The advent of minimally invasive approaches in bariatric surgery: an example of surgical revolution

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The advent of minimally invasive approaches in bariatric surgery: an example of surgical revolution

Thesis submitted to the Faculty of Medicine of
the University of Geneva

for the degree of Privat-Docent
by

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Abstract

Introduction

Bariatric surgery is currently the only validated treatment option for obesity that provides significant and long-term weight loss. Even though initially performed with open techniques, the vast majority of bariatric procedures are nowadays performed using minimally invasive surgery (MIS). The objective of the present systematic review was to compare postoperative outcomes after open and MIS bariatric procedures.

Methods

A systematic search of MEDLINE, EMBASE, PUBMED, Web of Science and Cochrane databases was performed to identify studies comparing open and MIS bariatric surgery among adult patients. The primary outcome was the rate of 30-day postoperative complications. Secondary outcomes included operative times, conversion to open surgery, length of hospital stay (LOS), readmissions and reoperations.

Results

A total of 35 studies were included, reporting on 82’843 participants who underwent open and 152’398 participants who underwent MIS bariatric surgery. The overall early postoperative complication rate was 21.9% (18’175/82’843) in the open group and 18.2% (27’767/152’398) in the MIS group ($p<0.0001$). The rate of early severe complications was 2.4% in the open group and 1.1% in the MIS group (OR 2.17, 95% CI 1.61-2.91, $p<0.0001$). Rates of individual postoperative complications were all lower among MIS patients in the pooled and subgroup analyses, except for a comparable rate of hemorrhagic complications. Participants who underwent open surgery had higher mortality, reoperation and readmission rates and a longer LOS.

Conclusion

Postoperative outcomes were significantly better after MIS compared to open bariatric surgery. These findings support the use of MIS as the gold-standard for bariatric procedures.

Introduction

The current obesity pandemic

Obesity, defined by the World Health Organization (WHO) as a body mass index (BMI) greater than 30 kg/m^2, has currently reached pandemic proportions, durably affecting an increasing number of people across all continents. Central European countries report an obesity prevalence between 10 and 30%, a number that climbs as high as 40% in the US[1]. In Switzerland, obesity affects 10.8% of the population[1]. Above these static figures, the constant rise in the prevalence of obesity in the last five decades is a great cause for concern[2]. Bariatric surgery is currently established as the only treatment for obesity offering significant and durable weight-loss, as well as improvement of obesity-related comorbidities such as type II diabetes mellitus (T2D), hypertension, dyslipidemia, obstructive sleep apnea syndrome (OSAS) and gastroesophageal reflux disease (GERD)[3-5].

A brief history of bariatric surgery

The first surgical procedures solely designed for weight loss purposes were performed in Minneapolis in the early 1950s by Kremen, Linner and Nelson[6]. Based on the observation that patients with major intestinal resections experienced significant weight loss, they designed an intestinal malabsorptive model by performing a jejunoileal bypass (Figure 1).

Inspired by this experimental procedure, Payne and his team performed jejunocolic bypasses (Figure 2) in ten patients in the late 1950s[7]. Despite the excitement generated by the significant and durable weight loss in these patients, a National Institute of Health (NIH) Consensus Conference held in 1978 recommended to abandon intestinal shunting due to major

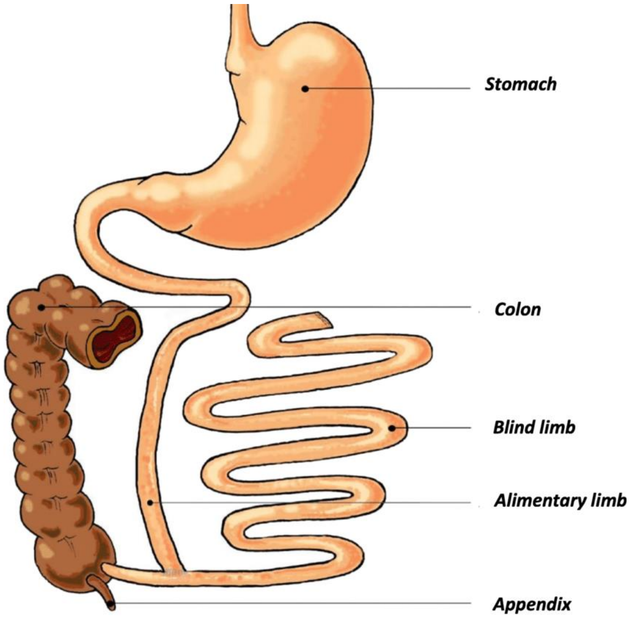


Figure 1: Jejuno-ileal bypass as described by Kremen in 1954 (adapted from Aarts EO, Mahawar, K. From the Knife to the Endoscope — a History of Bariatric Surgery. Curr Obes Rep 2020 9, 348–363)

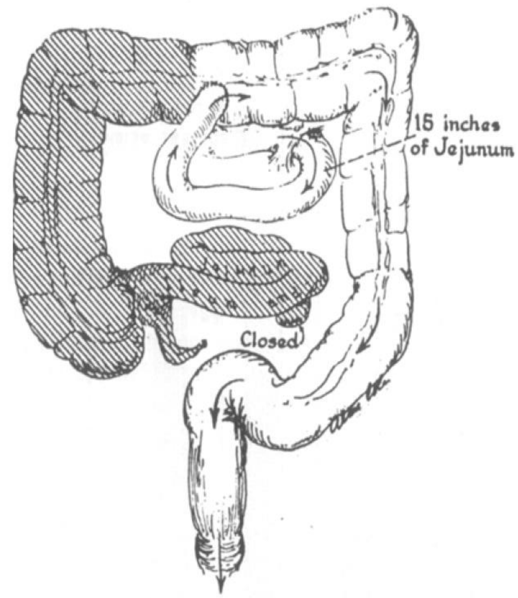


Figure 2: Jejuno-colic shunt as described by Payne in 1956 (adapted from Payne JH, DeWind LT, Commons RR. Metabolic observations in patients with jejunocolic shunts. 1963. Obes Res. 1996 May;4(3) :304-15)

complications such as severe nutritional deficiencies, nephrolithiasis, ketosis and liver failure[8]. In parallel, other surgeons were developing novel bariatric procedures in their respective academic centers. In an attempt to create a novel procedure to treat duodenal ulcers, Mason and Ito described an upper gastric partition with a side-to-side gastrojejunal anastomosis in 1967 (Figure 3)[9]. Although no improvement of peptic ulcer disease was seen, they observed significant weight loss among patients with obesity who underwent this procedure. It was the first description of a gastric bypass. The procedure underwent several modifications and was finally converted from an omega to a Roux-en-Y configuration (RYGB) to avoid intragastric reflux of intestinal content by Alden et al. in 1977 (Figure 4)[10].

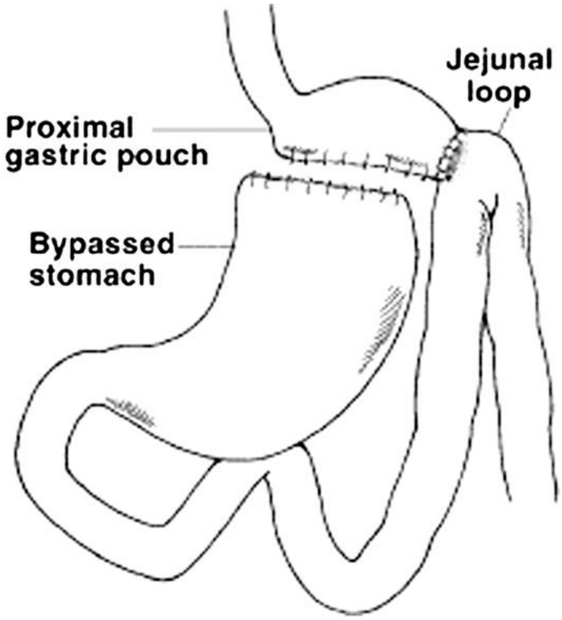


Figure 3: Original gastric bypass as described by Mason and Ito in 1966, with an omega jejunal loop (adapted from Baker MT. The history and evolution of bariatric surgical procedures. The Surgical clinics of North America (2011) 91 6: 1181-201, viii)

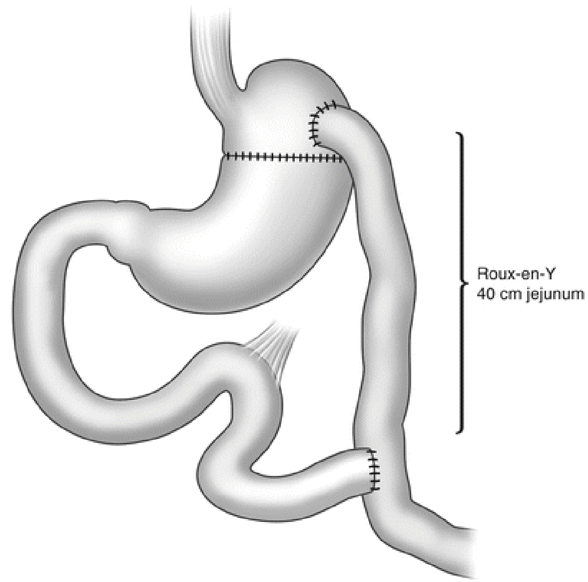


Figure 4: Roux-en-Y modification of the original gastric bypass as described by Alden in 1977 (adapted from Alden JF. Gastric and Jejunoileal Bypass. Archives of Surgery (1977) :1112(7), 799)

