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REVIEW

The Impact of Bariatric Surgery Versus Non-Surgical Treatment on Blood Pressure: Systematic Review and Meta-Analysis

Laicheng Wang[1] · Meihua Lin[1] · Jianjian Yu[1] · Zongcheng Fan[1] · Shunpeng Zhang[1] · Yunchai Lin[1] · Xin Chen[1] · Feng Peng[1]

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Abstract

The purpose of this study was to compare bariatric surgery versus non-surgical treatment on blood pressure for patients with obesity. Nineteen RCTs (1353 total patients) were included. In the pooled analyses, bariatric surgery reduces more systolic blood pressure (WMD: − 3.937 mmHg, CI95%: − 6.000 to − 1.875, $p < 0.001$, $I^2 = 0\%$), diastolic blood pressure (WMD: − 2.690 mmHg, CI95%: − 3.994 to − 1.385, $P < 0.001$, $I^2 = 0\%$) and more antihypertensives. In subgroup analyses, patients after Roux-en-Y gastric bypass, with poor control of hypertension (BP > 130/80 mmHg) and diabetes mellitus (HbA1C > 7.0%, FPG > 7.0 mmol/L), elder patients (> 45 years), non-severe obesity (BMI < 40 kg/cm^2, body weight < 120 kg), less waist circumference (< 115 cm) tend to decrease more blood pressure. Besides, patients after surgery also lost more weight ($p < 0.001$), decreased more waist circumference ($p < 0.001$), fasting plasma glucose ($p < 0.001$), glycosylated hemoglobin ($p < 0.001$), triglycerides ($p < 0.001$), hsCRP ($p = 0.001$), increased more high-density lipoprotein cholesterol ($p < 0.001$), and had better remission of metabolic syndrome ($p < 0.001$). Changes in total cholesterol, low-density lipoprotein cholesterol, renal function, resting heart rate, and 6-min walking test were not significantly different. Therefore, bariatric surgery is more effective than non-surgical treatment in controlling patients' blood pressure.

Keywords Bariatric surgery is a more effective way of controlling patients' blood pressure · RYGB has the most certain efficacy on blood pressure reduction among all surgeries · LAGB has no advantage in blood pressure control compared to non-surgical treatment

✉ Feng Peng
pengfeng@fjmu.edu.cn; fengpengfuzhou@yeah.net

Laicheng Wang
1772879623@qq.com

Meihua Lin
124770358@qq.com

Jianjian Yu
jianjianyu1994@126.com

Zongcheng Fan
14563628@qq.com

Shunpeng Zhang
sp872035645@163.com

Yunchai Lin
yunchailin@163.com

Xin Chen
chenxinmd@163.com

[1] Department of Cardiology, The First Affiliated Hospital of Fujian Medical University, Chazhong Road 20, Fuzhou 350005, Fujian, China

Introduction

Hypertension is the leading cause of death and disability-adjusted life-years worldwide [1]. Lowering blood pressure can significantly reduce cardiovascular disease and death [2]. Obesity and overweight are the main risks of hypertension [3]. Blood pressure elevated is associated with an increase in body mass index [4]. Weight loss treatment can effectively lower blood pressure and reduce cardiovascular disease and death [5, 6].

The most common treatment options for obesity are non-surgical treatment and bariatric surgery [7]. Non-surgical treatment based on lifestyle modifications, exercise, and pharmacological therapy presents a limited efficacy, possibly because of the difficulty in adhering to lifestyle changes and concerning about the safety of anti-obesity drugs [7, 8]. So that, researchers are increasingly focusing on the potential benefits of bariatric surgery in reducing cardiovascular risk and controlling hypertension [9]. The SOS study [10] and cohort study conducted by Wu et al. [11] demonstrated no differences in blood pressure between surgery and non-surgical group. The randomized controlled trial conducted by Mingrone et al. [12] shows no significant additional benefit after bariatric surgery in lowering blood pressure. A meta-analysis of RCT in 2013 also found that patients in the operation group did not decrease more blood pressure [13]. However, with more evidence emerges, Schiavon et al. [14] revealed that patients who underwent bariatric surgery had a more significant drop in blood pressure and antihypertensives. It is time to reevaluate the efficacy of bariatric surgery on blood pressure.

