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ORIGINAL CONTRIBUTIONS

Comparative Efficacy of Bariatric Surgery in the Treatment of Morbid Obesity and Diabetes Mellitus: a Systematic Review and Network Meta-Analysis

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Abstract

Introduction The comparative efficacy of various bariatric procedures has not been completely elucidated. We aimed to evaluate efficacy and safety of various bariatric procedures comprehensively.

Methods We searched for randomized controlled trials investigating the efficacy of bariatric surgery. Network meta-analyses were performed to determine the percentage of excess weight loss (%EWL) and remission of diabetes mellitus (DM).

Results Of 45 studies, 33 and 24 provided the data for %EWL and DM remission rates, respectively. Six months after surgery, biliopancreatic diversion with duodenal switch (BPD-DS), Roux-en-Y gastric bypass (RYGB), and sleeve gastrectomy (SG) showed superior efficacy for %EWL compared to the standard-of-care (mean difference [MD], [95% confidence interval [CI]]: BPD-DS, 38.2% [7.3%, 69.1%]; RYGB, 32.1% [3.1%, 61.1%]; SG, 32.5% [5.5%, 59.5%]). However, adjustable gastric banding was not superior to standard-of-care (MD [95% CI] = − 0.2% [− 19.6%, 19.2%]). At 1 year, all bariatric procedures were superior to standard-of-care. At 3 years, RYGB and SG showed superior efficacy when compared to standard-of-care (MD [95% CI]: RYGB, 45.0% [21.8%, 68.2%]; SG, 39.2% [15.2%, 63.3%]). With respect to DM remission 3–5 years after surgery, BPD-DS, RYGB, and SG were superior to standard-of-care. Hernias, obstruction/stricture, bleeding, and ulcers were less common in patients who underwent SG than in those who underwent RYGB.

Conclusions RYGB and SG had excellent long-term outcomes for both the %EWL and DM remission rates. Additionally, SG had a relatively lower risk of adverse events than RYGB.

Chan Hyuk Park and Seung-Joo Nam contributed equally to this work.

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Keywords Bariatric surgery · Metabolic surgery · Excessive weight loss · Diabetes · Network meta-analysis

Introduction

As the prevalence of obesity and its comorbidities increases, so do the number of bariatric surgeries [1, 2]. Historically, there are six dominant bariatric surgical techniques that chronologically include jejunoileal bypass, Roux-en-Y gastric bypass (RYGB), vertical-banded gastroplasty (VBG), biliopancreatic diversion with duodenal switch (BPD-DS), adjustable gastric-banding (AGB), and sleeve gastrectomy (SG) [3]. Overall, bariatric surgery results in approximately a 55% loss of excess weight [4]. In a previous systematic review and meta-analysis, weight reduction was greatest for BPD-DS followed by RYGB, gastroplasty, and AGB [4].

Although bariatric surgery was originally developed for weight reduction, it has also been known to be effective in reducing the risk of type 2 diabetes mellitus (DM) and cardiovascular diseases [5–7]. In patients who underwent bariatric surgery, however, it is not clear whether the effect of reducing the risk of metabolic diseases is correlated with weight change. In the STAMPEDE trial, for example, DM remission rates did not differ between patients who underwent RYGB and those who underwent SG, while body mass index (BMI) reduction was greater in patients who underwent RYGB than for those who underwent SG [8].

Until now, many head-to-head trials on various bariatric surgeries have been reported. For example, there have been studies comparing RYGB vs. BPD-DS [9–11], RYGB vs. SG [8, 12–26], RYGB vs. AGB [27, 28], and SG vs. AGB [29]. In this situation, direct comparison alone between any two treatment methods does not provide a comprehensive understanding. Therefore, we need to perform a network meta-analysis for all relevant trials, to fully analyze each pair-wise comparison [30]. Using the network meta-analysis, direct evidence from studies directly comparing treatment methods of interest, and indirect evidence from studies comparing treatment methods of interest with a common comparator can be combined [31]. Additionally, the precision of a mixed estimate (from direct and indirect estimates) is usually better than that of a direct or indirect estimate alone [31].

Here, we searched for all the published randomized controlled trials (RCTs) on bariatric surgery for patients with morbid obesity. A network meta-analysis was then performed to calculate the indirect and mixed estimates (from direct and indirect estimates) for evaluating the comparative efficacy of each bariatric procedure in terms of weight loss and DM remission.

Methods

This systematic review and network meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [32] and the report of the International Society for Pharmacoeconomics and Outcomes Research Task Force on Indirect Treatment Comparisons Good Research Practices [33].

Search Strategy

We searched for all relevant studies published between January 1990 and February 27, 2018 that investigated the efficacy of bariatric surgery using MEDLINE, EMBASE, and the Cochrane Library databases. The following search string was used: (((bariatric) OR (metabolic surgery) OR (weight loss surgery) OR (Roux-en-Y) OR (restrictive bypass) OR (gastric bypass) OR (gastrojejunal bypass) OR (gastro-jejunal bypass) OR (gastroileal bypass) OR (gastro-ileal bypass) OR (duodenojejunal bypass) OR (duodeno-jejunal bypass) OR (duodenoileal bypass) OR (duodeno-ileal bypass) OR (sleeve gastrectomy) OR (gastric band*) OR (intragastric band*) OR (gastroplast*) OR (gastric balloon*) OR (vertical band*) OR (lapband*) OR (lap-band*) OR (adjustable band*) OR (gastric belt*) OR (gastric bubble) OR (gastric partition) OR (stomach stapling) OR (biliopancreatic diversion) OR (duodenal switch)) OR (((obesity) OR (obese) OR (overweight)) AND (surgery))) AND (random*). The detailed search strategies for each database are shown in Appendix 1. In order to identify additional studies, we also examined references of the screened articles.