The European continent also started to show interest in bariatric surgery procedures at that time, especially in Italy, where Scopinaro described his well-known biliopancreatic diversion (BPD) in 1979 (Figure 5)[11]. Considering the complications of the gastric bypass procedure, especially anastomotic ulcers and leaks, as unacceptable, Mason decided to try a different approach by designing a pure gastric partition on the lesser curvature and controlling its outlet with a circular piece of mesh or silicone[12]. This procedure, described in 1982 and named vertical banded gastroplasty (VBG), rapidly became popular and was probably the most commonly performed bariatric procedure in the USA in the 1980s (Figure 6). Given the success and overall acceptance

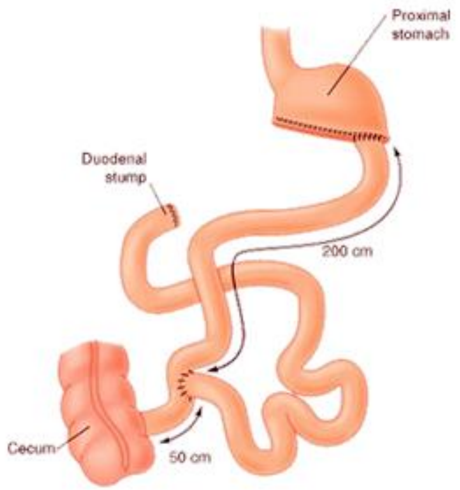


Figure 5: Biliopancreatic diversion as described by Scopinaro in 1979 (adapted from the International Federation for the Surgery of Obesity and Metabolic Disorders (IFSO), available at www.ifso.com/bilio-pancreatic-diversion)

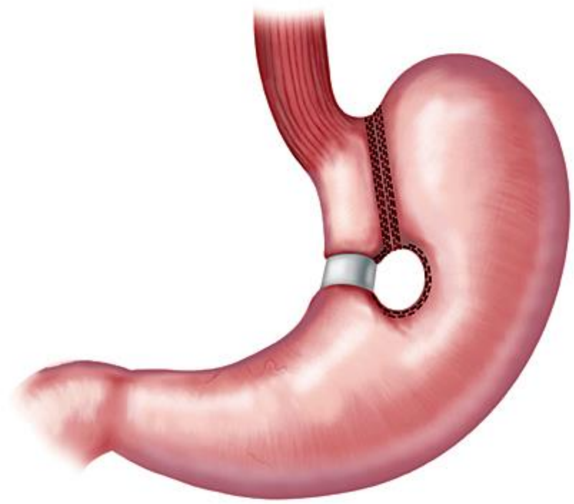


Figure 6: Vertical banded gastroplasty as described by Mason in 1982 (adapted from Jones DB, Schneider BE, Olbers T. Atlas of Metabolic and Weight Loss Surgery. Cine-Med, North Woodbury, Connecticut 2010)

of gastric restrictive procedures in North America, Kuzmak designed in 1986 a silicone ring with an integrated small, adjustable balloon, whose size could be modified through injection of fluid into a subcutaneous reservoir (Figure 7)[13]. This procedure, named adjustable gastric banding (ABG), was quickly adopted by a great number of surgeons across the world since it was associated with good results in terms of weight loss, fewer postoperative complications, the possibility to adjust the level of gastric restriction and, last but not least, this procedure was

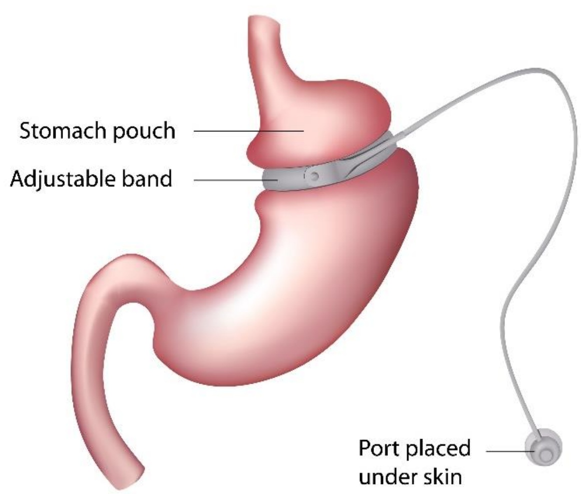


Figure 7: Adjustable gastric banding as described by Kuzmak in 1986 (adapted from Jones DB, Schneider BE, Olbers T. Atlas of Metabolic and Weight Loss Surgery. Cine-Med, North Woodbury, Connecticut 2010)

relatively easy to perform technically without any anastomosis or gastric partitioning. It is therefore no surprise that ABG became the very first bariatric procedure to be performed with minimally invasive techniques a few years later. In 1986, the same year ABG was first described, Hess and Hess modified Scopinaro's biliopancreatic diversion by adding a partial, vertical gastrectomy also called a "sleeve" gastrectomy, and by switching from a gastroileal to a duodenoileal anastomosis (Figure 8)[14]. This technically challenging and highly malabsorptive procedure was called biliopancreatic diversion with duodenal switch (BPD-DS) and it did not gain widespread acceptance initially. In the 1990s, ABG and RYGB were therefore probably the most commonly performed bariatric procedures across the globe, even though official statistics for bariatric surgery were not available yet. Given its higher morbidity and its exclusive indication in patients with grade V obesity (BMI $\geq$ 60 kg/m^2) in most centers, BPD-DS was often performed as a two-step procedure, starting with the sleeve gastrectomy (SG) only. The interest of bariatric surgeons in the SG as a standalone procedure progressively grew and its favorable outcomes were first published in 2004[15]. SG was subsequently defined as a full-fledged procedure on its own by several international consensus conferences[16, 17], and it has now become the most commonly performed bariatric procedure across the world for almost a decade[18].

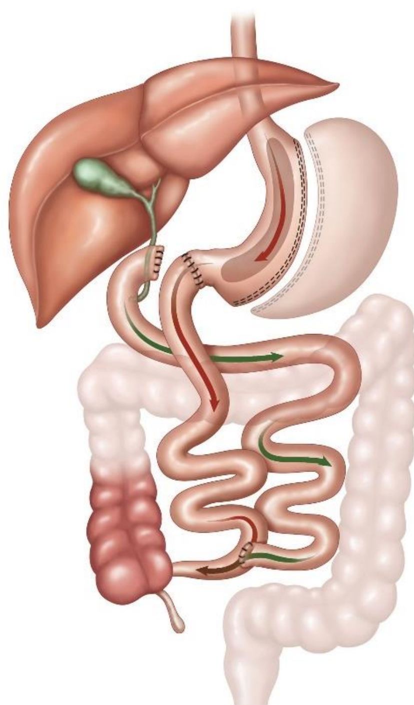


Figure 8: biliopancreatic diversion with duodenal switch, as described by Hess & Hess in 1986 (adapted from Jones DB, Schneider BE, Olbers T. Atlas of Metabolic and Weight Loss Surgery. Cine-Med, North Woodbury, Connecticut 2010)

Technologic advances in the field of bariatric surgery

From the very beginning, surgeons experimenting bariatric procedures had to face numerous challenges. First, patients with obesity have various amounts of fat in their subcutaneous, intraperitoneal (i.e. between intraabdominal organs, also named “visceral”) and intraparenchymal (e.g. hepatic steatosis) compartments. This excess of fatty tissue results in significant difficulty to perform abdominal surgery, especially when using the traditional open approach (laparotomy). To mention just a few, challenges faced by the early surgeons treating patients with obesity included higher rates of abdominal wall abscess and hernia, higher risk of bleeding and organ injury due to difficult identification of anatomic structures, as well as inability to perform certain procedures in narrow spaces such as the pelvis or the esophageal hiatus[19-22]. In addition, early bariatric procedures involving the stomach required handsewn closure of the partitioned gastric wall, which could be cumbersome and time-consuming. The development of bariatric surgery was thus hampered for decades by technical factors and increased postoperative morbidity. The first technical progress that significantly impacted bariatric surgery was the advent of tissue stapling devices. Even though the first surgical staplers were invented in 1908, their implementation in the western world took only place in the late 1970s[23]. Surgical staplers made bariatric procedures faster and more standardized, as described by Mason, who started using a circular and a linear stapler to perform VBG[12]. Progresses made in the field of anesthesia also benefited patients with obesity undergoing surgery, especially by decreasing cardiopulmonary morbidity[24, 25]. However, the key-element that literally revolutionized the field of bariatric surgery was undoubtedly the advent of minimally invasive approaches, the first of which was laparoscopy (Figure 9).