Materials and Methods

Search Strategy

We conducted a systematic review of the English language literature published up to May first, 2021, by searching abstracts MEDLINE via PubMed, Embase, the Cochrane library, and Clinical Trials Registry, using the search terms:(bariatric surgery OR obesity surgery OR metabolic surgery OR digestive system surgical procedures OR gastric bypass OR gastrointestinal surgery OR laparoscopic adjustable gastric banding OR LAGB OR Roux-en-Y gastric bypass OR sleeve gastrectomy OR (duodenal AND switch)) AND (medical therapy OR non-surgical treatment OR behavioral therapy OR dietary changes OR (reducing AND energy intake) OR pharmacotherapies OR physical activity) AND blood pressure. Additional cross-referencing was carried out for all the included studies. This systematic review was performed according to the recommendations of the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. Two researchers (LW and JY) independently searched for literature, selected studies, assessed quality, and extracted data from articles and then cross-checked. Any disagreement was resolved by consulting a third reviewer (ML).

Eligibility Criteria

Studies were eligible if they were randomized controlled trials($\geq$ 12-month follow-up); included individuals with a body mass index $\geq$ 28; investigated all currently available bariatric surgeries (including laparoscopic adjustable gastric banding (LAGB), Roux-en-Y gastric bypass (RYGB), sleeve gastrectomy (SG), biliopancreatic diversion with duodenal switch (BPD/DS), vertical banded gastroplasty, duodenal-jejunal bypass liner (DJBL)); investigated as comparator non-surgical treatment for obesity (diet, weight reducing drugs, behavioral therapy); and reported changes in blood pressure or changes in the use of antihypertension medications.

Risk of Bias

The risks of bias were assessed for all studies by two researchers (LW and JY) independently using the Cochrane collaboration's tool and risk of bias tool, which evaluates the selection, performance, detection, attrition, and reporting bias.

Data Extraction

The primary outcome was the mean change of systolic blood pressure, diastolic blood pressure, and antihypertensives. Furthermore, secondary outcomes comprised change in body weight (BW); body mass index (BMI); waist circumference (WC); fasting plasma glucose (FPG); glycosylated hemoglobin (HbA1c); fasting levels of plasma triglycerides concentration (TG), total cholesterol concentration (TC), high-density and low-density lipoproteins cholesterol concentration (HDL and LDL), remission of metabolic syndrome, 6-min walk test, resting heart rates, serum creatinine (Scr), glomerular filtration rate (GFR), and lipid-lowering medications and antidiabetic drugs, along with adverse events. We extracted the outcome parameters of all the included studies by using a standardized data form.

Statistical Analyses

The Stata software (v16.0, StataCorp LP, College Station, TX, USA) was used for statistical analysis. Individual weighted mean difference (WMD) and 95% confidence interval (95% CI) were calculated from each trial for continuous data. Relative risks (with 95% confidence intervals) were calculated for dichotomous data.

Outcome measures were quantitatively summarized using the DerSimonian and Laird method random-effects model [15]. For some studies, the mean change from baseline to end of follow-up was calculated. Missing standard deviations were derived from other statistics, such as confidence intervals and standard error. Because no other statistic was available, several studies' standard deviations were substituted by the mean standard deviations of similar studies [16]. For example, the standard deviation of the Tur's (2013) [17] study was replaced by the standard deviation of the Mingrone (2021) [12] study's BPD group. Some data were obtained from other reports of the same research.

We used I^2 value to quantify the heterogeneity between different trials. This value is calculated as the percentage of between-study diversity due to heterogeneity rather than chance, with higher values indicating stronger evidence of heterogeneity. Stratified analyses based on operation type, patients' age, weight, waist circumference, blood pressure, fasting blood glucose, blood lipids, and glycosylated hemoglobin were conducted to look for potential causes of heterogeneity. Publication bias was evaluated by the Begg's and Egger's tests; the significance level was defined as $P < 0.10$ [18].

Result

Eligible Trials

The flow diagram for the search is shown in Fig. 1. From 1728 records, 19 studies (n = 1 353) were eligible and included in the meta-analysis, including 663 subjects in the bariatric surgery group and 690 subjects in the control group. The average follow-up of all clinical trials was 2.80 years, with a range from 1 to 10 years. We illustrate the characteristics of all eligible trials and study patients in Table 1.