Study Selection

As the first step of our study selection, the titles and abstracts of articles retrieved by our keyword search were examined to exclude irrelevant articles. The full texts of all the selected studies were then screened according to our inclusion and exclusion criteria. The inclusion criteria were as follows: (a) patients: patients who underwent bariatric surgery, (b) intervention: bariatric surgery, (c) comparator: another method of bariatric surgery or standard-of-care without bariatric surgery, and (d) outcome: % excess weight loss (% EWL) from 6 months to 5 years and type 2 DM remission rate from 1 to 5 years. The exclusion criteria included (a) non-original studies, (b) non-RCTs, (c) non-human studies, (d) unpublished studies, and (e) non-English publications.

Two investigators (C. H. P. and S. N.) independently evaluated the studies for eligibility and resolved any disagreements through discussion and consensus. If an agreement could not be reached, a third investigator (H. L. L.) determined the study eligibility. The Cochrane Risk of Bias assessment tool was used for assessing the risk of bias in individual studies.

Data Extraction

Using a data extraction form developed in advance, two reviewers (C. H. P. and S. N.), independently extracted the following information: the first author, year of publication, study design, country, study period, publication language, eradication regimens, the number of study participants, % EWL, DM remission rate, and adverse events. The definition of DM remission in each study was also extracted. DM remission was usually defined as normalization of serum glucose parameters without glycemic therapy.

The primary endpoint of this meta-analysis was the comparative efficacy of bariatric surgery in terms of %EWL and DM remission rate. The secondary endpoint was the adverse event of bariatric surgery. Standard-of-care group including lifestyle modification and medication was regarded as a control group.

Statistical Analysis

Direct pairwise meta-analysis was conducted to calculate the pooled mean difference (MD) of %EWL or the risk ratio (RR) of DM remission using a random effects model. Statistical heterogeneity was assessed using two methods: Cochrane's Q test, which was considered statistically significant for heterogeneity if P was < 0.1, and I^2 statistics, wherein values $> 50\%$ suggested significant heterogeneity [34]. The test for funnel plot asymmetry was not conducted when the number of included studies for each pairwise comparison was less than 10 [35]. Direct pairwise meta-analysis was performed using Review Manager 5.3 statistical software (version 5.3.5; Cochrane Collaboration, Copenhagen, Denmark).

A frequentist network meta-analysis was performed to calculate the direct and indirect estimates and to combine the mixed estimates [36]. A network meta-analysis was conducted using R statistical software (version 3.5.1s; R Foundation for Statistical Computing, Vienna, Austria) with the *netmeta* package (version 0.9-1; Rücker et al.). The *netmeta* package is based on the graph theory methodology to model the relative treatment effects of multiple treatments under a frequentist framework [37].

Results

Study Selection

A flow diagram for our systematic review is shown in Fig. 1. Our literature search identified 9418 studies. After scanning the titles and abstracts, we discarded 2309 duplicate articles, which were retrieved through multiple search engines. Another 6948 irrelevant articles were excluded based on the titles and abstracts. After the full texts of the 161 remaining articles were reviewed, 116 were excluded because of the following reasons: (a) 4 non-original articles, (b) 12 non-RCTs, (c) 1 study that did not describe specific methods of bariatric surgery, (d) 4 studies on comparisons between open vs. laparoscopic techniques, (e) 64 studies that did not report relevant outcomes, (f) 23 studies with cohort overlap, and (g) 8 studies with unavailable full-texts. As a result, 45 studies were included in the network meta-analysis [5, 8–29, 38–59].

In this meta-analysis, weight loss was expressed as % EWL, with the calculation of ideal body weight as that equivalent to a BMI of 25 kg/m^2. However, lost to follow-up information could not be shown because not all included studies reported it.

Study Characteristics and Risk of Bias Assessment

The studies were published between 2005 and 2018 with an enrollment period that ranged from 1999 to 2015 (Table S1). They included a total of 4089 participants. Among the 45 included studies, 7 was designed as a three-arm trial, while the other 38 were two-arm study designs. The %EWL and the DM remission rates were reported using 33 and 24 studies, respectively.

The network of all included studies is shown in Fig. 2. Overall, RYGB was the most commonly compared regimen included in 36 comparisons. SG was the second most frequently compared regimen included in 26 comparisons. The comparative efficacy between RYGB vs. SG was analyzed in 16 studies. Besides, biliopancreatic diversion (BPD), RYGB, SG, and AGB were compared to controls (standard-of-care) in 2, 9, 3, and 5 studies, respectively.