Figure 9: Laparoscopic surgery, performed with an endoscope and instruments introduced through small abdominal incisions (adapted from freepik.com, image under open license)

A pivotal shift took place in the early 1990s, after Cadiere performed the first laparoscopic AGB in 1992[26], followed by Wittgrove & Clark who performed the first laparoscopic RYGB in 1993[27]: the number of bariatric surgery procedures grew exponentially over the following decades. Nowadays, an estimated 600'000 procedures are performed each year across the world[18], an ever-growing figure. In parallel with the first reports of laparoscopic VBG by Lönroth in 1996[28] and laparoscopic BPD-DS by Gagner in 1999[29], a first prototype of surgical telemanipulator, often mistakenly called "surgical robot", was being developed in California by a firm called Intuitive Surgical Inc (Figure 10). Taking advantage of the momentum produced by the laparoscopic approach, the feasibility of robotically-assisted bariatric procedures was rapidly demonstrated starting with Cadiere in 1999, who performed the first robotically-assisted AGB[30], followed by Sudan and Horgan, who performed the first BPD-DS and RYGB using the same approach in 2000 and 2001, respectively[31, 32]. The adoption of minimally invasive techniques as the gold-standard approach in bariatric surgery resulted in a radical change of landscape: perioperative mortality, which was above 1%, dropped to less than 0.2%, while the postoperative complications rates decreased almost threefold and the mean length of hospital stay was divided by two[33].

Figure 10: the da Vinci Surgical System®, a telemanipulator system for surgery developed by Intuitive Surgical Inc. This image shows the Si® version of the system (adapted from the Intuitive Surgical website, under www.intuitive.com)

Rationale and objective of the thesis

The rationale of the thesis was that even though the advent of minimally invasive surgery has certainly been a major catalyst of the exponential growth in the number of bariatric procedures in the last three decades and despite several authors individually reporting improved outcomes after minimally invasive bariatric surgery, there has been no systematic review of the literature confirming this hypothesis to the best of the author's knowledge. The objective of the present systematic review of the literature was therefore to analyze postoperative outcomes after bariatric surgery, comparing procedures performed through an open versus a minimally invasive approach, hypothesizing decreased perioperative morbidity when bariatric procedures are performed by the latter technique.

Material and Methods

The above mentioned hypothesis was tested using a systematic review of the current literature.

Eligibility criteria

- *Study design*

  Only randomized controlled trials and observational comparative studies comparing a minimally invasive surgery (MIS) approach, defined by either conventional or robotically-assisted laparoscopy, with an open approach were included. Endoscopic weight-loss procedures were excluded due to the absence of an equivalent surgical procedure performed by an open approach.
- *Population*

  This systematic review included adult patients (18 years and older) who underwent bariatric surgery for obesity, defined according to the WHO by a BMI of 30 kg/m^2 or higher.
- *Interventions*

  The following bariatric surgery procedures were included: Roux-en-Y gastric bypass (RYGB), sleeve gastrectomy (SG), adjustable gastric banding (AGB), vertical banded gastroplasty (VBG), biliopancreatic diversion (BPD, also named Scopinaro procedure) and biliopancreatic diversion with duodenal switch (BPD-DS). These procedures were selected based on their international recognition as standard bariatric surgeries by major national and international bariatric surgery societies such as the American Society for Metabolic and Bariatric Surgery (ASMBS) and the International Federation for the Surgery of Obesity and Metabolic Disorders (IFSO).

Information sources

The MEDLINE, MEDLINE Epubs Ahead of Print, EMBASE, PUBMED, Web of Science and Cochrane (Wiley) databases were searched on September 27, 2022. Studies published in any language were considered.

Search strategy

The search strategy was designed with the help of a professional medical librarian from the Faculty of Medicine of the University of Geneva, Switzerland. The following searching terms and Boolean operators were used:

('minimally invasive surgery'/de OR 'laparoscopic surgery'/de OR 'robot assisted surgery'/de OR 'robotic surgical system'/de OR 'minimally invasive surgery':ab,ti,kw OR 'laparoscopy':ab,ti,kw OR 'coelioscopy':ab,ti,kw OR 'robotic surgery':ab,ti,kw OR 'robotically-assisted surgery':ab,ti,kw OR 'endoscopic surgical procedure':ab,ti,kw) AND ('laparotomy'/de OR 'open surgery':ab,ti,kw OR 'laparotomy':ab,ti,kw OR 'minilaparotomy':ab,ti,kw OR 'celiotomy':ab,ti,kw OR 'peritoneotomy':ab,ti,kw) AND ('bariatric surgery'/exp OR 'gastric bypass surgery'/exp OR 'jejunoileal bypass'/de OR 'gastroplasty'/de OR 'stomach stapling':ab,ti,kw OR (((bariatric OR obesity OR 'weight loss' OR metabolic) NEAR/2 (surg* OR operation)):ab,ti,kw) OR 'gastr* bypass':ab,ti,kw OR 'adjustable gastric band':ab,ti,kw OR 'sleeve gastrectomy':ab,ti,kw OR 'biliopancreatic diversion':ab,ti,kw OR 'biliopancreatic bypass':ab,ti,kw OR 'duodenal switch':ab,ti,kw OR 'gastroplasty':ab,ti,kw OR 'roux-en-y gastric bypass':ab,ti,kw OR 'gastroileal bypass':ab,ti,kw).

Selection process

All retrieved study references were saved in EndNote (version 20, Clarivate Analytics, London, United Kingdom) for duplicate removal and subsequent reference management. The Privat-Docent candidate screened each record manually for inclusion according to the above mentioned eligibility criteria.

Collected Data and Outcomes

Baseline characteristics included age, sex, BMI, obesity-associated comorbidities and type of bariatric procedure. The primary outcome was the rate of postoperative complications, which were defined as early (<30 days after surgery) and late (>30 days after surgery). Postoperative complications were additionally ranked depending on available data either according to the Dindo-Clavien classification[34], with major complications defined by a score ≥III, or according to the ASMBS definition of minor and major postoperative complications[35]. Secondary outcomes included intraoperative complications, conversion to open surgery, operative times, length of hospital stay (LOS), early (<30 days after surgery) readmissions, reoperations for postoperative complications and/or insufficient weight loss as well as early (<30 days after surgery) mortality.

Statistical Analysis

All analyses were performed using SPSS Statistics version 26 (IBM Corporation, Armonk, NY, USA). Baseline characteristics, primary and secondary outcomes were compared between groups using Student T-test or Mann-Whitney U-test where appropriate for continuous variables, and Chi-Square or Fisher's exact test where appropriate for categorical variables. Differences in rates of specific complications were expressed as unadjusted odds ratios (OR). Adjusted ORs were not calculable due to the lack of patient individual data. Outcomes that were considered independent from the type of surgery, i.e. outcomes exclusively linked to the surgical approach (open versus MIS), were analyzed in a pooled fashion and by subgroups according to the type of bariatric procedure (RYGB, AGB, VBG, SG and BPD with/without DS). Pooled and subgroup analyses were also performed for gastrointestinal leak rates, with the exception of the AGB subgroup due to the absence of gastric partitioning or anastomosis. Procedure-specific outcomes were analyzed by subgroups only. Results were considered statistically significant if p-value < 0.05.

Quality considerations

Risk of bias was assessed for each study using the Cochrane tool for assessing risk of bias in randomised trials (version 2, RoB2)[36] for randomized trials and by the Newcastle-Ottawa Scale (NOS) for non-randomized comparative studies[37]. By missing data about the primary outcome in an eligible study, corresponding authors were contacted by email up to two times to obtain additional information. The present review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[38].

Results

A total of 1027 citations were identified. After screening and based on the previously mentioned eligibility criteria, 35 studies were included in the review[39-73], as shown on the PRISMA 2020 flow diagram (Figure 11).

Study characteristics are shown in Table 1. These studies were performed in 10 different countries and included 5 randomized controlled trials[40, 52, 61, 64, 73], 3 prospective cohort studies [48, 66, 72] and 27 retrospective cohort studies [39, 41-47, 49-51, 53-60, 62, 63, 65, 67-71]. Surgical procedures were RYGB in 24 studies, BPD/BPD-DS in 6 studies, AGB in 4 studies and VBG in 1 study. No study comparing MIS and open SG was found.

Patient baseline characteristics and operative times are shown in Table 2. Overall, data of 235’241 patients were collected, including 82’843 who underwent open and 152’398 who underwent MIS bariatric surgery. Among them, 81.5% were female and 18.5% were male. The overall mean BMI and age were 49.3 kg/m^2 and 42.0 years, respectively. The overall prevalence of diabetes mellitus and hypertension was 29.9% and 51.4%, respectively. The overall conversion rate from MIS to open surgery was 4.2%. Across all studies, late complications were only reported if requiring surgical management (Dindo-Clavien ≥III).

