 (50)	*	4/5 (80)	*	*	4/4 (100)
Dillard, 2007 (54)	*	*	*	*	*	*
Nadler, 2009 (45)	8/11 (72)	1/5 (20)	*	*	*	6/17 (35)
Holterman, 2010 (34)	9/9 (100)	*	*	8/18 (44)	*	7/16 (44)
Dabbas-Tyan, 2011 (55)	*	*	*	*	*	*
Silva, 2012 (56)	13/13 (100)	8/12 (67)	*	10/13 (77)	*	8/12 (67)
De Filippo, 2012 (57)	*	*	*	*	*	*
Roux-en-Y gastric bypass						
Strauss, 2001 (27)	3/3 (100)	2/2 (100)	*	*	*	*
Sugerman, 2003 (26)	9/11 (82)	6/6 (100)	2/2 (100)	*	1/1 (100)	*
Loux, 2008 (30)	*	*	*	*	*	*
Velhote, 2010 (59)	*	*	*	*	*	*
Inge, 2010 (46)	1/1 (100)†	*	8/9 (89)†	*	*	2/2 (100)†
Cruz-Muñoz, 2010 (25)	*	*	*	*	*	*
Teeple, 2012 (58)	*	*	4/6 (67)	*	*	*
Olbers, 2012 (33)	*	*	*	57/57 (100)	*	13/15 (87)
Sleeve gastrectomy						
Alqahtani, 2012 (32)	27/39 (69)	20/36 (56)	15/22 (68)	*	*	21/55 (38)
Nadler, 2012 (44)	*	4/5 (80)	0/1 (0)	2/4 (50)	0/1 (0)	0/1 (0)
Boza, 2012 (35)	4/4 (100)	*	1/2 (50)	26/27 (96)	*	7/12 (58)
Other						
Velhote, 2010 (59)	*	*	*	*	*	*
Marceau, 2010 (60)	*	*	*	*	*	*

*Not stated †Co-morbidity presence assessed by prescriptions.
PCOS, polycystic ovary syndrome.

RYGB. Complications after AGB were reported less often than for RYGB, although pouch dilation, port leakage and slippage required remedial operations, and conversions were more common after AGB than RYGB (Table 3). Again, thresholds for and definitions of complications varied among studies, ranging from asymptomatic anaemia through to reversal of surgery because of psychological intolerance. Complications from SG operations were rarely reported.

Co-morbidity resolution

Data on resolution of co-morbidities were of very poor quality. The types of co-morbidities examined in each study differed, and most studies did not report definitions for each co-morbidity. Five RYGB studies reported data on resolution of diagnosed co-morbidities (Table 4). While numbers were too low to draw meaningful conclusions, the majority of cases of hypertension, sleep apnoea, type 2 diabetes and dyslipidaemia were resolved at 1 year. In AGB, six studies reported co-morbidity resolution and results appeared less consistent. O'Brien (31) reported 25/25 cases of insulin resistance resolved at 1 year, while Holterman reported only 7/18 cases no longer having clinically relevant insulin resistance. Low sample sizes were likely to inflate the observed variation. Fielding (29) reported that treatment was no longer required for two children with type 2 diabetes, one child with sleep apnoea and two children with hypertension. An SG study by Al Qahtani (32) contained the largest sample of co-morbidities across all three surgery types, with 55 children with dyslipidaemia pre-surgery. Resolution rates were moderate in the larger sample, in comparison with the less powered studies, where resolution rates fluctuated from high to low across studies (Table 4).

HRQoL measures

Six studies reported results from three general HRQoL measures: the Short Form-36 (SF-36) (30,33), the Paediatric Quality of Life Inventory (PedsQL) (34) and the Child Health Questionnaire (CHQ) (31) and one obesity-specific measure: the Moorehead–Ardelt Quality of Life Questionaire (M-AQoLQ) (28,35). In a population of 33 adolescents undergoing RYGB (30), a statistically significant increase in both the mean SF-36 Physical Component Score (mean [standard deviation {SD}] 34.7 [10.1] to 55.5 [5.3]; $P < 0.01$) and the Mental Component Score (mean [SD] 40.6 [13.5] to 54.8 [8.4]; $P < 0.01$) was observed from time of surgery to 1-year follow-up. Similar results were observed in two laproscopic adjustable gastric banding (LAGB) studies (31,34) where both the PedsQL (mean [SD] 66 [14] to 82 [13]; $P = 0.01$) and general health domain of the CHQ increased (mean [SD] 47.8 [17] to 65.7 [21]) from baseline to follow-up. Mean scores for the obesity specific M-AQoLQ increased from 0.8 (SD = 0.3) to 2.1 (SD = 0.8) in 50 Austrian adolescents undergoing LAGB surgery (28). Among 51 adolescents undergoing laparoscopic SG, 60% reported a 'very good' quality of life and the remaining 40% reported a 'good' quality of life post-surgery (35).