Non-Surgical Treatment

All studies' participants in both groups receive standardized medical treatment containing low-carbon diet, life modification, pharmacotherapy, and regular consultation meeting. Four studies [19, 22, 24, 26] include very low-carbon diet; others depend on patients' willingness. Besides, medication use relies on physician decisions according to specific algorithms. Among these, three studies had pointed out using sibutramine or orlistat [19, 22, 31]. Two studies used GLP-1RA [23, 24], and one study used metformin as a comparator [33].

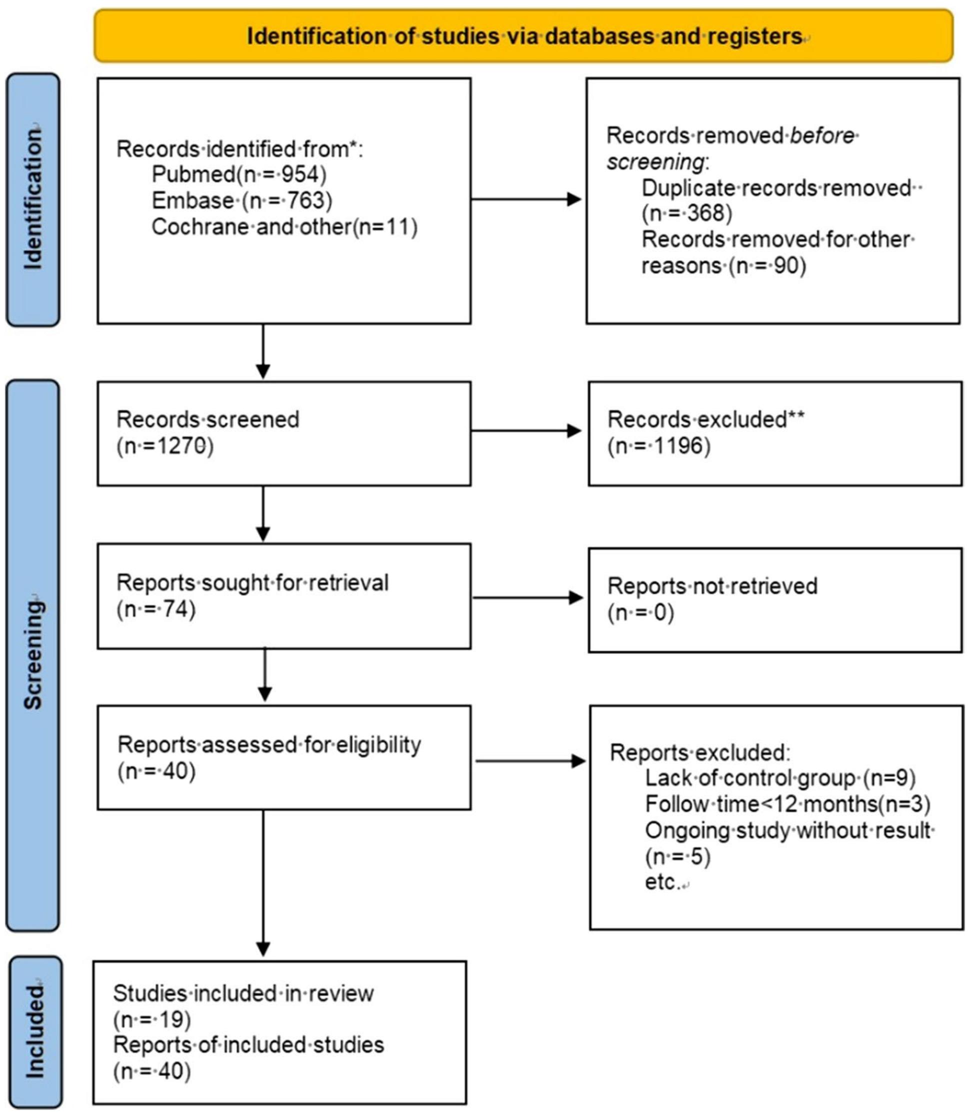


Fig. 1 Flow diagram of search strategy and trial selection

Table 1 The baseline characteristics of all eligible trials in this meta-analysis