Pooled analyses of outcomes

The overall early postoperative complication rate was 21.9% (18’175/82’843) in the open group and 18.2% (27’767/152’398) in the MIS group (p<0.0001). Types and rates of complications are detailed in Table 3. Gastrointestinal leak rates included RYGB and BPD/BPD-DS only and were significantly lower in the MIS group. The overall rate of early severe complications (Dindo-Clavien ≥III or major complication according to the ASMBS definition) was 2.4% in the open group and 1.1% in the MIS group (OR 2.17, 95% CI 1.61-2.91, p<0.0001). The overall 30-day mortality was 0.4% (335/82’279) in the open group and 0.1% (169/151’892) in the MIS group (OR 3.67, 95% CI 3.05-4.42, p<0.0001). The following late complications were considered dependent on the surgical approach only and not linked to the specific type of bariatric procedure, allowing for pooled analysis: incisional hernias (10.2% in the open group and 1.4% in the MIS group, OR 8.04, 95% CI 5.79-11.15, p<0.0001) and small bowel obstructions (2.4% in the open group and 1.9% in the MIS group, OR 1.32, 95% CI 0.94-1.86, p=0.1145).

Figure 11: PRISMA 2020 flow diagram

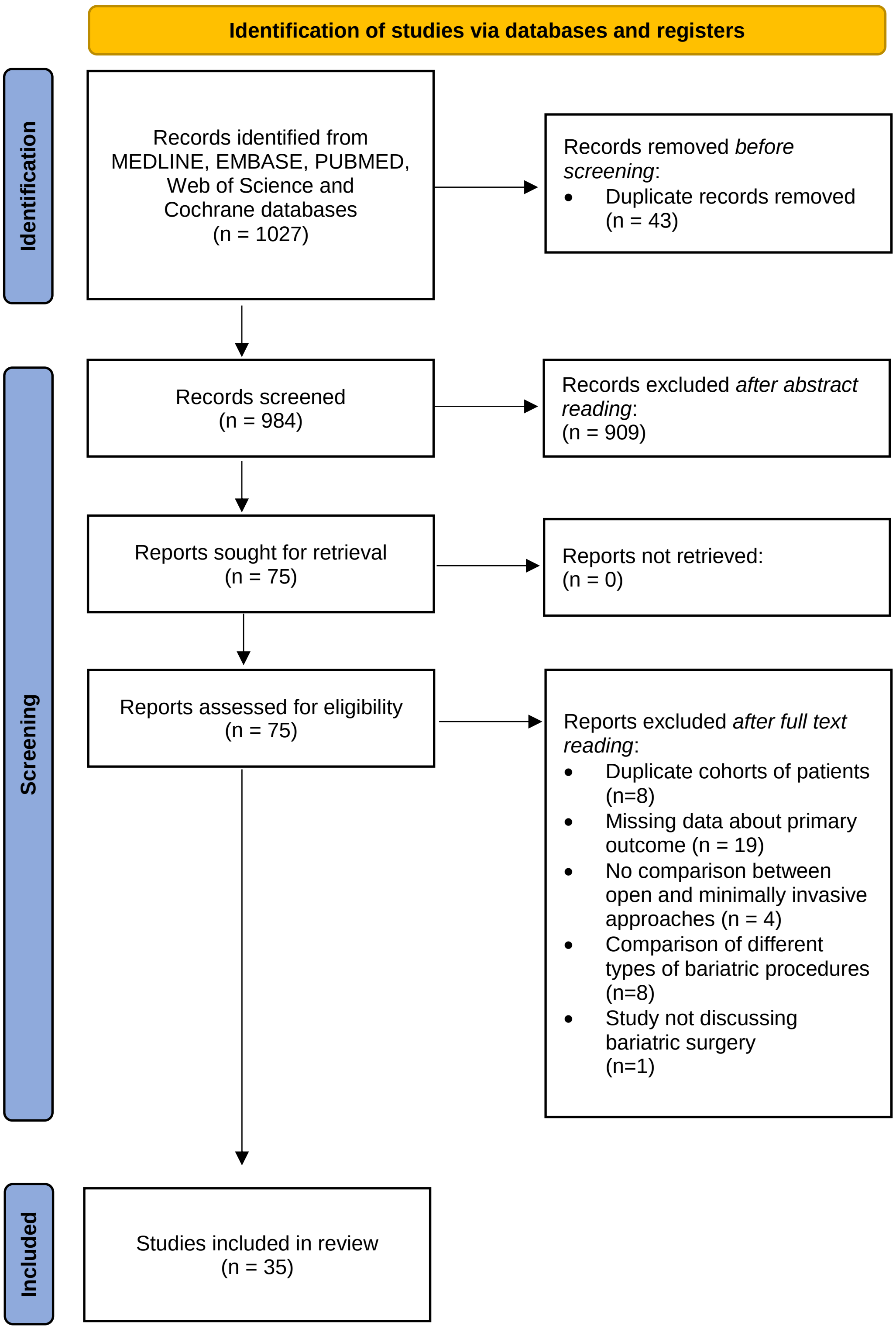


Table 1: Study characteristics

Study	Year	Country	Period of recruitment	Study design	Procedure
Agaba et al	2008	USA	1998-2004	Retrospective cohort	RYGB
Azagra et al	1999	Belgium	1995-1996	Randomized trial	VBG
Banka et al	2012	USA	2005-2007	Retrospective cohort	RYGB
Benotti et al	2009	USA	2002-2006	Retrospective cohort	RYGB
Bianchi et al	2022	Spain	1999-2015	Retrospective cohort	BPD (Scopinaro)
Biertho et al	2011	Canada	2006-2010	Retrospective cohort	BPD-DS
Buchs et al	2015	Switzerland	1997-2014	Retrospective cohort	RYGB
Buchs et al	2013	Switzerland	2000-2013	Retrospective cohort	RYGB
Campos et al	2007	USA	2003-2006	Retrospective cohort	RYGB
Ceriani et al	2010	Italy	2006-2007	Prospective cohort	BPD (Scopinaro)
Coskun et al	2003	Turkey	1998-2001	Retrospective cohort	AGB
Courcoulas et al	2003	USA	1999-2002	Retrospective cohort	RYGB
De Luca et al	2000	Italy	1994-1998	Retrospective cohort	AGB
de Wit et al	1999	Netherlands	1995-1997	Randomized trial	AGB
Edholm et al	2017	Sweden	2007-2014	Retrospective cohort	BPD-DS
Gonzalez et al	2007	USA	1998-2004	Retrospective cohort	RYGB
Hagen et al	2012	Switzerland	1997-2010	Retrospective cohort	RYGB
Hutter et al	2006	USA	2000-2003	Retrospective cohort	RYGB
Kim J et al	2009	USA	1995-2006	Retrospective cohort	RYGB
Kim W et al	2003	USA	1999-2001	Retrospective cohort	BPD-DS
Lancaster et al	2008	USA	2005-2006	Retrospective cohort	RYGB
Lindsey et al	2009	USA	2006	Retrospective cohort	RYGB
Luján et al	2004	Spain	1999-2002	Randomized trial	RYGB
Marema et al	2005	USA	1999-2002	Retrospective cohort	RYGB
Marsk et al	2009	Sweden	1997-2006	Retrospective cohort	RYGB
Nguyen et al	2000	USA	1998-1999	Prospective cohort	RYGB
Nguyen et al	2001	USA	1999-2001	Randomized trial	RYGB
Nguyen et al	2007	USA	2004-2006	Retrospective cohort	RYGB
Ricciardi et al	2006	USA	2001-2002	Retrospective cohort	RYGB
Sekhar et al	2007	USA	2001-2005	Retrospective cohort	RYGB
Skroubis et al	2011	Greece	1994-2008	Retrospective cohort	RYGB
Smith S et al	2004	USA	2000-2002	Retrospective cohort	RYGB
Stefanoni et al	2006	Italy	1993-2004	Retrospective cohort	BPD (Scopinaro)
Westling et al	1998	Sweden	1994-1996	Prospective cohort	AGB
Westling et al	2001	Sweden	1997-1998	Randomized trial	RYGB

RYGB = Roux-en-Y Gastric bypass, VBG = vertical banded gastroplasty, BPD(-DS) = biliopancreatic diversion (with duodenal switch), AGB = adjustable gastric banding

Table 2: Patient baseline characteristics and operative times for each included study