Quality assessments for individual studies are presented in Fig. S1. When evaluating the 45 included studies, 17 (37.8%) had an unclear risk of bias in the domain of random sequence generation. High risk of bias, in terms of allocation concealment, was identified in 3 studies (6.7%). In those studies, patients were informed of the group allocation before surgery. In addition, 25 studies (55.6%) had an unclear risk of bias in the domain of allocation concealment. Performance bias and detection bias were assessed as being low risk in all studies because the %EWL and the DM remission rates are less likely to be affected by blinding of the participants or investigators. Additionally, 6 studies (13.3%) were assessed as having a

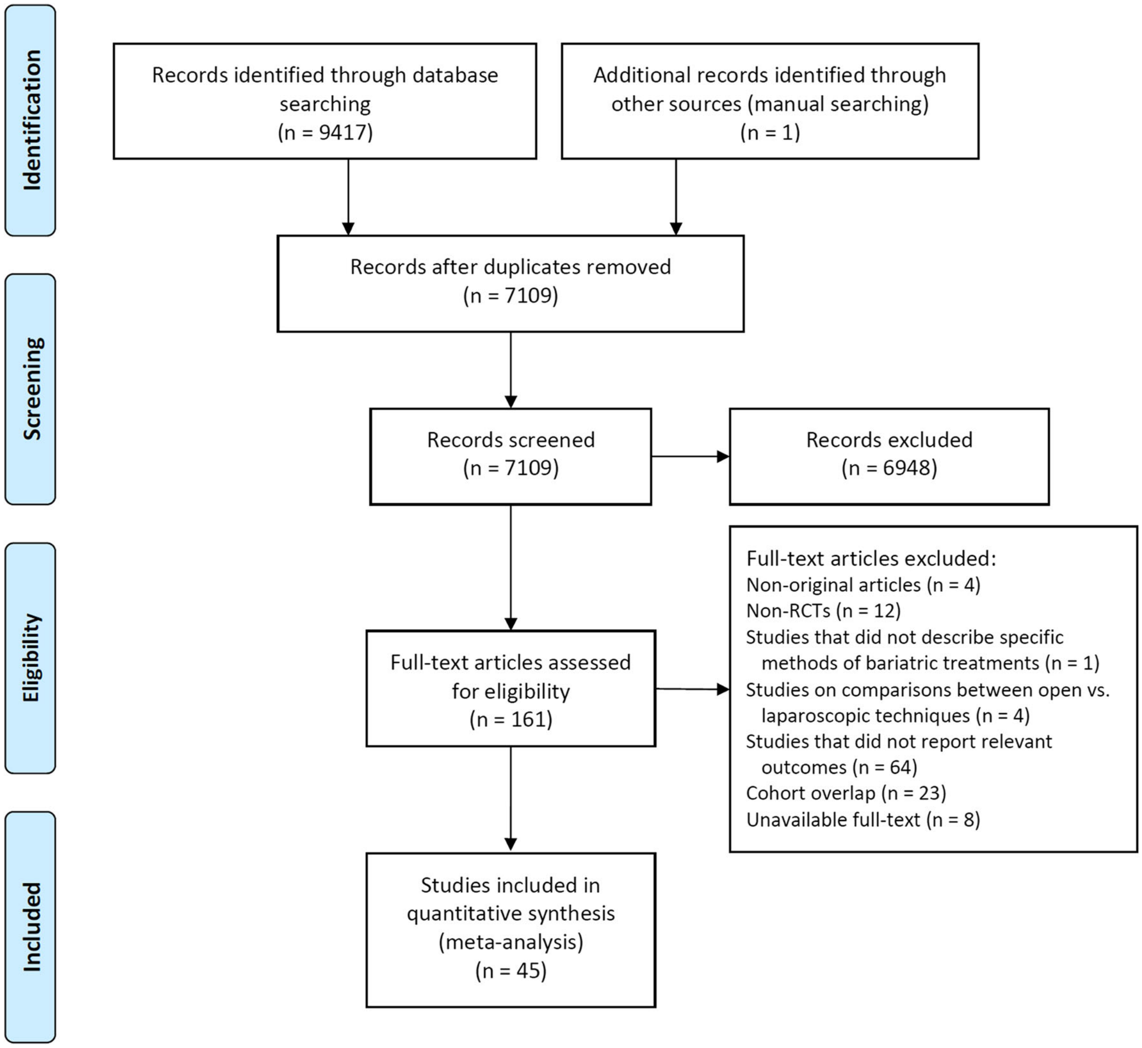

Fig. 1 Flow diagram of the studies included in the meta-analysis**.** RCT, randomized controlled trial

high risk of attrition bias, because the rate of follow-up loss did differ among the groups. Reporting bias was not identified in any study. Finally, 4 studies (8.9%) were assessed as having a high risk of other types of bias because baseline BMI did differ among the groups despite randomization.

Direct Meta-Analysis of Bariatric Surgery

Detailed data about %EWL according to the assessment timing were shown in Table S2. In the direct meta-analysis, SG showed superior %EWL efficacy compared to AGB at 6 months after the surgery (MD [95% CI] = 32.7% [20.7%, 44.8%]). However, AGB did not show superior %EWL efficacy compared to controls (MD [95% CI] = − 0.2% [− 13.3%, 12.9%]). In addition, there was no significant difference between BPD-DS vs. RYGB and RYGB vs. SG (MD [95% CI]: 6.1% [− 6.9%, 19.2%] and − 0.4% [− 10.0%, 9.2%], respectively).

In contrast to the results at 6 months, AGB was superior in terms of the %EWL compared to controls 1 year after surgery (MD [95% CI] = 27.4% [8.3%, 46.5%]). In addition, the %EWL of VBG was superior to that of AGB (MD [95% CI] = 17.8% [11.8%, 23.8%]). RYGB showed superior %EWL efficacy to VBG (MD [95% CI] = 15.4% [4.2%, 26.6%]). The %EWL did not differ between BPD-DS vs. RYGB (MD [95% CI] = 11.0% [− 7.1%, 29.1%]) groups.