Num	Study ID	Group	Ethnicity (country)	N,group	Follow-up (years)	Age (years)	Female%	BMI (kg/m^2)	Body weight (kg)	SBP (mmHg)	DBP (mmHg)	HT rate (%)	DM rate (%)	Ms rate (%)
1	O'Brien (2006) [19]	LAGB	Australian	40	2	41.8 (6.4)	75%	33.7 (1.8)	96.1 (11.2)	131.4 (14.0)	83.2 (11.7)	23%	100%	38%
		Control	Australian	40	2	40.1 (7.0)	78%	33.5 (1.4)	93.6 (11.9)	130.3 (13.5)	81.0 (9.7)	18%	100%	38%
2	Dixon2008[20]	LAGB	Australian	30	2	46.6 (7.4)	85%	37 (2.7)	105.6 (13.8)	136.4 (15.6)	86.6 (9.4)	28%	100%	29%
		Control	Australian	30	2	47.1 (8.7)	87%	37.2 (2.5)	105.9 (14.2)	135.3 (14.4)	84.5 (9.8)	27%	100%	29%
3	O'Brien2010[21]	LAGB	Australian	25	2	16.5 (1.4)	91%	42.3 (6.1)	120.7 (25.3)	122.0 (13.9)	72.4 (7.5)	NR	NR	36%
		Control	Australian	25	2	16.6 (1.2)	93%	40.4 (3.1)	115.4 (14.0)	132.8 (15.9)	76.5 (10.5)	NR	NR	40%
4	Dixon (2012) [22]	LAGB	Australian	30	2	47.4 (8.8)	43%	46.3 (6.0)	134.9 (22.1)	137.6 (18.7)	83.1 (8.2)	50%	33%	63%
		Control	Australian	30	2	50.0 (8.2)	40%	43.8 (4.9)	126.0 (19.3)	142.2 (16.9)	86.8 (8.8)	57%	33%	80%
5	Liang (2013) [23]	RYGB	China	31	1	50.8 (5.4)	29%	30.5 (0.9)	82.0 (3.5)	160.8 (7.8)	88.6 (5.5)	100%	100%	NA
		Control	China	70	1	51.4 (6.2)	31%	30.3 (1.7)	81.5 (4.3)	150.8 (10.3)	86.9 (8.9)	100%	100%	NA
6	Parikhe 2014[24]	SG	India	14	1	47 (12)	93%	40.5 (4.6)	99.5 (13.0)	NA	NA	82%	100%	NA
		Control	India	17	1	52 (12)	59%	35.8 (5.0)	90.4 (7.4)	NA	NA	86%	100%	NA
7	Koehestanie (2014) [25]	DJBL	Netherlands	34	1	49.5 (34.2)	38%	34.6 (12.2)	105.4 (38.3)	147 (36.3)	92 (30.0)	NA	NA	NA
		Control	Netherlands	39	1	49.0 (23.5)	36%	36.8 (20.0)	110.8 (63.6)	152 (47.0)	90 (30.0)	NA	NA	NA
8	Halperin 2014[26]	RYGB	American	22	1	50.7 (7.6)	68%	36.0 (3.5)	104.6 (15.5)	132.8 (10.5)	81.7 (7.4)	NA	NA	NA
		Control	American	21	1	52.6 (4.3)	53%	36.5 (3.4)	102.7 (17.0)	126.3 (14.7)	76.6 (8.8)	NA	NA	NA
9	Simonson (2019) [27]	LAGB	American	18	3	51.0 (12.7)	50%	36.4 (3.0)	106.8 (10.4)	129 (7)	79 (5)	NA	100%	NA
		Control	American	22	3	51.6 (7.5)	41%	36.7 (4.2)	111.6 (17.9)	126 (13)	81 (8)	NA	100%	NA
10	Courcoulas (2020) [28]	RYGB	American	24	3	46.3 (7.2)	79%	35.5 (2.6)	99.8 (12.8)	139.4 (12.1)	81.1 (9.2)	50%	100%	NA
		LAGB	American	22	3	47.3 (7.0)	82%	35.5 (3.4)	99.5 (14.1)	134.7(17.0)	77.2 (8.7)	59%	100%	NA
		Control	American	23	3	48.3 (4.7)	83%	35.7 (3.3)	102.6 (13.8)	132.0 (17.8)	76.3 (9.7)	70%	100%	NA
11	Schauer (2017) [29]	RYGB	American	50	5	48.3 (8.4)	52%	37.0 (3.3)	106.7 (14.8)	134.7 (18.9)	81.8 (10.2)	70%	100%	90%
		SG	American	50	5	47.9 (8.0)	78%	36.2 (3.9)	100.8 (16.4)	136.7 (17.9)	82.2 (11.7)	60%	100%	94%
		Control	American	50	5	49.7 (7.4)	62%	36.8 (3.0)	106.5 (14.7)	135.6 (17.7)	82.0 (11.4)	60%	100%	92%
12	Azevedo (2018) [30]	SG	Brazil	10	2	45 (10)	NA	33.4 (2.6)	102.2 (12.2)	NA	NA	90%	100%	NA
		Control	Brazil	10	2	56 (7)	NA	30.3 (2.1)	88.5 (11.7)	NA	NR	100%	100%	NA
13	Ikramuddin (2018) [31]	RYGB	American and Taiwan	60	5	49 (9)	63%	34.9 (3.0)	98.8 (14.0)	127 (15)	78 (12)	NA	100%	NA
		Control	American and Taiwan	60	5	49 (8)	57%	34.3 (3.1)	97.9 (17.0)	132 (14)	79 (10)	NR	100%	NR
14	Schiavon (2020) [14]	RYGB	Brazil	50	3	43.1 (9.2)	82%	37.5 (2.1)	NA	118.9 (16.6)	73.8 (14.1)	100%	8%	NA
		Control	Brazil	50	3	44.6 (9.2)	70%	36.6 (3.0)	NA	122.6 (16.6)	76.5 (14.1)	100%	8%	NA