Discussion

Bariatric surgery in obese children and adolescents is associated with a significant reduction in BMI after 12 months (average weighted mean BMI difference: −13.5 kg m^{-2}; 95% CI −15.1, −11.9). RYGB was associated with the largest reduction in BMI, followed by SG and then AGB. One study containing 10 adolescents was found for BPD, where weight loss and maintenance were high, with a reduction of 29.9 kg m^{-2} after 10 years. Quantification of peri-operative complications was not possible because of inconsistent reporting between studies. There was some evidence to suggest that bariatric surgery is related with co-morbidity resolution for hypertension, sleep apnoea, type 2 diabetes and dyslipidaemia, particularly with RYGB surgery. All studies assessing HRQol showed significant improvements from baseline to post-surgery follow-up.

Our findings are consistent with an earlier more limited meta-analysis of adolescents (17) (including 10 studies, six LAGB, four RYGB and no LSG studies) and a narrative review (16). The meta-analysis found a significant reduction in BMI after AGB (95% CI −13.7, −10.6 BMI units; six studies; $I^2 = 56\%$) and RYGB surgery (95% CI −22.3, −17.8 BMI units; four studies; $I^2 = 0\%$). The RYGB estimates presented here (95%CI −19.8, −15.5) fall within Treadwell's estimates, while there is significant overlap with our AGB estimates (95%CI −11.8, −8.9). The same report suggested that hypertension and type 2 diabetes appear to resolve after surgery. This finding is supported by the narrative review, where weight loss was associated with clear improvements in metabolic and psychosocial outcomes. Both reviews commented on the need for clearer guidance and further discussions on the risks, benefits and nature of consent of bariatric surgery in younger populations. Unfortunately this conclusion is still true for our systematic review despite the inclusion of more recent data.

Results from a Cochrane review showed that surgery is an effective means to manage severe obesity in adults, although the authors recommended that it should be used carefully as complications can be serious (7). A meta-analysis of adult bariatric surgery (36) estimated a BMI change after AGB of −10.4 (95% CI, −11.5, −9.3) and −16.7 (95% CI −18.4, −15.0), replicating the pattern observed in this study of adolescents. Buchwald *et al*. also reported that dyslipidaemia resolved in 70% of adult patients, diabetes in 77%, hypertension in 62% and sleep apnoea in 86% after bariatric surgery.

Information on exact surgical techniques used in earlier literature was sparse, but the stratification of RYGB, SG and AGB operations demonstrated three distinct sets of outcomes. As similar patterns have been identified in the adult literature, it is likely that the observed heterogeneity is due to treatment effectiveness (37,38), and the underlying populations to which the different surgery types were applied. The difference in outcomes by surgery types is unsurprising given that bariatric surgery includes a number of mechanistically different operations, some which impact on outcomes over and above weight loss. For example, gastric bypass, but also SG, has significant metabolic effects, in contrast to banding alone. We showed that RYGB surgery was often applied to populations with greater adiposity and is associated with greater weight loss in adults (7,39), a finding that was evident in this analysis of children and adolescents. Adult studies have also suggested that risk of complications may be lower in the less invasive AGB (7). There is weak evidence of this finding in adolescent studies. Validated HRQoL measurements reported in this review show significant short term improvement post-surgery (40,41).

Strengths and limitations

This meta-analysis doubles the number of studies included in previous reviews, and is the first to summarize the effect of the relatively new SG procedure. Ideally a meta-analysis of a surgical intervention would be evaluated using RCT data to provide the strongest level of evidence. However, only one RCT of adolescent bariatric surgery was retrieved in this systematic review (31). This trial contained small numbers ($n = 50$), and 28% of the non-surgical arm withdrew from the study post-randomization, potentially introducing bias; 84% (21/25) of participants randomized to the surgical arm lost more than 50% of their body weight compared to 12% (3/25) of those randomized to a physician and nurse led lifestyle programme. The remainder of the studies included in this systematic review were uncontrolled before and after studies (sequential case series). This finding reflects the ethical concerns of randomizing a vulnerable population (children/adolescents), clinical guidelines, and the setting in which decisions about whether to proceed with bariatric surgery are made. Individuals have to be resistant to available lifestyle interventions, and surgery is only recommended after intensive efforts at lifestyle and pharmacological intervention have failed (42,43). As such, it is difficult to satisfy the condition of equipoise in an RCT when comparing an instantly reversible therapy (lifestyle or pharmacological intervention) with a surgical intervention that has a different risk profile and cost, and would be difficult to remedy or reverse.

While five studies stated they were prospectively designed (31,34,44–46), the remainder are assumed to be retrospective. This is evident in the lack of reporting on patient selection criteria and loss to follow-up. Before and after studies are subject to all the potential biases and confounding inherent in observational study designs. Sample sizes are small in this clinical field because programmes are small and it is only recently that less invasive approaches have become available. This further hampers interpretation of results. The potential exists that the benefits of bariatric surgery have been inflated in the literature presented in this systematic review, as there were very few fixed study protocols before data collection and only clinics with promising records might have been incentivized to publish their data. Indeed, 17 other studies, more than half the number of studies included in this review, were reported only in conference abstracts, indicating that a substantial amount of available information will not be collected by a review of published data. The reporting of complications was generally poor, with few studies specifying definitions and data collection procedures for complications, which may have introduced reporting bias.