At 3 years, the %EWL of RYGB was not superior to that of SG (MD [95% CI] = 5.8% [− 0.6%, 12.1%]). RYGB showed superior %EWL efficacy compared to AGB (MD [95% CI] = 26.0% [19.7%, 32.3%]). In addition, RYGB at 5 years was superior in terms of the %EWL compared to SG (MD [95% CI] = 8.5% [4.9%, 12.2%]).

Detailed data on DM remission are shown in Table S3. In the direct meta-analysis, early-period DM remission rates (1–2 years after the surgery) for BPD, RYGB, SG, and AGB showed superior efficacy compared to controls (RR [95% CI]: BPD vs. control, 37.1 [2.4, 571.5]; RYGB vs. control,

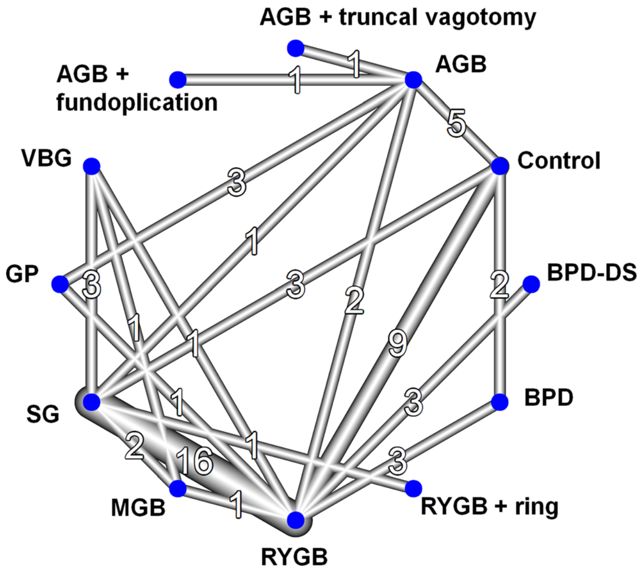

Fig. 2 Evidence network of different bariatric treatments. The line represents the comparison between bariatric surgery techniques. The thickness of the line represents the number of studies included in each comparison. BPD-DS, biliopancreatic diversion with duodenal switch; BPD, biliopancreatic diversion; RYGB, Roux-en-Y gastric bypass; MGB, mini gastric bypass; SG, sleeve gastrectomy; VBG, vertical banded gastroplasty; GP, gastric plication; AGB, adjusted gastric banding

15.2 [4.4, 52.4]; SG vs. control, 22.7 [1.4, 370.3]; and AGB vs. control, 5.2 [2.2, 12.5]). In the late period (3–5 years after the surgery), RYGB showed superior efficacy of DM remission rates compared to controls (RR [95% CI] = 8.7 [1.6, 46.6]). BPD and SG did not show superior efficacy for DM remission rates during the late period when compared to controls (RR [95% CI]: BPD vs. control, 12.0 [0.7, 194.6]; and SG vs. control, 12.2 [0.7, 206.8]).

Network Meta-Analysis of Bariatric Surgery in Terms of the Percentage of Excess Weight Loss

Network estimates of the %EWL in each bariatric surgical procedure compared to controls were plotted using Forrest plots (Fig. 3). In the network meta-analysis of the %EWL from 6 months to 5 years, network inconsistency was identified. The P and I^2 values of heterogeneity tests, according to the assessment timing, were as follows: at 6 months, < 0.01 and 87.9%; at 1 year, < 0.01 and 75.5%; at 2 years, < 0.01, and 88.9%; and at 3 years, < 0.01 and 75.1%.

Six months after the surgeries, BPD-DS, RYGB, and SG showed superior %EWL efficacy compared to controls (MD [95% CI]: BPD-DS vs. control, 38.2% [7.3%, 69.1%]; RYGB vs. control, 32.1% [3.1%, 61.1%]; and SG vs. control, 32.5% [5.5%, 59.5%]). However, AGB did not show superior %EWL efficacy compared to controls (MD [95% CI] = − 0.2% [− 19.6%, 19.2%]). BPD-DS, RYGB, and SG were also superior in terms of %EWL when compared to AGB (MD [95% CI]: BPD-DS vs. AGB, 38.4% [14.4%, 62.4%];