Table 1 (continued)

Num	Study ID	Group	Ethnicity (country)	N,group	Follow-up (years)	Age (years)	Female%	BMI (kg/m^2)	Body weight (kg)	SBP (mmHg)	DBP (mmHg)	HT rate (%)	DM rate (%)	Ms rate (%)
15	Mingrone (2021) [12]	BPD	Italy	20	10	42.75 (8.0)	50%	45.14 (7.8)	137.85 (30.35)	154.50 (29.7)	95.9 (12.9)	NA	100%	NA
		RYGB	Italy	20	10	43.90 (7.6)	60%	44.85 (5.2)	129.84 (22.58)	145.75 (20.5)	91.5 (14.2)	NA	100%	NA
		Control	Italy	20	10	43.45 (7.3)	50%	45.62 (6.2)	136.40 (21.94)	155.20 (34.2)	96.0 (17.5)	NA	100%	NA
16	Tur (2013) [17]	BPD	Spain	37	1	44.12 (9.8)	72%	49.23 (5.9)	132.81 (24.37)	132.57 (14.4)	82.84 (8.9)	NA	NA	NA
		Control	Spain	106	1	47.84 (11.5)	70%	45.79 (5.0)	122.24 (20.05)	131.85 (18.7)	86.83 (10.0)	NA	NA	NA
17	Cummings (2016) [32]	RYGB	American	15	1	52.0 (8.3)	80%	38.3 (3.7)	108.8 (14.9)	129.3 (20.6)	77.0 (10.2)	80%	100%	NA
		Control	American	17	1	54.6 (6.3)	59%	37.1 (3.5)	112.8 (16.5)	120.1 (9.6)	74.8 (7.5)	94%	100%	NA
18	Xiang (2018) [33]	LAGB	American	36	2	47 (10)	77%	35.7 (2.9)	97.5 (12.2)	127.1 (10.5)	78.3 (7.5)	NA	100%	NA
		Control	American	34	2	51 (9)	79%	35 (2.9)	96.1 (10.9)	126.4 (10)	75.9 (8.1)	NA	100%	NA
19	Wentworth (2014) [34]	LAGB	Australian	25	2	53 (6)	76%	29 (1)	81 (10)	130 (18)	83 (10)	NA	100%	NA
		Control	Australian	26	2	53 (7)	65%	29 (1)	83 (12)	131 (11)	84 (9)	NA	100%	NA

Data are presented as mean (SD) unless otherwise indicated

N group stands for participates number in each groups; *SBP* stands for systolic blood pressure; *DBP* stands for diastolic blood pressure; *HT rate* stands for hypertension prevalence (%); *DM rates* stand for type 2 diabetes Prevalence (%); *MS rates* stand for metabolic syndrome prevalence(%); *NA* stands for no addressed in the study

