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REVIEW

Remission of Type 2 Diabetes and Sleeve Gastrectomy in Morbid Obesity: a Comparative Systematic Review and Meta-analysis

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Abstract

Background The sleeve gastrectomy (SG) has gained popularity which has resulted in a rising number of patients with T2DM to undergo this procedure. This systematic review and meta-analysis aimed to compare the long-term effects of SG on T2DM remission with remission seen after Roux-en-Y gastric bypass (RYGB) or gastric banding (GB).

Methods A literature search was performed in PubMed and Cochrane Library using the following search terms: 'sleeve gastrectomy', 'diabetes', 'gastric bypass' and 'gastric banding'. Studies published between January 2000 and April 2018, and with following inclusion criteria were selected for this review: BMI ≥ 35 kg/m2, age ≥ 18 years, follow-up ≥ 1 year, T2DM. Data was statistically analysed using a random-effects model and results were expressed as odds ratio with 95% confidence interval.

Results After exclusion, 35 out of an initial 748 studies, consisting of 18 138 T2DM patients, remained for inclusion. Of these patients, 2480 underwent a SG. The remaining patients underwent a RYGB (n = 10,597) or GB (n = 5061). One year postoperatively, SG patients reached significantly (OR 0.71, $p = 0.003$) less T2DM remission than RYGB. After stratifying for different criteria for remission, RYGB still tended to result in higher remission rates, but the difference was not statistically significant. Beyond 1 year of follow-up, the difference between RYGB and SG in terms of T2DM remission decreased. SG was superior to the GB (OR 2.17, $p = 0.001$) after 1 year of follow-up.

Conclusion This review demonstrates important remission of T2DM following SG. Nevertheless, as remission was significantly more often observed following RYGB surgery, the latter procedure remains the gold standard for reaching T2DM remission in patients with concurrent obesity.

Keywords Sleeve gastrectomy · Roux-en-Y gastric bypass · Gastric banding · Diabetes remission · T2DM

Abbreviations

BMI	Body mass index
EWL	Excess weight loss
GB	Gastric banding
RYGB	Roux-en-Y gastric bypass
SG	Sleeve gastrectomy
T2DM	Type 2 diabetes mellitus

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Introduction

Globally, over 400 million people suffer from obesity according to WHO estimates and the prevalence of morbid obesity is presumed to continue to increase during the forthcoming years [1]. While momentarily the highest prevalence is seen in Western Europe and the USA, a rise in prevalence is expected to occur in Asia and the Middle East [1–4]. On the long-term, obesity is associated with a reduced life expectancy and different health problems such as obstructive sleep apnea, hypertension, liver steatosis, cardiovascular disease and kidney failure [5–8]. Possibly, the most important comorbidity of obesity is type 2 diabetes mellitus (T2DM), as it plays a central role in the development of other comorbidities and further aggravates the metabolic syndrome.

Bariatric surgery has been identified as the most effective treatment in terms of sustaining weight loss and resolution of comorbidities compared to other weight loss techniques. Especially for the induction of T2DM resolution has bariatric surgery been proven superior to conventional weight loss inducing methods [9–14]. After the initial report of diabetes remission occurring after bariatric surgery [10], many other studies have observed remission of T2DM after bariatric surgery. This was subsequently confirmed by Buchwald et al. in their meta-analysis [15]. Even on the long-term, up to 15 years after surgery, metabolic effects of bariatric surgery have been demonstrated [13].

However, while the RYGB is still considered as the gold standard, in recent years, the sleeve gastrectomy (SG) has gained ground. SG is not solely a restrictive procedure but also has been found to lead to an accelerated gastric emptying [16]. After this procedure, a significant weight loss and remission of comorbidities have been observed. The main difference of this procedure in comparison to the RYGB technique is the absence of GI tract modification in SG, potentially causing less malabsorption [17–20]. In case of a SG procedure, the following mechanisms for T2DM remission are presumed to play a role: restrictive effect of SG, increased secretion of the incretin GLP-1 due to faster emptying of the stomach or decreased secretion of ghrelin due to complete resection of the fundus [21–27].

Although both procedures have been proven to improve glucose homeostasis and cause significant T2DM remission, literature comparing the long-term effects of the SG on T2DM with the remission seen following the RYGB is limited. Therefore, the aim of this systematic review and meta-analysis is to evaluate the effect of SG on T2DM remission in patients with morbid obesity and to compare these remission rates with those achieved following a RYGB or GB.

Materials and Methods

Data Search

In this study, we performed a systematic literature search in PubMed and Cochrane, using the following search terms: ‘sleeve gastrectomy’ AND ‘diabetes’ AND (‘gastric bypass’ OR ‘gastric banding’) in PubMed. In case of the search in Cochrane, we conducted two separate searches: the first search consisted of ‘sleeve gastrectomy’ AND ‘diabetes’ AND ‘gastric bypass’, in the second search ‘gastric bypass’ was replaced by ‘gastric banding’. Studies had to be published between January 1, 2000, and April 1, 2018, the date on which the last literature retrieval was performed.

Study Selection

Studies were selected for this review based upon stringent inclusion and exclusion criteria (Table 1). The following publication types were included: randomised controlled trials, non-randomised trials, retrospective cohort studies and prospective observational studies. In case of studies with overlapping patient cohorts, the study with the best-defined cohort, scoring the best on the quality assessment and with the most recent publication date was selected and included only once in the analysis in order to prevent duplicate publication bias. A BMI of 35 kg/m^2 or higher and an age of 18 years or older were required for inclusion. Studies had reported on T2DM remission with a minimum follow-up period of 1 year. Exclusion criteria were non-human studies, case reports, application of a variety of SG and patients with previous bariatric surgery.