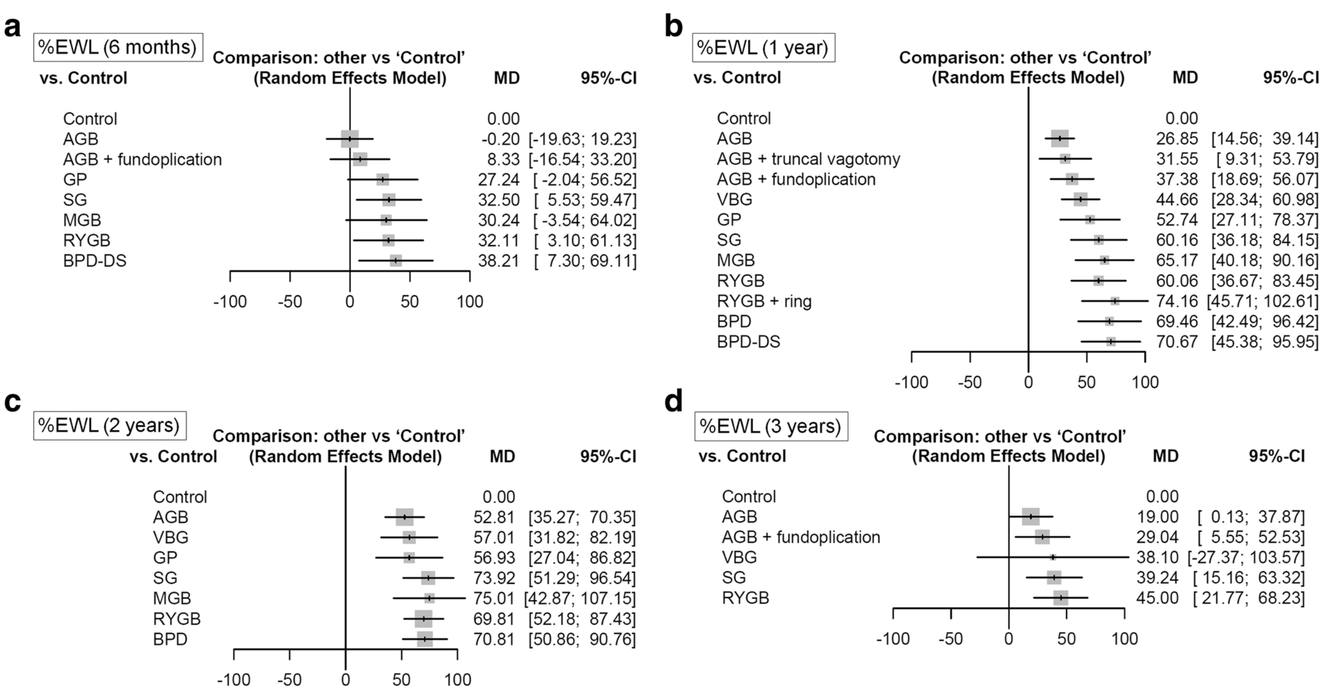

Fig. 3 Comparative efficacy for the %EWL of bariatric procedures from the network meta-analysis at **a** 6 months, **b**) 1 year, **c** 2 years, and **d** 3 years. The network estimate of the %EWL at 5 years was not calculated, because the included studies did not construct a %EWL loop at 5 years. %EWL, percent of excess weight loss; BPD-DS, biliopancreatic diversion with duodenal switch; BPD, biliopancreatic diversion; RYGB, roux-en-Y gastric bypass; MGB, mini gastric bypass; SG, sleeve gastrectomy; VBG, vertical banded gastroplasty; GP, gastric plication; AGB, adjusted gastric banding

RYGB vs. AGB, 32.3% [10.8%, 53.9%]; and SG vs. AGB, 32.7% [14.0%, 51.4%]).

One year after the surgeries, all bariatric procedures showed superior %EWL efficacy compared to controls. The %EWL MD was highest in RYGB with the ring method (74.2%), followed by BPD-DS (70.7%), BPD (69.5%), mini-gastric bypass (MGB) (65.2%), SG (60.2%), RYGB (60.1%), gastric plication (GP) (52.7%), and VBG (44.7%). AGB and its derivative methods (AGB with truncal vagotomy and AGB with fundoplication) had the lowest %EWL MD among bariatric procedures (AGB with fundoplication, 37.4%; AGB with truncal vagotomy, 31.6%; and AGB, 26.9%).

At both 2 and 3 years after surgery, major procedures including RYGB and SG showed superior %EWL efficacy to controls (MD [95% CI]: at 2 years, RYGB vs. control, 69.8% [52.2%, 87.4%]; at 2 years, SG vs. control, 73.9% [51.3%, 96.5%]; at 3 years, RYGB vs. control, 45.0% [21.8%, 68.2%]; and at 3 years, SG vs. control, 39.2% [15.2%, 63.3%]). Network estimates of the %EWL at 5 years were not calculated, because the included studies did not construct a %EWL loop at 5 years.

Figure 4 indicates the %EWL MD changes according to the assessment timing in the bariatric procedures compared to controls. The %EWL MD in bariatric surgeries gradually increased from 6 to 24 months; however, it decreased slightly at 36 months.

Nerk Meta-Analysis of Bariatric Surgery in Terms of Type 2 Diabetes Remission Rates

Network inconsistency was not identified for DM remission rates (early period: $P = 0.309$, $I^2 = 12.6\%$; and late period: $P = 0.859$, $I^2 = 0\%$). As shown in Fig. 5, all bariatric procedures showed superior DM remission rate efficacy compared to controls for both the early and late periods. Comparative efficacy of DM remission rates did not differ among BPD-DS, RYGB, and SG (e.g., RYGB vs. SG: early period, MD [95% CI] = 1.2 [0.9, 1.6]; late period, MD [95% CI] = 1.1 [0.9–1.4]).