Study	Procedure	Number of patients (N)		Age (mean ± SD, years)		Sex (F:M)		BMI (mean ± SD, kg/m2)		HTN (N)		T2D (N)		Operative times (mean ± SD, min)	
		Open	MIS	Open	MIS	Open	MIS	Open	MIS	Open	MIS	Open	MIS	Open	MIS
Agaba et al	RYGB	561	806	NA	NA	430:131	411:395	47.6 ± 5.69	46.2 ± 4.7	68	563	145	133	90 ± NA	116 ± NA
Azagra et al	VBG	34	34	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	60 ± NA	150 ± NA
Banka et al	RYGB	41094	115177	NA	NA	33081:8013	95482:19695	NA	NA	21657	61505	12904	34092	NA	NA
Benotti et al	RYGB	466	415	46 ± 10	43 ± 10	350:116	342:73	51 ± 8.4	46.3 ± 5.6	NA	NA	NA	NA	NA	NA
Bianchi et al	BPD (Scopinaro)	205	72	41.3 ± 11.7	46.5 ± 12.4	149:56	60:12	53.4 ± 7.3	51.6 ± 6.1	NA	NA	NA	NA	176.8 ± 44.9	174.7 ± 42.8
Biertho et al	BPD-DS	772	228	43.9 ± 10.1	40.3 ± 10.6	489:283	188:40	52.4 ± 8.4	46.8 ± 6.4	NA	NA	NA	NA	176 ± 39.7	224.2 ± 57.5
Buchs et al	RYGB	95	119	41 ± 10.7	41 ± 10.8	72:23	77:42	56 ± 6.9	53.9 ± 4.5	23	48	25	32	217 ± 41.2	241 ± 82.6
Buchs et al	RYGB	28	32	43 ± 11.7	44.3 ± 10	27:1	27:5	42 ± 9.6	40.7 ± 6.6	2	4	4	2	250 ± 65	298.2 ± 90.9
Campos et al	RYGB	72	332	NA	NA	49:23	287:45	57.4 ± NA	46.4 ± NA	NA	NA	NA	NA	322 ± NA	266 ± NA
Ceriani et al	BPD (Scopinaro)	40	40	41.7 ± 9.57	41.7 ± 9.57	28:12	26:14	54.6 ± 6.48	55.2 ± 5.71	NA	NA	NA	NA	190.8 ± 21.8	174.3 ± 35.1
Coskun et al	AGB	35	35	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	120 ± NA	150 ± NA
Courcoulas et al	RYGB	80	80	42 ± NA	43 ± NA	75:5	75:5	46 ± NA	44 ± NA	NA	NA	NA	NA	NA	NA
De Luca et al	AGB	17	47	36.3 ± NA	33.2 ±NA	NA	NA	51.7 ± NA	47.6 ± NA	NA	NA	NA	NA	110 ± NA	170 ± NA
de Wit et al	AGB	25	25	NA	NA	17:8	17:8	49.7 ± 5.6	51.3 ± 10.4	2	4	0	3	76 ± 20	150 ± 48
Edholm et al	BPD-DS	264	53	39.1 ± 9.9	35 ± 11.2	148:116	32:21	56.9 ± 6	55.7 ± 8.8	87	15	50	9	150 ± 31	163 ± 38
Gonzalez et al	RYGB	136	164	46.2 ± NA	45.2 ± NA	99:37	150:14	57.4 ± NA	49 ± NA	NA	NA	NA	NA	149.2 ± NA	174.6 ± NA
Hagen et al	RYGB	524	466	41.4 ± 10.1	41.8 ± 10.5	409:115	364:102	45.3 ± 6.8	44.5 ± 5.3	NA	NA	NA	NA	NA	NA
Hutter et al	RYGB	955	401	43.1 ± NA	41 ± NA	752:203	344:57	50.5 ± NA	47.5 ± NA	428	146	235	61	188.4 ± NA	204 ± NA
Kim J et al	RYGB	264	488	41.9 ± 9.1	43.1 ± 9.4	247:67	353:85	58.2 ± 11.1	51.4 ± 8.8	NA	NA	NA	NA	215.5 ± 62	182.9 ± 59.4

Kim W et al	BPD-DS	28	26	42 ± 8	42 ± 8	13:15	15:11	68.9 ± 10.1	66.9 ± 7.5	12	15	9	7	259 ± 60	210 ± 68
Lancaster et al	RYGB	1146	4631	44.1 ± 11.2	44 ± 11	915:231	3733:898	50.5 ± 10.1	47.9 ± 8.3	646	2445	371	1241	127.7 ± 61.6	144.5 ± 59.8
Lindsey et al	RYGB	2009	3912	42.6 ± NA	41.8 ± NA	1637:372	3197:715	NA	NA	1064	1883	586	1008	NA	NA
Luján et al	RYGB	51	53	38 ± NA	37 ± NA	38:13	43:10	52.2 ± NA	48.53 ± NA	NA	NA	NA	NA	201.7 ± NA	186.4 ± NA
Marema et al	RYGB	1198	1077	43.5 ± 0.4	45.5 ± 0.3	982:216	905:172	52 ± 0.4	47.9 ± 0.53	NA	NA	NA	NA	85 ± NA	95 ± NA
Marsk et al	RYGB	3040	1661	41.5 ± 10.2	40.4 ± 9.9	2332:708	1272:389	NA	NA	NA	NA	NA	NA	NA	NA
Nguyen et al	RYGB	35	35	42 ± 9	41 ± 9	32:3	30:5	48 ± 6	51 ± 6	18	17	15	7	294 ± 79	246 ± 70
Nguyen et al	RYGB	76	79	42 ± 9	40 ± 8	67:9	72:7	48.4 ± 5.4	47.6 ± 4.7	31	26	14	8	195 ± 41	225 ± 40
Nguyen et al	RYGB	6065	16357	NA	NA	4791:1274	13618:2739	NA	NA	3501	9015	2124	4979	NA	NA
Ricciardi et al	RYGB	22558	4382	41.5 ± 11.3	41.4 ± 10.5	18655:3903	3747:635	NA	NA	NA	NA	NA	NA	NA	NA
Sekhar et al	RYGB	399	568	42.9 ± NA	42.9 ± NA	305:94	489:79	58.9 ± 10.6	49.1 ± 7.6	NA	NA	NA	NA	195 ± 50	164 ± 50
Skroubis et al	RYGB	90	137	33.4 ± 9.9	36.7 ± 9.1	NA	NA	45.6 ± 5.2	46.4 ± 3.3	20	18	12	18	NA	NA
Smith S et al	RYGB	328	328	38 ± NA	41 ± NA	NA	NA	49.5 ± NA	46.7 ± NA	NA	NA	NA	NA	119 ± NA	155 ± NA
Stefanoni et al	BPD (Scopinaro)	105	45	38 ± NA	41 ± NA	82:23	35:10	49 ± NA	46 ± NA	NA	NA	NA	NA	140 ± NA	190 ± NA
Westling et al	AGB	27	63	NA	NA	NA	NA	45 ± NA	41.5 ± NA	NA	NA	NA	NA	91 ± NA	165 ± NA
Westling et al	RYGB	21	30	NA	NA	NA	NA	44 ± 4	41 ± 4	0	7	0	1	100 ± NA	241 ± NA

SD = standard deviation, BMI = body mass index, HTN = hypertension, T2D = type II diabetes mellitus, NA = data not available, RYGB = Roux-en-Y Gastric bypass, VBG = vertical banded gastroplasty, BPD(-DS) = biliopancreatic diversion (with duodenal switch), AGB = adjustable gastric banding, MIS = minimally invasive surgery

Table 3: Pooled early complication and mortality rates

Type of early complication	Number of occurrences		Rate		OR	95% CI	P-value
	Open group	MIS group	Open group	MIS group			
Gastrointestinal leak*	1101/58144	1737/142944	1.9%	1.2%	1.57	1.45-1.69	<0.0001
Wound infection/abscess	1473/79668	876/150578	1.8%	0.6%	3.22	2.96-3.50	<0.0001
Thromboembolic event	853/58648	1864/146331	1.5%	1.3%	1.14	1.05-1.24	0.0012
Cardiac complication	3000/72006	4284/132576	4.2%	3.2%	1.30	1.24-1.37	<0.0001
Pulmonary complication	3283/81206	3721/150713	4.0%	2.5%	1.66	1.59-1.75	<0.0001
Gastrointestinal obstruction	567/51403	1083/135607	1.1%	0.8%	1.38	1.25-1.53	<0.0001
Intraperitoneal abscess	328/54092	499/143735	0.6%	0.3%	1.75	1.52-2.01	<0.0001
Bleeding	941/58648	2480/146331	1.6%	1.7%	0.95	0.88-1.02	0.1492
Other	6629/59846	11223/147408	11.1%	7.6%	1.51	1.46-1.56	<0.0001
Mortality	335/82279	169/151892	0.4%	0.1%	3.67	3.05-4.42	<0.0001

*Patients who underwent adjustable gastric banding were not considered due to the absence of anastomosis and/or gastric partitioning

Odds ratios >1 favor minimally invasive surgery (MIS). Odds ratios <1 favor open surgery

MIS = minimally invasive surgery, OR = odds ratio, CI = confidence interval

Subgroup analyses

Subgroup analyses were performed for three types of bariatric procedures identified in this review, namely RYGB, AGB and BPD with/without DS. No subgroup analyses were performed for VBG due to limited data (only one available study with a total of 68 patients). For each subgroup, patient baseline characteristics, operative times and LOS are shown in Table 4. Comparison of patient baseline characteristics between open and MIS procedures was not possible in the AGB subgroup due to lack of data. In the other subgroups (RYGB and BPD with/without DS), the proportion of female patients was higher, the BMI lower and the LOS shorter among MIS patients ($p<0.0001$ for all three variables). Overall and individual complication rates for each bariatric procedure are shown in Figure 12.