Table 2 Summary of risk of bias assessment for studies included in meta-analysis

RCT study	Random sequence generation	Allocation concealment	Blinding for participate and personnel	Blinding of outcome assessment	free of Incomplete data assessment	Free of selective reporting	Free of other sources of bias
O'Brien (2006)	Yes	Yes	No	Unclear	No	Yes	Yes
Dixon (2008)	Yes	Yes	No	Unclear	Yes	Yes	Yes
O'Brien (2010)	Unclear	Yes	No	Unclear	No	Yes	Yes
Dixon (2012)	Yes	Yes	No	Unclear	Yes	Yes	Yes
Liang (2013)	Yes	Yes	No	Unclear	Yes	Unclear	Yes
Parikhe (2014)	Unclear	Unclear	No	Unclear	Yes	Unclear	Yes
Koehestanie (2014)	Unclear	Unclear	Yes	Unclear	Yes	Unclear	Yes
Halperin (2014)	Yes	Yes	No	Unclear	No	Yes	Yes
Simonson (2019)	Yes	Yes	No	Unclear	No	Yes	Yes
Courcoulas (2020)	Yes	Yes	No	Unclear	Yes	Yes	Yes
Schauer (2017)	Yes	Yes	No	Unclear	Yes	Yes	Yes
Azevedo (2018)	Yes	Yes	No	Unclear	Yes	Yes	No
Ikramuddin (2018)	Yes	Yes	No	Yes	No	Yes	Yes
Schiavon (2020)	Yes	Yes	No	Yes	No	Yes	Yes
Mingrone (2021)	Yes	Yes	No	Yes	No	Yes	Yes
Tur (2013)	Yes	Yes	No	Unclear	No	Unclear	Yes
Cummings (2016)	Yes	Yes	No	Yes	Yes	Yes	Yes
Xiang (2018)	Yes	Yes	No	Unclear	No	Yes	Yes
Wentworth (2014)	Yes	Yes	No	Unclear	Yes	Yes	Yes

More information about risk of bias assessment in Supplementary S1

Risk of Bias Assessment

Results of the risk of bias assessment are presented in Table 2 and Supplementary S1. One study had a high bias for deviations from intended interventions. Two studies had high biases for missing outcomes because of the high rate of loss to follow-up. Bias for the randomization process, measurement of the outcome, and selection reported were low in most studies.

Outcomes

Change of Systolic Blood Pressure

Overall effect estimates and subgroup analysis by operation type of systolic blood pressure are provided in Fig. 2. Systolic blood pressure decreased more after bariatric surgery, with a mean reduction of − 3.937 mmHg (CI95%: − 6.000 to − 1.875, $p<0.001$). Heterogeneity among studies was low ($I^2=0\%$).

Subgroup analyses by operation type, age, body weight, waist circumference, blood pressure, fasting blood glucose, blood lipids, and glycosylated hemoglobin of trial patients are summarized in Table 3; patients after Roux-en-Y gastric bypass decrease − 5.751 mmHg (CI95%: − 10.104 to − 1.398, $P=0.01$, $I^2=40.8\%$) more than the non-surgical group. No statistical significantly difference of systolic blood pressure was found in LAGB group ($p=0.115$), DJBL group ($p=0.323$), SG group ($p=0.433$), and BPD group ($p=0.298$). Bariatric surgery tends to reduce more systolic blood pressure in patients with poor control of hypertension (BP > 130/80 mmHg) and diabetes mellitus (HbA1C > 7.0%, FPG > 7.0 mmol/L), elder age (> 45 years), non-severe obesity (BMI < 40 kg/cm^2, body weight < 120 kg), and less waist circumference (WC < 115 cm).

Change of Diastolic Blood Pressure

The mean change in diastolic blood pressure was pooled for 16 studies (Fig. 3). Diastolic blood pressure in the surgery group decreased 2.690 mmHg (CI95%: − 3.994 to − 1.385, $P<0.001$) more than in the non-surgical group. Heterogeneity among studies was low ($I^2=0.0\%$).