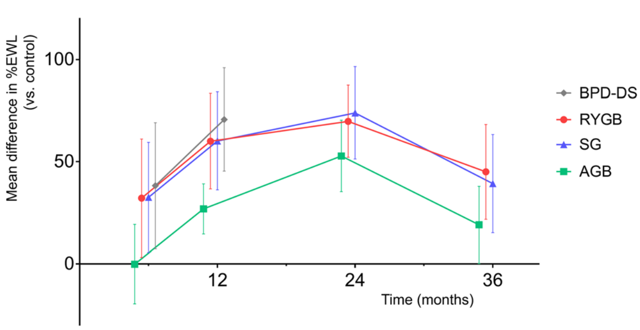

Fig. 4 Changes of mean difference in %EWL according to assessment timing in the bariatric surgery techniques compared to controls. Bar indicates 95% confidence interval of the mean difference in %EWL. %EWL, percent of excess weight loss; BPD-DS, biliopancreatic diversion with duodenal switch; RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy; AGB, adjusted gastric banding

Adverse Events

Mortality and other surgical adverse events according to the individual study and treatment group are shown in Table S4. There was no mortality in patients who underwent BPD-DS, SG, and AGB. Although two patients died after receiving RYGB (mortality rate 0.1% [95% CI = 0.0–0.7%]; one due to lymphoma and one due to drug abuse), there was no surgery-related mortality. Overall, three patients who underwent bariatric surgery each died of pulmonary thromboembolism, sepsis, and pneumonia (one patient after GP [1.1%] and two patients after VBG [2.0%]).

In 1183 patients who underwent RYGB in studies that reported the detailed number of surgical adverse events, hernias were the most common adverse event (5.1% [95% CI, 4.0–6.5%]), followed by obstruction/stricture (4.0% [95% CI, 3.0–5.3%]), gastrointestinal bleeding (2.0% [95% CI, 1.4–3.0%]), and ulcers (1.5% [95% CI, 1.0–2.4%]). Hernias, obstruction/stricture, gastrointestinal bleeding, and ulcers were less common in patients who underwent SG than in those who underwent RYGB (Fig. 6). Band-related adverse events, namely pouch dilatation/slippage, band erosion, and band slippage occurred in 10.9%, 0.8%, and 0.8% of patients who underwent AGB, respectively.

Discussion

Our network meta-analysis showed that all bariatric procedures were effective for both weight reduction and DM control. The %EWLs for major procedures including BPD-DS, RYGB, and SG were superior to control groups 6 months after surgery. As shown in Fig. 4, the %EWL comparative efficacy for RYGB and SG reached its maximum of 2 years postoperatively and persisted up to 3 years. Although there were no data regarding the efficacy of bariatric procedures compared to control groups 5 years post-surgery, the efficacy appears to be long-lasting. Previous long-term follow-up studies comparing RYGB and SG reported that the % EWLs were about 75% and 65% in RYGB and SG, respectively, 5 years after the surgery [18, 23].

Compared to the results of BPD-DS, RYGB, and SG, the AGB %EWL seemed to be relatively low. Six months after surgery, the AGB %EWL was not superior to controls. At 1 year, the AGB %EWL was superior to controls; however, it was still inferior to other procedures including BPD-DS, RYGB, and SG. At 3 years, the AGB %EWL was marginally superior to controls, whereas it was inferior to RYGB and SG.

DM remission rate efficacy was similar among various bariatric procedures. The DM remission RRs of BPD-DS, RYGB, and SG during the early period were 11.0, 11.2, and 9.1, respectively, and 7.5, 7.5, and 6.7, respectively, during

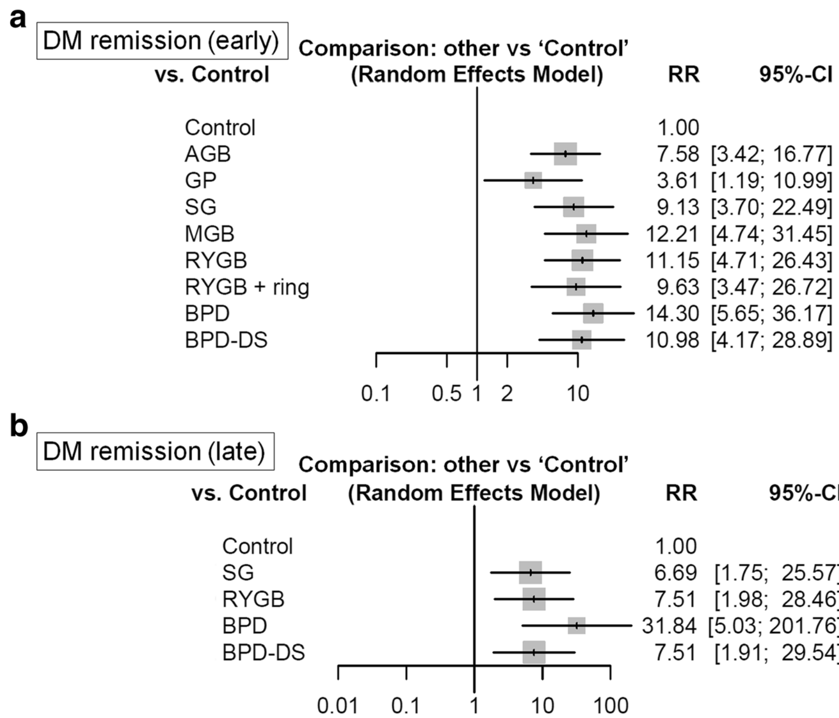

Fig. 5 Comparative efficacy of DM remission rates for bariatric procedures from the network meta-analysis. **a** Early period (1–2 years after the surgery), **b** Late period (3–5 years after the surgery). DM, diabetes mellitus; BPD-DS, biliopancreatic diversion with duodenal switch; BPD, biliopancreatic diversion; RYGB, Roux-en-Y gastric bypass; MGB, mini gastric bypass; SG, sleeve gastrectomy; GP, gastric plication; AGB, adjusted gastric banding

the late period. AGB also showed superior efficacy compared to controls in DM remission rates during the early period; however, there were no AGB DM remission rate data for the late period.