Data Collection and Analysis

In the present study, means, frequencies and odds ratios with confidence intervals of 95% were extracted in order to summarise data on studies, patients and outcomes. A primary meta-analysis was conducted, comparing the T2DM remission rates between patients who either underwent a SG, or a

Table 1 Overview of the inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Age ≥ 18 year	Non-human studies
BMI ≥ 35 kg/m^2	Varieties of SG
Follow-up of ≥ 1 year	Case reports
T2DM remission as an outcome	Non-comparative studies
Studies written in English	Previous bariatric procedures
Published between January 1, 2000–April 1, 2018	Case-control studies

BMI, body mass index; *T2DM*, type 2 diabetes mellitus

RYGB, the current gold standard for surgical weight loss. Analyses were also conducted for subpopulations, stratifying for the used remission criteria. Additionally, the effects of these procedures on T2DM after multiple years of follow-up were assessed. Furthermore, secondary analyses were performed to compare T2DM remission following the SG or RYGB procedure and gastric banding. Considering significant heterogeneity between studies included in this review, statistical analysis was performed using a random-effects model. In this model, sample size and width of the confidence intervals of every study determined the assigned weight in the final meta-analysis. Outcomes were expressed as the odds ratio with 95% confidence interval. Differences in remission rates were considered to be significant if the corresponding p value was below 0.05. Descriptive statistics were used to analyse general characteristics of the included studies. These analyses were performed with SPSS version 23 (IBM, Chicago, IL). The meta-analysis component was performed with Review Manager version 5.3 (Cochrane Collaboration, Copenhagen). Funnel plots were used in order to assess publication bias in the meta-analysis.

Three investigators (F.M., R.J. and I.M.) performed the literature search and reviewed the articles based on title and abstract to assess whether the publications met eligibility criteria for inclusion. In case of discrepancy about inclusion of certain studies, consensus was achieved by discussion between the previously mentioned investigators and two other investigators (P.P. and G.H.). Quality of the included studies and the risk of bias were assessed using the QUADAS-2 tool, determining the risk of a selection, performance, detection, attrition and reporting bias for each individual study.

Results

Literature Search

After the initial search in PubMed and Cochrane library, a total of 748 publications were retrieved. Following the initial screening based upon title and abstract, and after removal of duplicates, 137 studies remained. The full texts of these articles were subsequently screened for their relevance to the subject and compliance with the predefined inclusion and exclusion criteria. As a result, of the remaining studies, 87 publications were excluded due to being irrelevant on basis of full text, 7 studies were solely available in the form of abstracts

Fig. 1 Flowchart of the literature search and study selection procedure

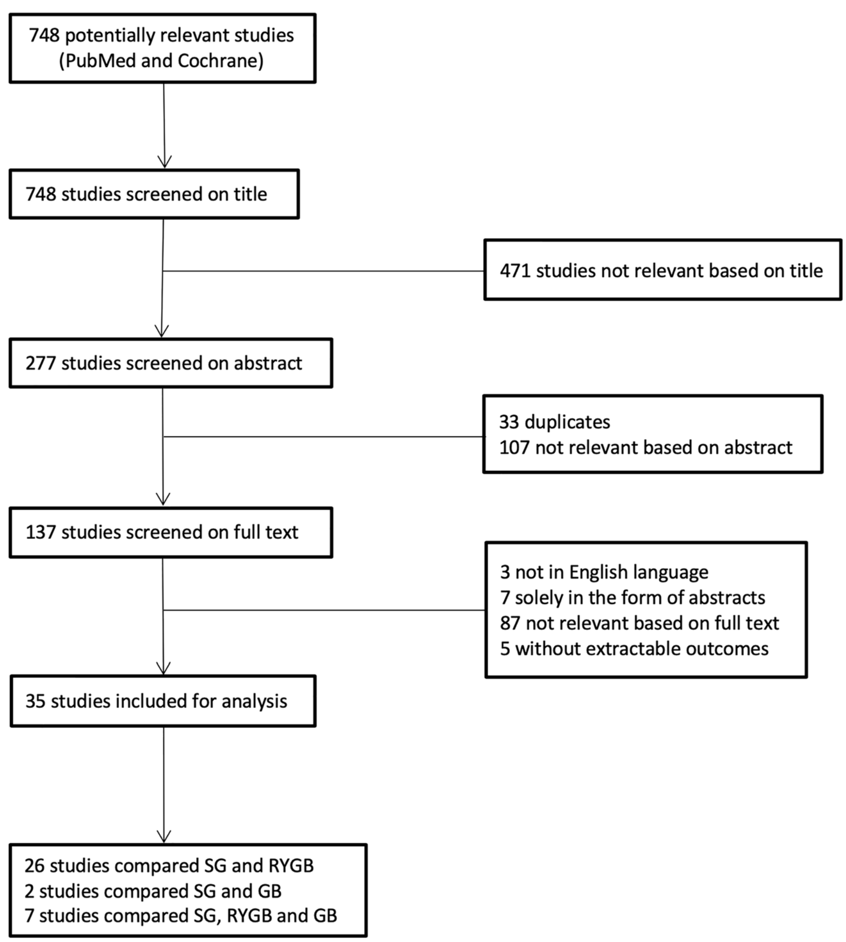


Table 2: Overview of the inclusion and exclusion criteria for the comparison between SG and RYGB