RYGB subgroup

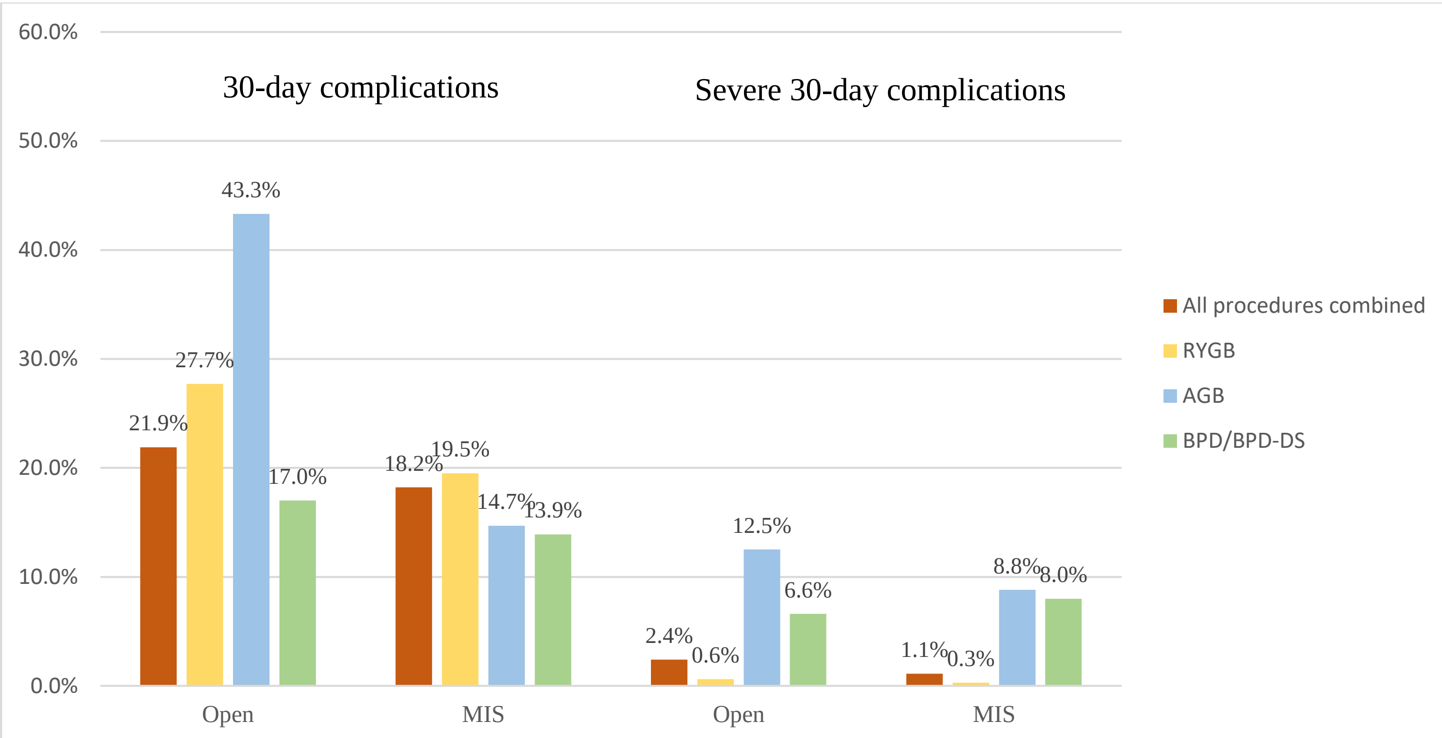
Data of 233'021 patients who underwent RYGB were collected across 24 studies, including 81'291 open and 151'730 MIS procedures. Operative times were significantly shorter among MIS patients. Intraoperative complications were reported in 4 studies and included 1 stapling of nasogastric tube, 7 splenic injuries requiring splenectomy and 1 splenic vein injury requiring suture repair for open cases, as well as 2 stapler misfirings and 1 trocar insertion injury to the duodenum for MIS cases, all three of which required conversion to open surgery. The rate of conversion to open surgery was 4.3% overall. Early and late postoperative complications after RYGB are shown in Table 5 and Figure 13. The rate of early major postoperative complications was significantly higher among patients undergoing open RYGB (0.6% [501/80'767) versus 0.3% [397/151'264], OR 2.37 with 95% CI 2.08-2.7, $p<0.0001$). When looking at each type of postoperative complication individually, incidence rates were all significantly lower among patients undergoing MIS procedures, including gastrointestinal leak rates, with the exception of comparable rates of bleeding (early complication), as well as anastomotic ulcers/strictures and small bowel obstruction requiring operative management (late complications). Reoperations (1.4%, [625/45'116] versus 0.5% [614/122'832], OR 2.80, 95% CI 2.50-3.13, $p<0.0001$) and readmissions (5.7% [578/10'137] versus 1.4%, [607/19'724], OR 1.90, 95% CI 1.69-2.14, $p<0.0001$) were significantly more frequent in patients undergoing open RYGB. These patients also had a significantly higher 30-day mortality compared to MIS patients (0.4% versus 0.1%, OR 3.76, 95%, CI 3.12 – 4.52, $p<0.0001$).

Table 4: Patient baseline characteristics, operative times and length of hospital stay for each type of bariatric procedure

	RYGB			AGB			BPD/BPD-DS		
	Open	MIS	P-value	Open	MIS	P-value	Open	MIS	P-value
Patients (N)	81291	151730	-	104	170	-	1414	464	-
Age (mean, years)	41.7 ± 10.9	42.6 ± 10.2	<0.0001	NA	NA	NA	42.4 ± 10.4	40.9 ± 11.2	0.013
Female patients (%)	80.8%	82.7%	<0.0001	68.0%	68.0%	0.9953	64.3%	76.7%	<0.0001
BMI (mean, kg/m2)	51.0 ± 8.5	47.8 ± 7.2	<0.0001	48.4 ± NA	45.4 ± NA	-	53.9 ± 8.3	50.8 ± 8.6	<0.0001
Hypertension (%)	52.6%	53.4%	0.0025	8.0%	16.0%	0.0491	33.9%	38.0%	0.5003
Diabetes Mellitus (%)	31.5%	29.3%	<0.0001	0.0%	12.0%	0.0001	20.2%	20.3%	0.9925
Operative times (mean, min)	163.4 ± 72.4	153.9 ± 63.8	<0.0001	100.3 ± NA	161.1 ± NA	NA	173.1 ± 42.5	202.3 ± 57.8	<0.0001
LOS (mean, days)	4.8 ± 12.6	2.9 ± 6.4	<0.0001	6.1 ± NA	3.5 ± NA	NA	7.6 ± 12.5	5.5 ± 11.7	0.003

RYGB = Roux-en-Y Gastric bypass, AGB = adjustable gastric banding, BPD(-DS) = biliopancreatic diversion (with duodenal switch), MIS = minimally invasive surgery, BMI = body mass index, NA = data not available or parameter not calculable, LOS = length of hospital stay

Figure 12: Rates of overall and severe 30-day complications



Severe complications are defined by a Dindo-Clavien score[34] ≥III or according to the American Society for Metabolic and Bariatric Surgery (ASMBS) criteria[35]

MIS = minimally invasive surgery, RYGB = Roux-en-Y Gastric bypass, AGB = adjustable gastric banding, BPD/BPD-DS = biliopancreatic diversion (- with duodenal switch),

Table 5: Early and late postoperative complications after Roux-en-Y gastric bypass