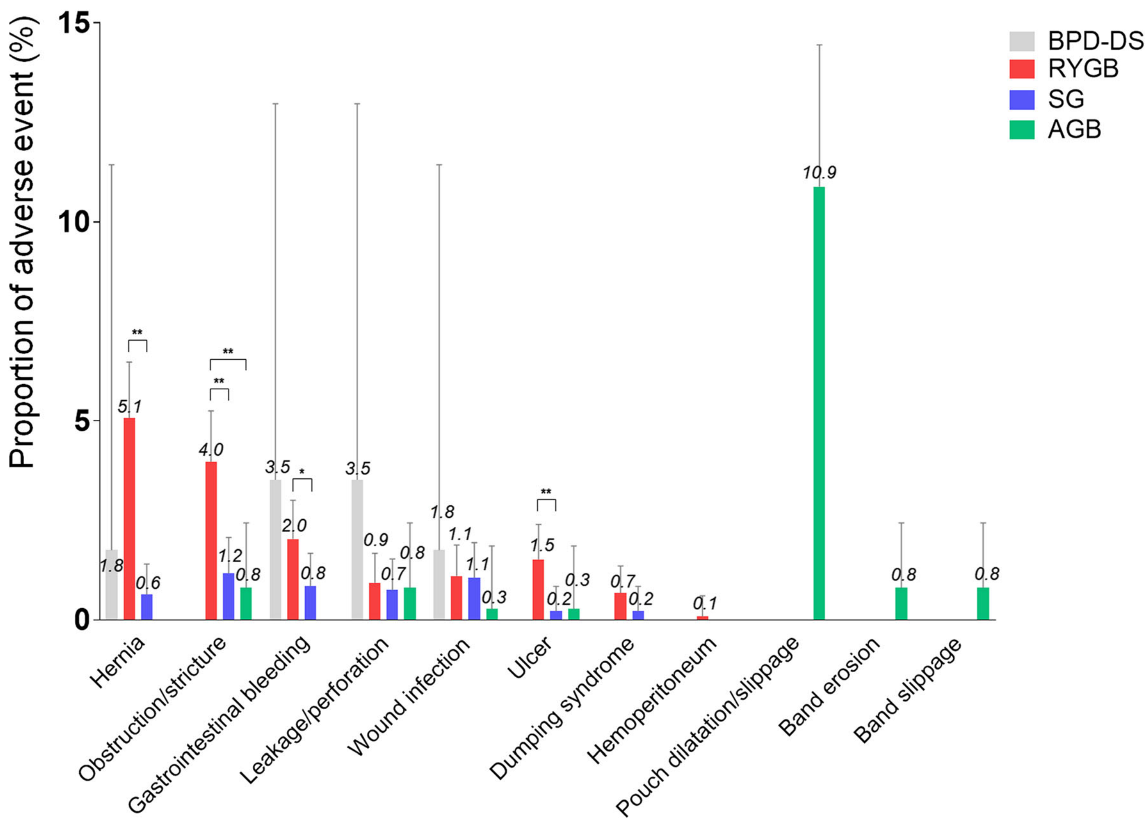

Fig. 6 The proportion of surgical adverse events in major operation techniques including BPD-DS, RYGB, SG, and AGB. *$P < 0.05$; **$P < 0.01$. BPD-DS, biliopancreatic diversion with duodenal switch; RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy; AGB, adjusted gastric banding

Based on efficacy results from the comprehensive analyses of bariatric procedures, we recommend BPD-DS, RYGB, and SG in morbidly obese patients, especially for those with DM, who were not controlled by lifestyle modifications and/or medical treatments. Although other procedures including MGB, GP, and AGB may also be chosen as bariatric treatments, long-term efficacy data for DM remission is insufficient. In addition to efficacy, we should consider procedural adverse events. Taking both efficacy and adverse events together, SG appears to be the best choice. Compared to RYGB, SG had a significantly lower risk of developing hernias, gastrointestinal obstruction/stricture, bleeding, and ulcers. In other words, SG seemed to have comparable efficacies of weight reduction and DM remission rates compared to RYGB, and favorable outcomes in terms of low rates of adverse events, especially hernias, gastrointestinal obstruction/stricture, bleeding, and ulcers. Nevertheless, we should cautiously interpret the results, because long-term data about comparative efficacy between SG and BPD-DS are still lacking.

In cases of AGB, the risk of adverse events including obstruction/stricture, bleeding, leakage/perforation, wound infection, and ulcers were very low and comparable to SG. Laparoscopic AGB is the least invasive form of bariatric surgery and has been proven to be fast and effective in the treatment of morbid obesity. However, the relatively low %EWL efficacy and lack of sufficient evidence in DM remission rates through long-term follow-ups are a significant concern for AGB. Band-related adverse events of over 10% are also concerns. Pouch dilatation associated with band slippage may be quite severe and often requires additional revision surgery [46].