SG-RYGB	Year	T2DM population		Type	Rem. crit.	Female gender (%)		Age (y)		Baseline BMI		T2DM duration (y)	
		SG	RYGB			SG	RYGB	SG	RYGB	SG	RYGB	SG	RYGB
Benaiges et al. [28]	2013	20	29	PCT	ADA	76.9	87.8	45.6 ± 9	45.0 ± 8.6	43.9 ± 5.0	45.8 ± 4.3	1.5 ± 2	1.3 ± 2
Casajoana et al. [29]	2017	14	15	RCT	ADA	66.7	53.3	49.20 ± 9.16	51.10 ± 7.70	38.7 ± 2.01	39.0 ± 1.68	10	4.5
Cutolo et al. [30]	2012	15	15	RS	MC	53.3	56.3	45 ± 7	45 ± 8	51 ± 8		> 1 (3 ± 2)	
De Gordejuela et al. [31]	2011	30	60	RS	MC	-	-	47 (31-62)	51 (37-59)	56.8	46.2	4	5
Dicker et al. [32]	2016	845	116	RS	OC	61.0	71.0	47.7 ± 10.8	47.4 ± 9.5	43.6 ± 6.4	42.4 ± 5.6	-	-
Gan et al. [33]	2007	21	39	PS	MC	61.9	46.2	-	-	52.8	43.5	-	-
Gray et al. [34]	2018	33	47	RS	OC	59.0		65 (60-74)	63 (60-75)	44.4 ± 6.3	43.6 ± 5.9	-	-
Hariri et al. [35]	2018	88	30	RS	OC	75.3		52.3 ± 12.2		43.8 ± 7.8		-	-
Haruta et al. [36]	2017	65	13	RS	ADA	56.0		41		42		-	-
Hong et al. [37]	2018	9	8	RS	OC	44.3	67.3	43.65 ± 16	44.58 ± 12	55.21 ± 8	57.7 ± 9.2	-	-
Inabnet et al. [38]	2012	406	7285	RS	MC	78		45.5 ± 11.76		48.6 ± 9.03	47.6 ± 7.9	-	-
Jimenez et al. [39]	2012	55	98	RCS	OC	52.0	68.0	52.4 ± 9.1	49.6 ± 8.2	49.8 ± 7.2	44.8 ± 4.6	5.6 ± 5	6.1 ± 5
Jimenez et al. [40]	2015	111	121	RCS	OC	58.6	69.4	53.3 ± 9.6	49.6 ± 8.2	47.5 ± 7.1	44.5 ± 4.9	5	4
Keidar et al. [41]	2013	18	19	RCT	MC	50.0	40.0	47.7 ± 11.7	51.45 ± 8.3	42.5 ± 5.2	42 ± 4.8	6.7 ± 5	5.4 ± 5
Lemus et al. [42]	2018	261	1786	RCS	MC	-	-	-	-	-	-	-	-
Mas-Lorenzo et al. [43]	2014	21	34	PCS	ADA	76.1	82.3	50.6 ± 7.2	49.0 ± 6.0	45.2 ± 5.8	45.5 ± 4.3	1.5 ± 2	1.1 ± 2
Menguer et al. [44]	2017	11	14	RCS	Hb	66.7	81.0	41.0 ± 11.5	40.9 ± 10.6	45.6 ± 8.0	43.1 ± 5.2	-	-
Mohos et al. [45]	2011	13	10	RS	MC	74.5	74.5	46 ± 9.22	38.8 ± 10.42	50.3 ± 9.70	46.1 ± 5.78	-	-
Murphy et al. [46]	2018	53	56	RCT	Hb	45.0	59.0	45.5 ± 6.4	46.6 ± 6.7	BMI 43 ± 6		> 0.5	
Nocca et al. [18]	2011	33	35	PS	MC	63.6	80.0	46.49	47.52	50.618	47.921	7.9	7.8
Nosso et al. [47]	2016	19	14	PS	ADA	57.9	57.1	44 ± 10	49 ± 7	46 ± 9	42 ± 6	4 ± 4	5 ± 5
Peterli et al. [48]	2017	26	28	RCT	ADA	72.0	72.0	43 ± 5.3		43.6 ± 5.3	44.2 ± 5.3	-	-
Pournaras et al. [49]	2012	19	160	RS	ADA	57.9	65.6	53 ± 14	47 ± 9	50 ± 8	48 ± 7	-	-
Robert et al. [50]	2013	9	26	RS	ADA	56.0	64.0	51.1 ± 3.5	46.9 ± 1.8	49.5 ± 1.22		3.0	4.0
Salminen et al. [51]	2018	41	40	RCT	ADA	71.9	76.2	48.5 ± 9.6	48.4 ± 9.3	45.5 ± 6.2	46.4 ± 5.9	-	-
Stallard et al. [52]	2017	8	69	RCS	MC	77.8		49.7 ± 1.7		49.7 (48.1–51.1)		-	-
Thereaux et al. [53]	2015	39	90	RS	Hb	64.9	73.7	45.5 ± 13.7	40.9 ± 12.2	57.2 ± 7.1	56.7 ± 5.5	-	-
Vidal et al. [54]	2008	39	52	PS	MC	59.0	67.3	49.9 ± 1.5	49.3 ± 1.3	51.9 ± 1.2	47.7 ± 0.7	-	-
Vitello et al. [55]	2016	31	24	RS	OC	27.5	20.6	55	51.6	44.2	47	-	-
Wallenius et al. [56]	2017	15	17	RS	MC	-	-	51.9 ± 1.9	51.2 ± 1.6	36.9 ± 0.7	38.6 ± 0.8	6.5 ± 1	5.7 ± 0.6
Yaghoubian et al. [57]	2012	42	112	RS	MC	-	-	48	46	43	47	-	-
Zenti et al. [58]	2015	17	77	PS	ADA	64.7	58.4	49 ± 11	50 ± 8	50.2 ± 8.8	45.7 ± 6.8	-	-
Zhang et al. [59]	2013	29	58	PS	MC	71.0	79.1	44.2 ± 11.8	47.5 ± 18.5	47.9 ± 10.2	46.1 ± 7.1	-	-
TOTAL		2 456	10 597										

Rem. crit., remission criteria; *PCT*, prospective cohort study; *CCT*, case-control study; *RCT*, randomised controlled trial; *RS*, retrospective study; *PS*, prospective study; *RCS*, retrospective cohort study; *RR*, retrospective review; *ADA*, American Diabetes Association; *MC*, medication cessation; *OC*, other criteria; *Hb*, HbA1c < 6.5%

presented at congresses of which no full text could be found, 5 studies did not describe extractable outcomes and 3 studies were not written in English. Therefore, out of an initial 748 studies, only 35 articles fully complied with the inclusion and exclusion criteria and were included in this meta-analysis (Fig. 1).