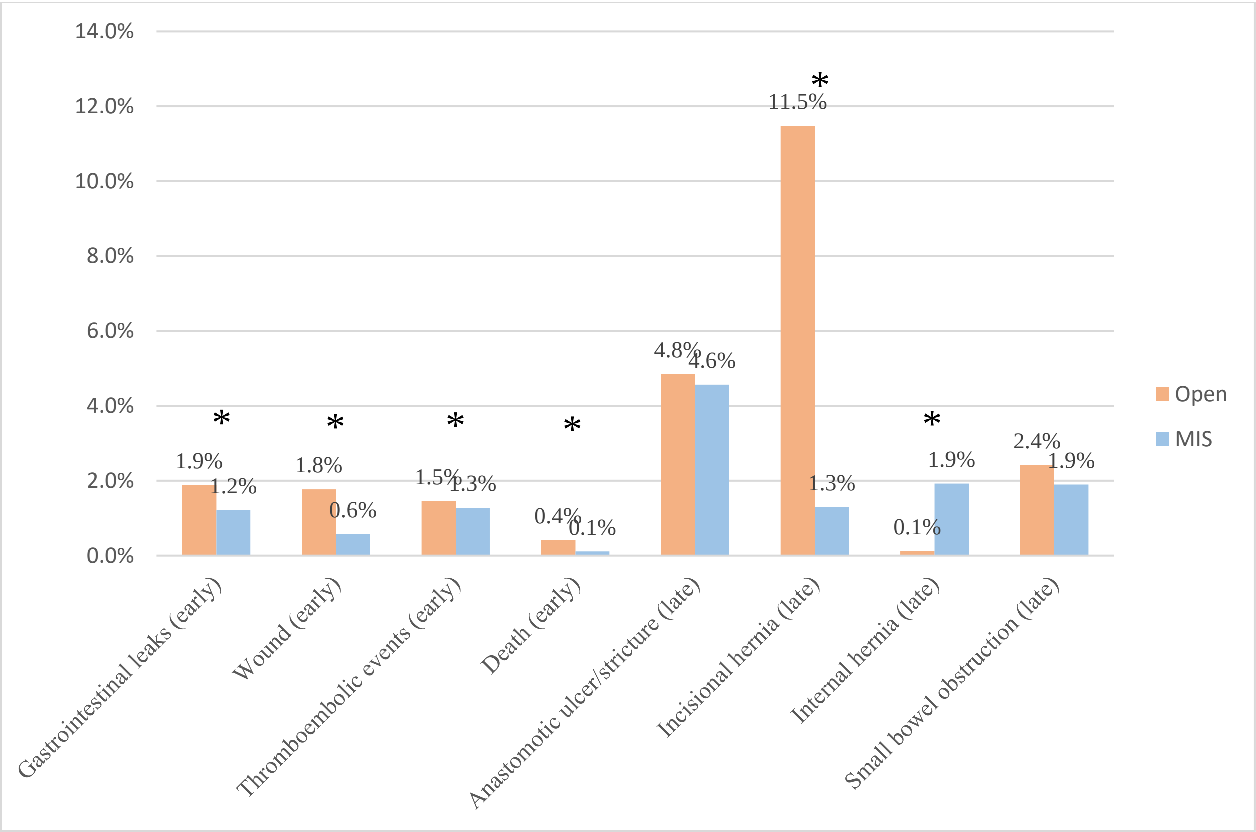
Type of complication	Number of occurrences		Rate		OR	95% CI	P-value
	Open group	MIS group	Open group	MIS group			
Early (<30 days)							
- Gastrointestinal leak	1066/56632	1725/142316	1.9%	1.2%	1.56	1.45-1.69	<0.0001
- Wound infection/abscess	1386/78156	866/149950	1.8%	0.6%	3.11	2.85-3.38	<0.0001
- Thromboembolic event	837/57136	1862/145703	1.5%	1.3%	1.15	1.06-1.25	0.0009
- Cardiac complication	2997/76559	4284/132067	3.9%	3.2%	1.22	1.16-1.27	<0.0001
- Pulmonary complication	3272/79694	3713/150085	4.1%	2.5%	1.69	1.61-1.77	<0.0001
- Gastrointestinal obstruction	539/49891	1061/119023	1.1%	0.9%	1.21	1.09-1.35	0.0003
- Intraperitoneal abscess	317/52580	496/127151	0.6%	0.4%	1.55	1.34-1.78	<0.0001
- Bleeding	926/57136	2476/145703	1.6%	1.7%	0.95	0.88-1.03	0.2147
- Other	6553/58239	11200/146780	11.3%	7.6%	1.53	1.49-1.58	<0.0001
- Death	332/80767	166/151264	0.4%	0.1%	3.76	3.12-4.53	<0.0001
Late (>30 days)							
- Anastomotic ulcer/stricture	106/2187	122/2673	4.8%	4.6%	1.07	0.82-1.39	0.6429
- Incisional hernia	251/2186	31/2378	11.5%	1.3%	9.82	6.83-14.33	<0.0001
- Internal hernia	2/1585	33/1716	0.1%	1.9%	0.06	0.016-0.27	<0.0001
- Small bowel obstruction[a]	57/2359	54/2839	2.4%	1.9%	1.28	0.88-1.86	0.2017

[a] Only includes patients who required operative management

Odds ratios >1 favor minimally invasive surgery. Odds ratios <1 favor open surgery.

MIS = minimally invasive surgery, OR = odds ratio, CI = confidence interval

Figure 13: Comparison of individual early and late postoperative complications after Roux-en-Y gastric bypass



Asterisks indicate statistically significant differences

MIS = minimally invasive surgery

AGB subgroup

Data of 274 patients who underwent AGB were collected, including 104 open and 170 MIS procedures. The rate of conversion to open surgery was 17.0%. One study reported a single intraoperative complication, which was a splenic injury requiring splenectomy which occurred during a MIS case. Early and late postoperative complications are shown in Table 6. The rate of early major postoperative complications was comparable between MIS and open patients (12.5% [13/104] versus 8.8% [15/170], OR 1.48, 95% CI 0.67-3.24, p=0.332). Patients who underwent MIS procedures had significantly lower rates of wound infections (early complications) and incisional hernias (late complications), and they underwent reoperations less frequently (8.85% [15/170] versus 53.9% [56/104], OR 0.08, 95% CI 0.04-0.16, p<0.0001). Readmission rates could not be calculated due to missing data. Early mortality was very low and comparable between both subpopulations.

BPD with/without DS subgroup

Data of 1878 patients who underwent BPD or BPD-DS were collected, including 1414 open and 464 MIS procedures. The rate of conversion to open surgery was 2.5%. One study reported intraoperative complications, which were 2 splenic injuries requiring splenectomy during open cases. Operative times were significantly longer among MIS patients. Early and late postoperative complications are shown in Table 7. The rate of early major postoperative complications was comparable among MIS and open cases (6.6% [90/1374] versus 8.0% [34/424], OR 0.80, 95% CI 0.53-1.21, p=0.298). Patients who underwent MIS procedures had significantly lower rates of wound infections (early complications) and incisional hernias (late complications), as well as significantly higher rates of anastomotic ulcers/strictures and reoperations due to severe nutritional deficiencies (late complications). There was a non-significant trend towards a higher rate of reoperations among MIS patients (7.3% [29/398] versus 4.8% [65/1346], OR 1.55, 95% CI 0.98-2.44, p=0.058). Readmissions and early mortality were comparable between both subpopulations.

Table 6: Early and late postoperative complications after adjustable gastric banding

Type of complication	Number of occurrences		Rate		OR	95% CI	P-value
	Open group	MIS group	Open group	MIS group			
Early (<30 days)							
- Wound infection/abscess	19/104	2/170	18.3%	1.2%	18.78	4.28-82.50	<0.0001
- Pulmonary complication	3/104	2/170	2.9%	1.2%	2.50	0.41-15.19	0.3211
- Band slippage	12/104	13/170	11.5%	7.6%	1.58	0.69-3.60	0.2777
- Other	11/104	7/170	10.6%	4.1%	2.75	1.03-7.35	0.0430
- Death	0/104	1/170	0.0%	0.6%	0.54	0.02-13.40	0.7073
Late (>30 days)							
- Incisional hernia	20/77	1/107	26.0%	0.9%	37.19	4.87-284.34	0.0005

Odds ratios >1 favor minimally invasive surgery. Odds ratios <1 favor open surgery.

MIS = minimally invasive surgery, OR = odds ratio, CI = confidence interval

Table 7: Early and late postoperative complications after biliopancreatic diversion with or without duodenal switch

Type of complication	Number of occurrences		Rate		OR	95% CI	P-value
	Open group	MIS group	Open group	MIS group			
Early (<30 days)							
- Gastrointestinal leak	33	11	2.4%	2.6%	0.92	0.46-1.84	0.8225
- Wound infection/abscess	64	7	4.7%	1.7%	2.91	1.32-6.40	0.0079
- Thromboembolic event	15	2	1.1%	0.5%	2.33	0.53-10.23	0.2627
- Cardiac complication	3	0	0.2%	0.0%	2.17	0.11-42.03	0.6093
- Pulmonary complication	8	5	0.6%	1.2%	0.49	0.16-1.51	0.2140
- Gastrointestinal obstruction	16	9	1.2%	2.1%	0.54	0.24-1.24	0.1467
- Intraperitoneal abscess	11	3	0.8%	0.7%	1.13	0.31-4.08	0.8489
- Bleeding	15	4	1.1%	0.9%	1.16	0.38-3.51	0.2610
- Other	65	16	4.7%	3.8%	1.27	0.72-2.22	0.4072
- Death	3	2	0.2%	0.5%	0.46	0.08-2.77	0.3981
Late (>30 days)							
- Anastomotic ulcer/stricture	31/1082	27/345	2.9%	7.8%	0.35	0.20-0.59	<0.0001
- Incisional hernia	82/1150	9/411	7.1%	2.2%	3.43	1.71-6.89	0.0005
- Small bowel obstruction[a]	22/877	4/273	2.5%	1.5%	1.73	0.59-5.07	0.3170
- Severe nutritional deficiencies[a]	1/772	4/228	0.1%	1.8%	0.07	0.01-0.65	0.0193

[a] Only includes patients who required operative management

Odds ratios >1 favor minimally invasive surgery. Odds ratios <1 favor open surgery.

MIS = minimally invasive surgery, OR = odds ratio, CI = confidence interval

Discussion

This systematic review of the literature showed overall significantly better postoperative outcomes in patients undergoing MIS compared to open bariatric surgery, with some nuances between the different types of bariatric procedures. These findings are in line with studies evaluating other types of abdominal surgeries, such as hepatobiliary and colorectal procedures[74-79], and support the use of MIS approaches as gold-standards for bariatric surgery. Of note, nearly 70% (24/35) of the studies considered in the present systematic review compared MIS and open RYGB, providing nearly 99% (233'021/235'173) of the patient population. The analyses were therefore mostly driven by the results of the RYGB subgroup, with AGB and BPD/BPD-DS subgroups having only a marginal impact. In addition, AGB studies and to a lesser extent BPD/BPD-DS studies mostly included initial laparoscopic experiences, whereas RYGB studies also included large cohorts of patients operated by surgeons with laparoscopic expertise. These elements certainly contributed to the differences in outcomes seen across bariatric procedures.