Although this study is the first network meta-analysis to compare both weight reduction percentages and DM remission rates of various bariatric procedures, it has several limitations. First, a relatively small number of studies were included in several outcomes, although many studies were incorporated in our meta-analysis. Our primary endpoints, weight reduction percentages, and DM remission rates, should be assessed according to the assessment timing, because they may vary depending on the time since surgery. Therefore, there was a lack of direct evidence in several comparisons. However, differences in the efficacy among the bariatric procedures were relatively consistent according to the assessment timing (6 months vs. 1 year vs. 2 years vs. 3 years in the %EWL, and early vs. late periods for DM remission rates). We believe that our meta-analysis has sufficient data for determining the comparative efficacy between major bariatric procedures including RYGB, SG, and AGB. Second, there was significant heterogeneity in the network of comparisons for the %EWL. Therefore, comparative efficacy in terms of %EWL among bariatric procedures should be interpreted with caution. As mentioned above, however, comparative efficacy of %EWL was relatively consistent according to the assessment timing. Moreover, heterogeneity was not identified in the network of comparisons for the DM remission rates. Third, all studies included in the meta-analysis included patients who had been screened and who wanted bariatric surgery. Therefore, it is important to think carefully about which is the best treatment option for patients with morbid obesity. Moreover, the optimal bariatric procedure may differ depending on the local situations including national or private insurance reimbursement of operation fees, cost of operation device, and availability of medical resources [60]. Although we identified that SG was an effective and safe procedure for morbid obesity, the surgical treatment option should be selected based on the local situations.

Despite these limitations, our network meta-analysis provides a better understanding of the efficacy of bariatric surgery in patients with morbid obesity. In terms of both the %EWL and DM remission rates, RYGB and SG had excellent long-term follow-up results. In addition, SG had a relatively lower risk of adverse events than RYGB.

Compliance with Ethical Standards

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

Statement of Informed Consent Informed consent was exempted because this study was a meta-analysis based on the published studies.

Statement of Human and Animal Rights It is not applicable for this meta-analysis study.

Appendix 1. Detailed search strategy

MEDLINE (Pubmed)

((bariatric[TW] OR (metabolic surgery[TW]) OR (weight loss surgery[TW]) OR Roux-en-Y[TW] OR (restrictive bypass[TW]) OR (gastric bypass[TW]) OR (gastrojejunal bypass[TW]) OR (gastro-jejunal bypass[TW]) OR (gastroileal bypass[TW]) OR (gastro-ileal bypass[TW]) OR (duodenojejunal bypass[TW]) OR (duodeno-jejunal bypass[TW]) OR (duodenoileal bypass[TW]) OR (duodeno-ileal bypass[TW]) OR (sleeve gastrectomy[TW]) OR (gastric band*[TW]) OR (intragastric band*[TW]) OR (gastroplast*[TW]) OR (gastric balloon*[TW]) OR (vertical band*[TW]) OR (lapband*[TW]) OR (lap-band*[TW]) OR (adjustable band*[TW]) OR (gastric belt*[TW]) OR (gastric bubble[TW]) OR (gastric partition[TW]) OR (stomach stapling[TW]) OR (biliopancreatic diversion[TW]) OR (duodenal switch[TW])) OR ((obesity[Mesh] OR obesity[TW] OR obese[TW] OR overweight[Mesh] OR overweight[TW]) AND (surgery[Mesh] OR surgery[TW]))) AND (random*[TW]) AND ("1990/01/01"[Date - Publication]: "2018/02/27"[Date - Publication])

EMBASE (Ovid)

((bariatric or 'metabolic surgery' or 'weight loss surgery' or Roux-en-Y or 'restrictive bypass' or 'gastric bypass' or 'gastrojejunal bypass' or 'gastro-jejunal bypass' or 'gastroileal bypass' or 'gastro-ileal bypass' or 'duodenojejunal bypass' or 'duodeno-jejunal bypass' or 'duodenoileal bypass' or 'duodeno-ileal bypass' or 'sleeve gastrectomy' or 'gastric band*' or 'intragastric band*' or 'gastroplast*' or 'gastric balloon*' or 'vertical band*' or 'lapband*' or 'lap-band*' or 'adjustable band*' or 'gastric belt*' or 'gastric bubble' or 'gastric partition' or 'stomach stapling' or 'biliopancreatic diversion' or 'duodenal switch' or ((obesity or obese or overweight) and surgery)) and random*).ab,ti.

Cochrane library

bariatric or 'metabolic surgery' or 'weight loss surgery' or Roux-en-Y or 'restrictive bypass' or 'gastric bypass' or 'gastrojejunal bypass' or 'gastro-jejunal bypass' or 'gastroileal bypass' or 'gastro-ileal bypass' or 'duodenojejunal bypass' or 'duodeno-jejunal bypass' or 'duodenoileal bypass' or 'duodeno-ileal bypass' or 'sleeve gastrectomy' or 'gastric band*' or 'intragastric band*' or 'gastroplast*' or 'gastric balloon*' or 'vertical band*' or 'lapband*' or 'lap-band*' or 'adjustable band*' or 'gastric belt*' or 'gastric bubble' or 'gastric partition' or 'stomach stapling' or 'biliopancreatic diversion' or 'duodenal switch'

1. obesity or obese or overweight
2. korea*
3. #2 and #3
4. #1 or #4
5. random*
6. #5 and #6 (Limit to trials published from 1990 to 2018)

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