Study Characteristics

Five RCTs, 8 prospective studies and 22 retrospective studies comprising a total of 18,138 diabetic patients were included in this meta-analysis (Tables 2 and 3). All patients included in this review were followed for at least 1 year after the bariatric procedure, had an age above 18 years and a BMI above 35 kg/m^2. Only 2480 patients (13.67%) underwent a SG. Remission rates of these patients were compared with patients undergoing a RYGB (n = 10,597; 58.42%) or GB (n = 5061; 27.90%).

In general, weight loss was reported as the percentage of excess weight loss (EWL), percentage excess BMI loss or total weight loss. Compared to the SG, patients undergoing a RYGB tended to lose more weight during the first year after surgery. Fifteen studies reported on EWL between the SG and the RYGB at 12 months of follow-up [18, 30, 31, 33, 34, 36, 37, 44, 47, 50, 53, 54, 56, 57, 59]. The RYGB remained superior in terms of weight loss, with 13 out of 15 studies reporting higher percentage of EWL for RYGB. Eventually, the difference between RYGB and SG became less distinct in the subsequent years in 4 studies, and these studies even demonstrated higher EWL in the SG group [30, 31, 34, 37]. Finally, 4 studies which reported on weight loss between SG and GB showed better weight loss with SG [33, 50, 60, 61].

Remission of Type 2 Diabetes Mellitus

The primary analysis, comparing SG to RYGB at 1-year follow-up, included 2018 SG patients and 9926 RYGB patients. When analysing outcomes independent of the used definition of T2DM remission, this meta-analysis demonstrated T2DM remission to occur significantly less often after SG compared to RYGB (OR 0.71, 95% CI [0.56–0.89], p = 0.003). The absolute difference between studies at this moment was however limited, with remission achieved in 56.29% of patients after SG and 60.91% after RYGB. Subsequently, these studies were stratified based on the criteria used to define T2DM remission (Fig. 2). While RYGB still appeared to be superior to SG in terms of T2DM remission, when defined by the ADA-criteria (HbA1c < 6.0% and fasting plasma glucose < 100 mg/dl without the use of antidiabetic medication for at least 1 year) or by an HbA1c cut-off of 6.5% (48 mmol/mol), these differences were not statistically significant. In contrast, cessation of antidiabetic drugs was significantly more frequent following RYGB compared to SG (OR 0.73, 95% CI [0.55–0.96], p = 0.03). Some studies also reported T2DM remission rates after more than 1 year of follow-up (Fig. 3). Analysis of these studies again demonstrated significantly lower T2DM remission rates after SG when compared to RYGB (OR 0.76, 95% CI [0.62–0.94], p = 0.01. Noteworthy, currently few studies have published long-term T2DM remission outcomes, reducing power beyond 3 years of follow-up.

The secondary analysis comparing SG and GB at 1-year follow-up included 1295 SG patients and 5005 GB patients. This analysis demonstrated a significant difference of T2DM remission in favour of SG (OR 2.17, 95% CI [1.36–3.47], p = 0.001; Fig. 4). Beyond 1 year of follow-up, a separate

Table 3 Overview of the inclusion and exclusion criteria for the comparison between SG and GB

	Year	T2DM population		Type	Rem. crit.	Female gender (%)		Age (y)		Baseline BMI		T2DM duration (y)	
SG-GB		SG	GB			SG	GB	SG	GB	SG	GB	SG	GB
Dicker et al. [32]	2016	845	724	RS	OC	61.0	67.9	47.7 ± 10.8	46.5 ± 10.8	43.6 ± 6.4	43.5 ± 6.2	-	-
Gan et al. [33]	2007	21	12	PS	MC	61.9	83.3	-	-	52.8	45.6	-	-
Haruta et al. [36]	2017	65	9	RS	ADA	56.0		41		42		-	-
Inabnet et al. [38]	2012	406	4245	RS	MC	78.0		45.5 ± 12		48.6 ± 9	45 ± 7	-	-
Omana et al. [60]	2010	14	13	RR	OC	73.5	78.4	45 ± 12	41 ± 14	52 ± 11	44 ± 5	-	-
Pournaras et al. [49]	2012	19	30	RS	ADA	57.9	70.0	53 ± 14	46 ± 10	50 ± 8	47 ± 9	-	-
Robert et al. [50]	2013	9	11	RS	ADA	56.0	73.0	51.1 ± 3.5	36.8 ± 3.4	49.5 ± 1.22		3.0	2.0
Vitiello et al. [61]	2018	10	6	RS	OC	67.2	67.2	36 ± 10	36 ± 10	45.27 ± 3.6	45.34 ± 4	-	-
Zenti et al. [58]	2015	17	11	PS	ADA	64.7	90.9	49 ± 11	47 ± 10	50.2 ± 8.8	42.3 ± 8	-	-
TOTAL		1406	5061										