Three studies that met the inclusion criteria were not included in the meta-analysis as they reported only the median and range of BMI values (47–49). Spacing of follow-up time points varied across the studies. We made a pragmatic decision to report 12-month outcomes as this result was the most consistently reported in the literature. However, it should be acknowledged that weight loss or diminished weight gain continues for more than 12 months and most often reaches a nadir with varying duration before a gradual increase ensues (7). For example, using data from a small sample of adolescents ($n = 9$), Sugerman (26) demonstrated that weight losses after bypass surgery at 1 year were largely maintained at 14 years. This finding is consistent with the more robust adult-based literature (51). Plots of BMI change over time vary significantly between the generically different operations, which supports our finding of different outcomes by surgery type. The trajectory of weight loss also varies during critical periods of pre-adolescence. Similarly, evaluation of co-morbidity reduction as well as HRQL is premature at 12 months. The trajectories of different morbidities differ and depend on type of operation. Longer-term assessments of HRQL often exhibit return to baseline or worse (8,50).

There is consensus that it is critically important that young patients have meticulous follow-up after bariatric surgery. The potential exists that some of the benefits of weight loss seen in this review may have been mediated through other factors, such as contact with nurses, psychologists and dieticians. The extent of these secondary sources of change are not quantifiable, as the only RCT included in this review used a control group that had contact only once every 6 weeks with the lifestyle team (31). However, follow-up is often poor and the intensity may be no greater than with non-operative treatment. There is consequently a need for more information to understand the long-term effects of bariatric surgery, on weight loss, co-morbidity resolution, peri-operative complications, HRQol and clinical care. Improved methods for retaining young patients in studies would aid this endeavour.

Recommendations

NICE guidelines for the clinical management of obesity provide a general appraisal of the evidence, with broad suggestions for care pathways. More substantive guidelines on how to manage paediatric-adolescent bariatric surgery populations, advice concerning, which complications and co-morbidities to measure, and encouraging longer-term follow-up would benefit both patients and clinicians. In terms of choice of operation, bariatric procedures have significantly different mechanisms and outcomes, with particular importance in youth. During development, the differences between purely gastric restrictive operations (e.g. banding), which are more dependent on cognitive restraint, and the neuro-endocrine regulatory operations with autonomic mechanisms (e.g. bypass) are crucial, affecting adherence and potential side effects over the long term (5–10 years). It is therefore difficult to recommend a particular procedure based on the literature reviewed here and decisions should continue to be taken on a case-by-case basis.

Studies routinely combined data from both men and women, children, and adolescents. While our sensitivity analysis did not find a difference in outcomes by either age or sex, future studies should report results separately by sex and by children and adolescents. There is significant variability in responses to the different operations depending on physiologic development differences between ages 10 and 18 years. Neuro-endocrine and skeletal maturation (e.g. Tanner staging, gonadal steroids, cognitive testing) should be evaluated before and after surgery, yet such information is scarce (50).

In the absence of RCT data, observational studies are likely to continue to be the main source of evidence for bariatric adolescent surgery. Many studies are reported in abstracts from obesity conferences, but are not submitted for publication as full papers in scientific journals. Authors should be encouraged to publish their finding, whether positive or negative, and to be transparent about the study design they used. Prospective data collection would also aid our understanding of both the complications and co-morbidity resolution potential of bariatric surgery in young populations. Better collection and reporting of long-term outcome data is also needed, ideally from national studies covering both private and public health systems. A notable example of this is the Swedish Nationwide Survey: Adolescent Morbid Obesity Surgery (AMOS) study (33), but unless action is taken before AMOS reaches its 10-year follow-up, a comparable prospective study with a similar level of follow-up will not be possible for a further decade.

Conclusion

Bariatric surgery in adolescents results in similar short-term weight outcomes to adults, with RYGB producing the greatest weight loss with the most robust evidence base. There are currently no other evidence-based medical interventions that results in similar magnitudes of weight loss, and this review suggests that bariatric surgery should be a treatment option, especially where there are weight-related complications.

As bariatric surgery seems to be associated with a risk of complications and has the potential to impact on dietary patterns for a lifetime, a balance must be made between the potential benefits and harms at an individual case level. Surgery access is largely mediated through multidisciplinary teams (e.g. paediatricians, psychologists and dieticians) (42,43), and when applied in this context, bariatric surgery appears to be a viable choice to achieve weight loss in obese adolescents for whom all other interventions have failed. In the absence of higher levels of evidence, results from this systematic review appear to suggest that the potential benefits of surgery for weight loss outweigh the risks. Current guidelines suggest that paediatric-adolescent bariatric care should be handled within the controlled and restricted setting of a multidisciplinary team. However, long-term, prospectively designed studies, with clear inclusion criteria and reporting of effects, side effects, complications and co-morbidity resolution, alongside measures of HRQol, are needed to more firmly establish the harms and benefits of bariatric surgery in children and adolescents.

Conflict of interest statement

No conflict of interest was declared.

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Supporting information

Additional Supporting Information may be found in the online version of this article, http://dx.doi.org/10.1111/obr.12037

Supplementary Digital Content 1. Further notes on study design