In the pooled analyses, MIS was superior to open surgery for all early postoperative complications, except for a comparable rate of postoperative bleeding, independently from the type of bariatric procedure. The differences in rates of wound complications, deep abdominal abscesses and pulmonary complications were particularly striking, with OR of 3.2, 1.7 and 1.8 against the open approach, respectively. Using minimal incisions and trocars most likely decreases the risk of wound contamination and subsequent complications such as wound abscess, dehiscence and incisional hernias when performing abdominal surgery, especially in patients with obesity[80-82]. MIS approaches also result in less pain and lower consumption of pain medication, allowing for more breathing comfort and subsequently decreasing the rate of pulmonary complications which are often linked to insufficient breathing patterns, especially after upper abdominal surgery[83, 84]. The lower gastrointestinal leak rate found among MIS patients could be explained by the technical difficulties and challenges to perform open upper abdominal anastomoses (i.e. gastrojejunostomy) in patients with obesity due to the excess of intraabdominal fatty tissue and the poor access to the hiatal region in these patients through a midline incision. This finding should however be considered with caution, since it could be influenced by a number of factors such as patient selection or surgical technique. Despite the absence of proof that a surgical technique to perform gastrointestinal anastomoses is superior to another (handsewn versus stapled, double- versus single-layer etc.), some studies report higher leak and stricture rates when gastrojejunal anastomoses are performed with a circular stapler[85, 86]. Indeed, circular staplers were used during the open era and at the beginning of the laparoscopic era to perform gastrojejunal anastomoses during bariatric surgery[27]. A more frequent usage of circular staplers to perform gastrointestinal anastomoses in the open group could therefore be a potential explanation for the increased leak rate. This hypothesis is supported by recent studies who found very low gastrointestinal leak rates (<0.5%) with the use of linear staplers during bariatric surgery[87, 88]. This hypothesis could unfortunately not be analyzed in the present article due to lack of detailed data about surgical techniques, especially in registry-based studies. A significantly lower rate of thromboembolic events was found among MIS patients as well, a finding in line with the recent literature[89, 90].. Several studies have shown that MIS results in decreased surgical trauma and adrenergic systemic response, which potentially explains the lower rate of postoperative cardiac complications in this group, despite the potentially adverse effects of pneumoperitoneum on hemodynamics[91]. Interestingly, bleeding rate was the only outcome that was comparable between groups (1.6% and 1.7%, p=0.1492). Although it could seem intuitive that bleeding control should be easier to perform during open surgery, by for instance allowing the use of vessel ligation and compression maneuvers that might be difficult to perform laparoscopically, several studies have shown decreased bleeding during laparoscopic surgery most likely due to a beneficial influence of the pneumoperitoneum and the emergence of advanced hemostatic devices[84, 92, 93]. The almost four-fold lower mortality in the MIS group (0.1% versus 0.4%, OR 3.67, p<0.0001) seems to be the logical consequence of the cumulative effect of all these improved individual outcomes after MIS.

In terms of late complications, the rate of incisional hernia was significantly lower in the MIS group in the overall analyses as well as in subgroup analyses. This expected finding has been previously confirmed in the literature[94]. The rate of incisional hernia in the open group might even be underestimated, since only patients who underwent surgical repair were reported. The present study however failed to show a higher rate of small bowel obstruction, as would be expected considering the increased intraabdominal adhesions usually created after open abdominal surgeries. Once again, included studies only reported small bowel obstructions requiring surgical management, thus potentially underestimating their real incidence in the open group.

Regarding secondary outcomes, patient undergoing MIS procedures had a significantly shorter LOS. Readmissions and reoperations were also less frequent among MIS patients in the RYGB subgroup, but a significant difference in these outcomes was not found in the AGB and BPD-BPD/DS subgroups probably due to the low number of patients. Even though reported in a few studies only, intraoperative complications seemed less frequent in the MIS group, especially in terms of intraoperative splenic injuries requiring splenectomy, which occurred in none of the MIS and in 10 open procedures. The overall rate of conversion to open surgery (4.2%) was reasonable, although most likely overestimated due to the inclusion of surgeons initial learning curves for laparoscopic surgery in the early studies.

When considering subgroups, there were significant differences in a number of baseline characteristics between the open and MIS patient cohorts, especially in the RYGB group, where patients undergoing open surgery were more likely to be male, to have a higher BMI and a higher prevalence of diabetes. This potential selection bias might result from a tendency to choose lower risk patients for the MIS approach in non-randomized studies, especially in the early era where laparoscopic expertise was still lacking. In the author's opinion, these differences were however too small to be clinically relevant (Δ = +1.9% for the proportion of male patients, +3.2 kg/m2 for BMI and +2.2% for the prevalence of diabetes) and unlikely to explain such remarkable differences in outcomes between open and MIS patients. Of note, the higher proportion of women undergoing MIS in the RYGB and BPD/BPD-DS subgroups could also reflect the greater consciousness and demand for better cosmetic results of female patients, as previously described in other studies[95, 96]. Interestingly, MIS operative times were significantly longer for AGB and BPD/BPD-DS, but shorter for RYGB, compared to open times. A hypothesis could be the increased time required to open and close a midline laparotomy incision during open surgery and the faster performance of stapled versus handsewn gastrointestinal anastomoses during laparoscopic RYGB, especially for surgeons who were beyond their laparoscopic learning curve. The rate of internal hernia after RYGB was interestingly one of the rare arguments in favor of the open approach, with a marked difference between the open and the MIS groups (0.1% versus 1.9%, $p<0.0001$). Although impossible to assess due to missing data, it is very likely that closure of the classical RYGB defects, which include the Petersen, the intermesenteric and the retrocolic spaces depending on RYGB technique, was not systematically performed in all studies, especially in the MIS groups. Indeed, many centers, including the author's institution, did not initially perform systematic closure of these defects when performing laparoscopic and robotically-assisted RYGB for the sake of diminishing operative times and probably also due to an underestimation of the risk of internal hernia. This attitude changed over time when increasing evidence showed a higher than expected incidence of internal hernia and leading most highvolume centers to perform systematic defect closure[97]. Even without defect closure, patients undergoing open RYGB would still be expected to have lower rates of internal hernia due to the formation of intraabdominal adhesions, which can theoretically close these defects and/or prevent intestinal loops from herniating through them. Unlike RYGB, BPD with/without DS performed by MIS resulted in a significantly higher rate of anastomotic strictures and ulcers compared to their open counterparts. This difference is most likely linked to the frequent use of relatively small-diameter (21mm and 25 mm) circular staplers to perform duodenoileostomy among MIS patients, especially in the studies performing BPD with duodenal switch [44, 58]. The only study where handsewn anastomoses were performed did not report rates of anastomotic ulcers or strictures[53]. The higher rate of reoperation due to severe nutritional deficiencies among patients who underwent MIS BPD/BPD-DS could potentially be linked to these anastomotic issues, since the authors did not report any other variations between their MIS and open surgical techniques. Of note, the advantages of the MIS approach were overall less marked in the AGB and the BPD/BPD-DS subgroups, with still a clear advantage for MIS in terms of wound infections and incisional hernias. Conclusions in these subgroups should however be taken with caution due to the limited number of patients.

This systematic review has several limitations. The majority of included studies were comparative retrospective cohorts, with only 5 randomized trials and 3 prospective cohorts, thus limiting the overall evidence level of the present review. A number of included studies were registry-based, with an inherent risk of collection bias. The potential heterogeneity and lack of detailed information about surgical techniques could also lead to potential biases and consequently limit the interpretation of the analyses. As mentioned above and showed in Table 4, the mean BMI, the proportion of male patients and the prevalence of diabetes MIS patients were all significantly lower among MIS patients, possibly leading to a selection bias and consequently to better outcomes for this approach, even though the differences were most likely too small to be clinically relevant. Consideration of independent predictors of postoperative complications with performance of a multiple logistic regression and calculation of adjusted odd ratios was unfortunately not possible due to the lack of detailed data, especially among registry-based studies where only pooled analyses were given. Of note, the inclusion of early studies where surgeons were still in their learning curves for laparoscopic and/or robotic procedures could have resulted in a bias towards poorer outcomes among MIS patients; given the nevertheless better outcomes of patients undergoing MIS procedures, this limitation actually turns into another argument in favor of an MIS approach.

Conclusion

In conclusion, this systematic review confirms the significant and numerous advantages of MIS over open approaches for patients undergoing bariatric surgery. Even though some specific findings, such as decreased gastrointestinal leak rates in the MIS group, should be considered with caution due to the limitations of the study, overall complication rates, especially surgical site infection and incisional hernia rates, were remarkably more favorable in the MIS group and ultimately resulted in an overall decrease in early postoperative mortality. These findings support the use of MIS as the gold-standard approach for bariatric surgery.

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