Rem. crit., remission criteria; *PCT*, prospective cohort study; *CCT*, case-control study; *RCT*, randomised controlled trial; *RS*, retrospective study; *PS*, prospective study; *RCS*, retrospective cohort study; *RR*, retrospective review; *ADA*, American Diabetes Association; *MC*, medication cessation; *OC*, other criteria; *Hb*, HbA1c < 6.5%

Study or Subgroup	SG Events	SG Total	RYGB Events	RYGB Total	Weight	Odds Ratio IV, Random, 95% CI
1.1.1 ADA-Criteria						
Casajoana 2017	8	15	12	15	1.8%	0.29 [0.06, 1.45]
Nosso 2016	14	19	12	14	1.5%	0.47 [0.08, 2.86]
Robert 2013	4	9	19	26	1.9%	0.29 [0.06, 1.42]
Subtotal (95% CI)		**43**		**55**	**5.2%**	**0.33 [0.13, 0.86]**
Total events	26		43			
Heterogeneity: Tau² = 0.00; Chi² = 0.19, df = 2 (P = 0.91); I² = 0%						
Test for overall effect: Z = 2.26 (P = 0.02)						
1.1.2 HbA1c<6.5						
Menguer 2017	5	11	12	14	1.3%	0.14 [0.02, 0.94]
Murphy 2018	38	53	42	56	5.3%	0.84 [0.36, 1.98]
Thereaux 2015	18	39	63	90	6.0%	0.37 [0.17, 0.80]
Subtotal (95% CI)		**103**		**160**	**12.7%**	**0.45 [0.20, 1.02]**
Total events	61		117			
Heterogeneity: Tau² = 0.24; Chi² = 3.77, df = 2 (P = 0.15); I² = 47%						
Test for overall effect: Z = 1.91 (P = 0.06)						
1.1.3 Medication cessation						
Cutolo 2012	13	15	14	15	0.8%	0.46 [0.04, 5.75]
de Gordejuela 2011	24	30	55	60	2.8%	0.36 [0.10, 1.31]
Gan 2007	7	21	27	39	3.4%	0.22 [0.07, 0.69]
Inabnet 2012	211	406	4532	7285	16.7%	0.66 [0.54, 0.80]
Keidar 2013	14	18	9	19	2.3%	3.89 [0.93, 16.26]
Lemus 2018	104	261	905	1786	15.2%	0.64 [0.49, 0.84]
Mohos 2011	7	13	9	10	0.9%	0.13 [0.01, 1.34]
Nocca 2011	25	33	21	35	3.9%	2.08 [0.73, 5.92]
Stallard 2017	6	8	46	69	1.7%	1.50 [0.28, 8.02]
Vidal 2008	33	39	44	52	3.3%	1.00 [0.32, 3.16]
Wallenius 2017	9	15	10	17	2.3%	1.05 [0.26, 4.32]
Yaghoubian 2012	31	42	87	112	5.6%	0.81 [0.36, 1.84]
Zhang 2013	17	29	38	58	4.7%	0.75 [0.30, 1.86]
Subtotal (95% CI)		**930**		**9557**	**63.6%**	**0.73 [0.55, 0.96]**
Total events	501		5797			
Heterogeneity: Tau² = 0.06; Chi² = 18.93, df = 12 (P = 0.09); I² = 37%						
Test for overall effect: Z = 2.24 (P = 0.03)						
1.1.4 Other Criteria						
Dicker 2016	494	845	68	116	12.2%	0.99 [0.67, 1.47]
Hariri 2018	48	88	14	30	5.5%	1.37 [0.60, 3.15]
Hong 2018	6	9	7	8	0.8%	0.29 [0.02, 3.52]
Subtotal (95% CI)		**942**		**154**	**18.5%**	**1.03 [0.72, 1.46]**
Total events	548		89			
Heterogeneity: Tau² = 0.00; Chi² = 1.49, df = 2 (P = 0.47); I² = 0%						
Test for overall effect: Z = 0.15 (P = 0.88)						
Total (95% CI)		**2018**		**9926**	**100.0%**	**0.71 [0.56, 0.89]**
Total events	1136		6046			
Heterogeneity: Tau² = 0.07; Chi² = 33.27, df = 21 (P = 0.04); I² = 37%						
Test for overall effect: Z = 2.95 (P = 0.003)						
Test for subgroup differences: Chi² = 7.36, df = 3 (P = 0.06), I² = 59.3%						

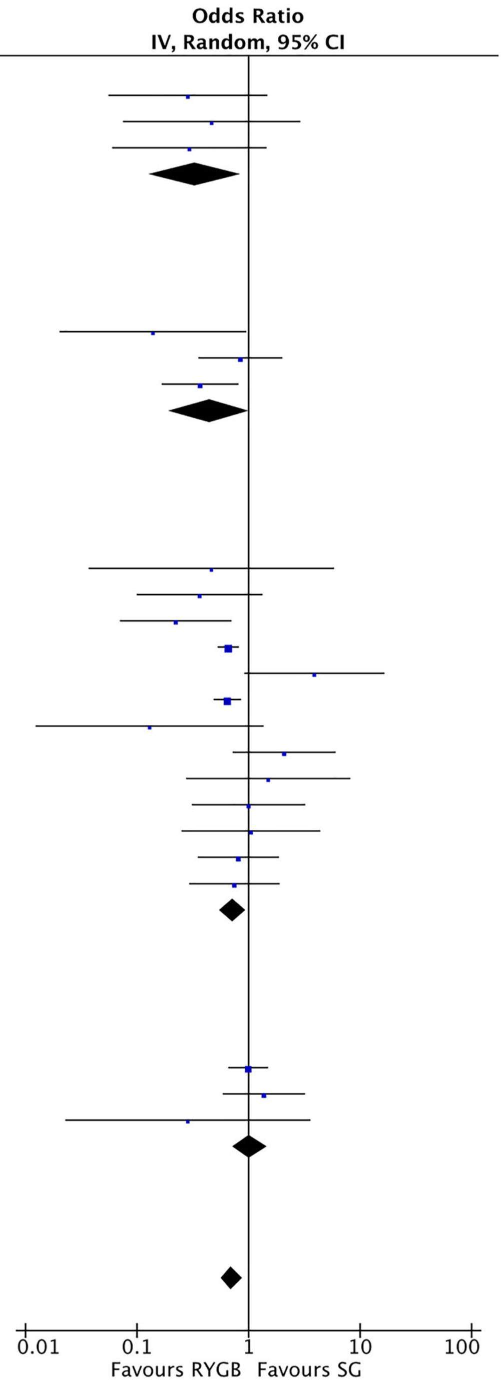


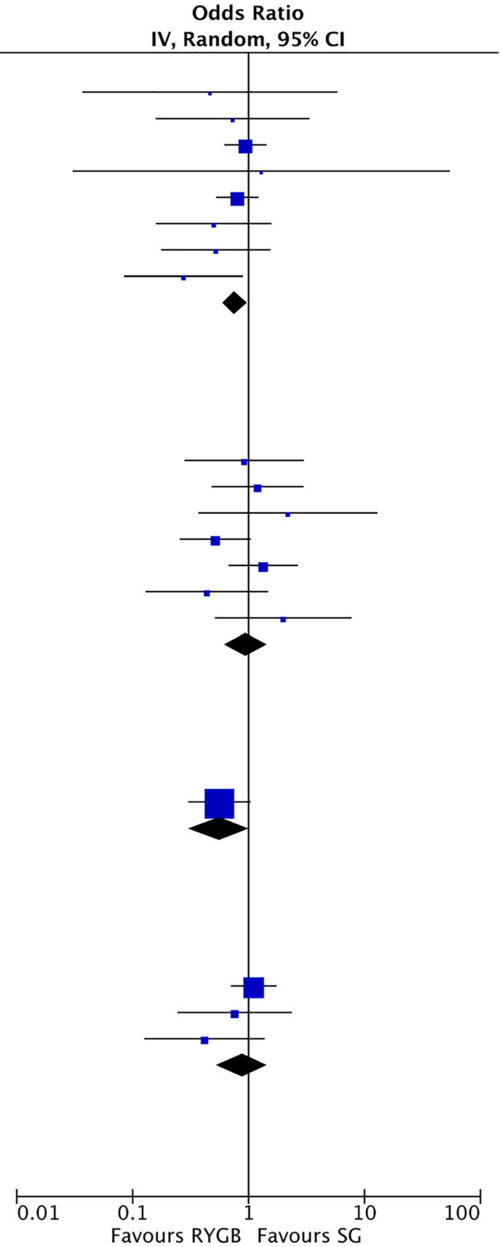
Fig. 2 Meta-analysis of T2DM remission criteria between SG and RYGB at 1 year of follow up stratified by remission criteria

analysis, with inclusion of 991 SG patients and 873 GB patients, also indicated T2DM remission to occur significantly (OR 3.16, 95% CI [1.22–8.18], $p = 0.02$) more often after SG than following the GB (Fig. 5). After analysis of the patient characteristics in these cohorts, however, a disparity in BMI/disease severity was observed, with the GB group having lower BMI, shorter duration of T2DM or younger age than the SG group.

Discussion

Obesity is becoming more and more a global concern and is expected to significantly impact future healthcare because of the multiple comorbidities associated with morbid obesity [62, 63]. One of these comorbidities, T2DM, has been well described to improve after RYGB procedures. While similar effects of SG have been reported, the extent of this

Study or Subgroup	SG Events	SG Total	RYGB Events	RYGB Total	Weight	Odds Ratio IV, Random, 95% CI
1.2.1 2 years						
Cutolo 2012	13	15	14	15	1.0%	0.46 [0.04, 5.75]
de Gordejuela 2011	24	27	55	60	2.8%	0.73 [0.16, 3.29]
Dicker 2016	554	880	76	118	40.3%	0.94 [0.63, 1.40]
Hong 2018	1	1	3	4	0.5%	1.29 [0.03, 53.51]
Lemus 2018	52	106	488	893	39.9%	0.80 [0.53, 1.20]
Mas-Lorenzo 2014	7	21	17	34	5.1%	0.50 [0.16, 1.55]
Pournaras 2012	5	19	65	160	5.7%	0.52 [0.18, 1.52]
Vitello 2016	14	31	18	24	4.8%	0.27 [0.09, 0.88]
Subtotal (95% CI)		**1100**		**1308**	**100.0%**	**0.77 [0.60, 0.99]**
Total events	670		736			
Heterogeneity: Tau² = 0.00; Chi² = 5.30, df = 7 (P = 0.62); I² = 0%						
Test for overall effect: Z = 2.04 (P = 0.04)						
1.2.2 3 years						
Benaiges 2013	12	20	18	29	11.0%	0.92 [0.29, 2.95]
Gray 2018	19	33	25	47	16.5%	1.19 [0.49, 2.93]
Haruta 2017	60	65	11	13	5.4%	2.18 [0.37, 12.70]
Jimenez 2012	31	55	70	98	23.6%	0.52 [0.26, 1.03]
Lemus 2018	22	38	215	424	24.4%	1.34 [0.68, 2.62]
Peterli 2017	16	26	22	28	10.5%	0.44 [0.13, 1.45]
Zenti 2015	14	17	54	77	8.7%	1.99 [0.52, 7.58]
Subtotal (95% CI)		**254**		**716**	**100.0%**	**0.95 [0.62, 1.46]**
Total events	174		415			
Heterogeneity: Tau² = 0.08; Chi² = 7.87, df = 6 (P = 0.25); I² = 24%						
Test for overall effect: Z = 0.23 (P = 0.82)						
1.2.3 4 years						
Jimenez 2015	77	111	97	121	100.0%	0.56 [0.31, 1.02]
Subtotal (95% CI)		**111**		**121**	**100.0%**	**0.56 [0.31, 1.02]**
Total events	77		97			
Heterogeneity: Not applicable						
Test for overall effect: Z = 1.89 (P = 0.06)						
1.2.4 5 years						
Dicker 2016	372	694	47	92	66.1%	1.11 [0.72, 1.71]
Peterli 2018	16	26	19	28	17.7%	0.76 [0.25, 2.32]
Salminen 2018	5	41	10	40	16.2%	0.42 [0.13, 1.35]
Subtotal (95% CI)		**761**		**160**	**100.0%**	**0.88 [0.53, 1.47]**
Total events	393		76			
Heterogeneity: Tau² = 0.05; Chi² = 2.51, df = 2 (P = 0.29); I² = 20%						
Test for overall effect: Z = 0.48 (P = 0.63)						



Test for subgroup differences: Chi² = 2.21, df = 3 (P = 0.53), I² = 0%

Fig. 3 Meta-analysis of T2DM remission rate between SG and RYGB beyond 1 year of follow up stratified by years of follow up

Study or Subgroup	SG Events	SG Total	GB Events	GB Total	Weight	Odds Ratio IV, Random, 95% CI
Dicker 2016	494	845	334	724	42.9%	1.64 [1.35, 2.01]
Gan 2007	7	21	2	12	6.1%	2.50 [0.43, 14.66]
Inabnet 2012	211	406	1206	4245	42.7%	2.73 [2.22, 3.35]
Omana 2010	14	14	6	13	2.3%	33.46 [1.65, 677.83]
Robert 2013	4	9	5	11	6.1%	0.96 [0.16, 5.64]
Total (95% CI)		**1295**		**5005**	**100.0%**	**2.17 [1.36, 3.47]**
Total events	730		1553			
Heterogeneity: Tau² = 0.12; Chi² = 15.99, df = 4 (P = 0.003); I² = 75%						
Test for overall effect: Z = 3.24 (P = 0.001)						

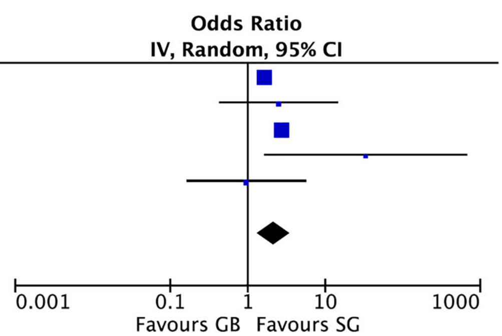


Fig. 4 Meta-analysis of T2DM remission rate between SG and GB at 1 year of follow up

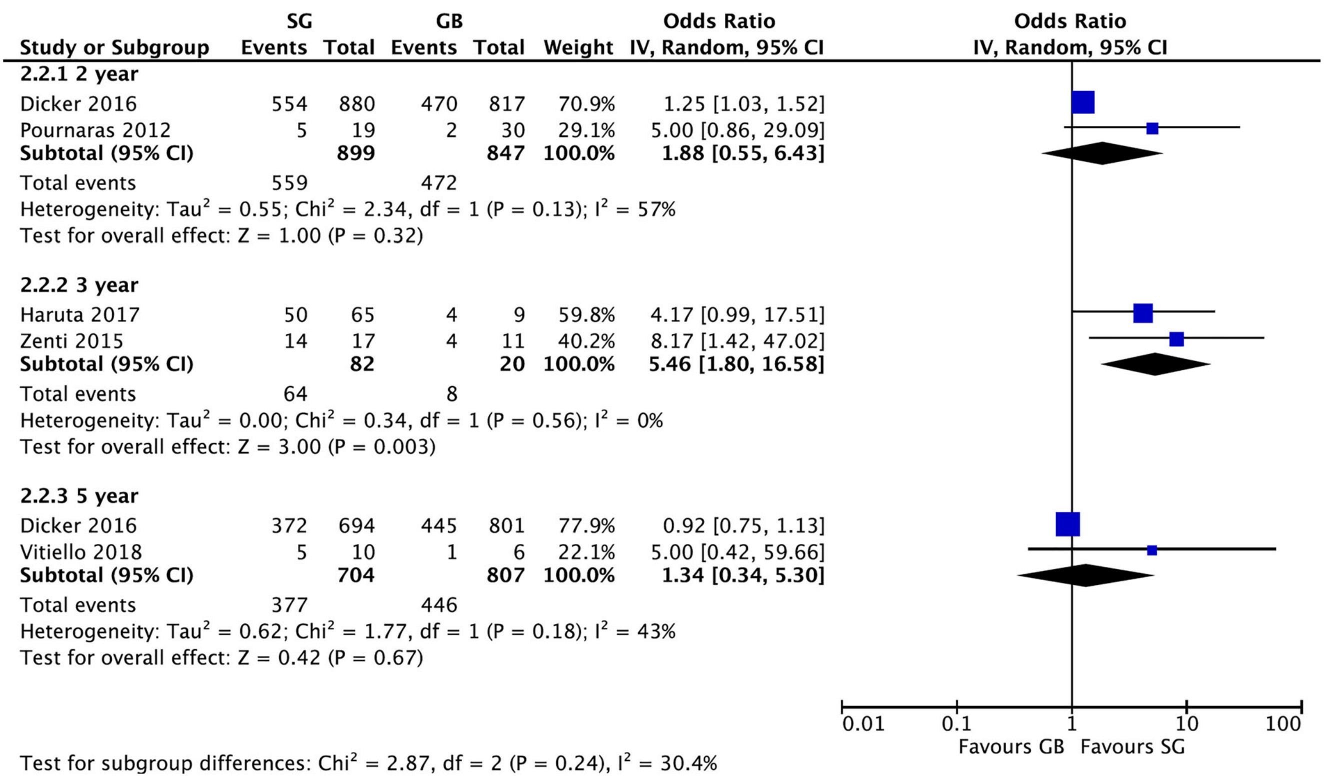


Fig. 5 Meta-analysis of T2DM remission rate between SG and GB beyond 1 year of follow up

improvement of T2DM in comparison to other bariatric procedures remains debatable. With the current study, we aimed to evaluate the effect of SG on T2DM remission in patients suffering from morbid obesity in comparison with the RYGB and secondarily with the GB.

In this systematic review, despite strict inclusion and exclusion criteria, a large number of studies could be included. Our results demonstrated significantly lower overall T2DM remission rates after SG compared to RYGB at 1-year of follow-up. However, beyond 1 year, no significant differences between SG and the RYGB could be observed. Additionally, the criteria used to describe T2DM remission had an important effect on the results. Only the criteria medication cessation showed a significant difference of T2DM remission, whereas the ADA criteria, HbA1c < 6.5% and other criteria did not produce significant results. SG was superior to GB in terms of T2DM remission.

Our results clearly demonstrate the conflicting outcomes of current literature concerning T2DM remission after SG, and unfortunately also suggest the lack of large, multicentre, prospective studies.

Previously, four RCT's compared SG and RYGB. None of these studies was able to demonstrate a significant difference on T2DM remission 1 year after surgery [41, 46, 51, 64]. Similarly, in another review containing 29 studies, Li et al. reported higher remission following RYGB, but compared to the SG, this result was not significant [65]. On the other hand, different studies and meta-analyses reported remarkably better T2DM remission rates for RYGB compared to those achieved after SG [66–68]. Melissas et al. [68] could demonstrate significantly better T2DM remission rates after RYGB in the early postoperative period and up to 5 years after surgery.

Several factors are responsible for the lack of consensus regarding the comparison of the effects on of the RYGB and SG on T2DM remission [69, 70]. Firstly, although these procedures are technically different and exhibit different metabolic effects, they do share common pathways in which they improve glucose tolerance. Both procedures restrict food intake and limit the amount of glucose absorbed [69–72]. Insulin resistance is reduced following both procedures and frequently normalises with gradual loss of visceral adiposity. Both procedures significantly alter the incretin secretion [70, 71, 73]. The difference in terms of weight loss between both procedures is quite similar, and although SG is generally considered to cause less weight loss, this difference is unlikely to influence T2DM remission rates; most patients already achieve T2DM remission before stabilisation of their body weight [69]. Furthermore, a recent study from the Cleveland Clinic, which categorised patients in three different groups according to a severity score, described similar outcomes between SG and RYGB in the mild and severe group, which is in line with our results. However, in the intermediate group, higher remission rates after RYGB were described. This result was attributed to a likely more pronounced neurohormonal effect after RYGB [74].

There are, however, several other factors that can explain the important heterogeneity between studies. Although this review included 37 studies, with a total of 18,226 patients, the number of patients that underwent a SG was relatively low. As a result, several studies only included a small number of SG procedures, and thus these studies had limited power. Due to the recent gain of popularity of the SG, we expected a limited amount of studies, small sample sizes and significant heterogeneity between studies. Therefore, we opted for stringent inclusion and exclusion criteria, stratified our study cohort based upon the used definitions of remission and analysed our results using a random-effects model. Nevertheless, heterogeneity undoubtedly remains the main limitation of this meta-analysis and necessitates future large, prospective studies.

Other factors that presumably have increased heterogeneity between and within studies are patient- and surgery-related characteristics, including geographic differences, different surgical techniques, differences in postoperative management and follow-up, dietary differences and other ways of defining T2DM remission. Finally, because RYGB is generally associated with T2DM remission, a selection bias cannot be ruled out. Patients with better prognostic parameters, like a healthier lifestyle, shorter duration of diabetes or limited antidiabetic therapy requirements, could therefore be favoured to undergo a SG instead of a RYGB. Furthermore, about 5 to 10 years ago, many patients who underwent SG tended to have more severe obesity and were operated with the intention to undergo a second stage procedure later on, which can be considered as a potential selection bias influencing the older studies.

In conclusion, the current study suggests that T2DM remission is less frequently achieved following SG compared to RYGB. In an overall analysis, independent of the way T2DM was defined, RYGB performed significantly better compared to SG. However, after stratification of studies based on the definition of remission and duration of follow-up, no significant difference between SG an RYGB could be observed. Therefore, at this moment, there is no clear supporting evidence to choose one procedure over the other. In fact, the absolute difference in remission between both procedures is minimal and presumably other factors, like gastroesophageal reflux disease, dietary habits, patient preferences and surgical possibilities should direct the choice between a SG or RYGB. SG does reach a higher rate of T2DM remission in comparison to GB.

Finally, more importantly, this review demonstrates current literature comparing these procedures are limited, large cohort studies are lacking and the long-term effects of SG on T2DM remission are virtually unexplored. Further research is therefore necessary in order to determine the definite role of SG in patients suffering from obesity and T2DM.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed Consent For this type of study, formal consent is not required.

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