Subgroup analyses by operation type, age, body weight, waist circumference, blood pressure, fasting blood glucose, blood lipids, and glycosylated hemoglobin of trial patients in Table 3, diastolic blood pressure decreased more after Roux-en-Y gastric bypass surgery(WMD: − 2.536, CI95%: − 4.690 to − 0.382, $p<0.001$, I^2:0.0%) and duodenal-jejunal bypass liner surgery(WMD: − 5.000, CI95%: − 9.819 to − 0.181, $p=0.042$). No significant difference of diastolic blood

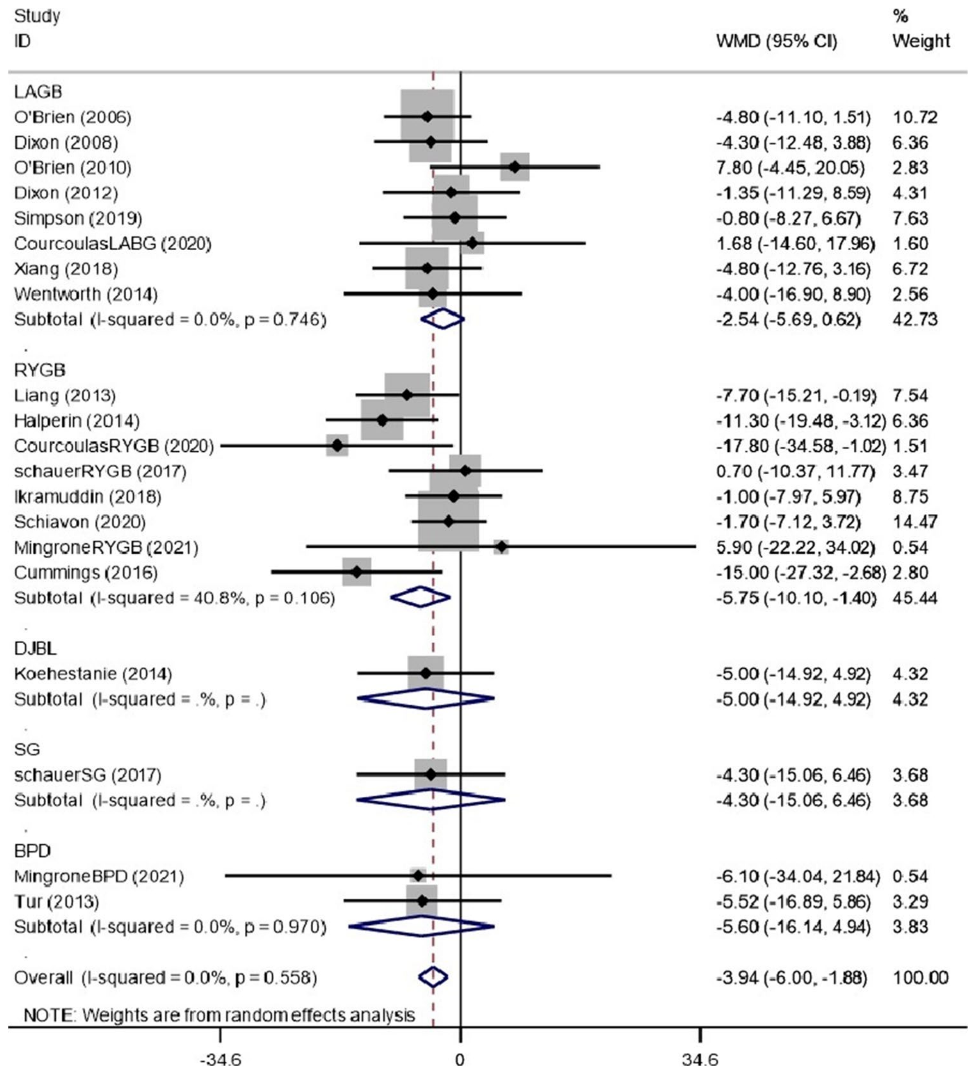


Fig. 2 Overall estimate and subgroup analysis by surgical type of mean change in systolic blood pressure after bariatric surgery versus control groups. Standard deviations (SD) were imputed by taking the median SD of the LABG groups for Xiang (2018). Standard deviations (SD) were imputed by taking the median SD of the RYGB groups for Cummings (2026) and Liang (2013). Standard deviations (SD) were imputed by taking the median SD of the BPD groups for Tur (2013)

pressure was found in LAGB group (p = 0.098, I^2: 37.1%), SG group (p = 0.249), and BPD group (p = 0.479, I^2 = 0.0%). Besides that, patients with poor control of hypertension (BP > 130/80 mmHg) and diabetes mellitus (HbA1C > 7.0%, FPG > 7.0 mmol/L), elder age (> 45 years), non-severe obesity (BMI < 40 kg/cm2, body weight < 120 kg), and less waist circumference (WC < 115 cm) may decrease more diastolic blood pressure after surgery.

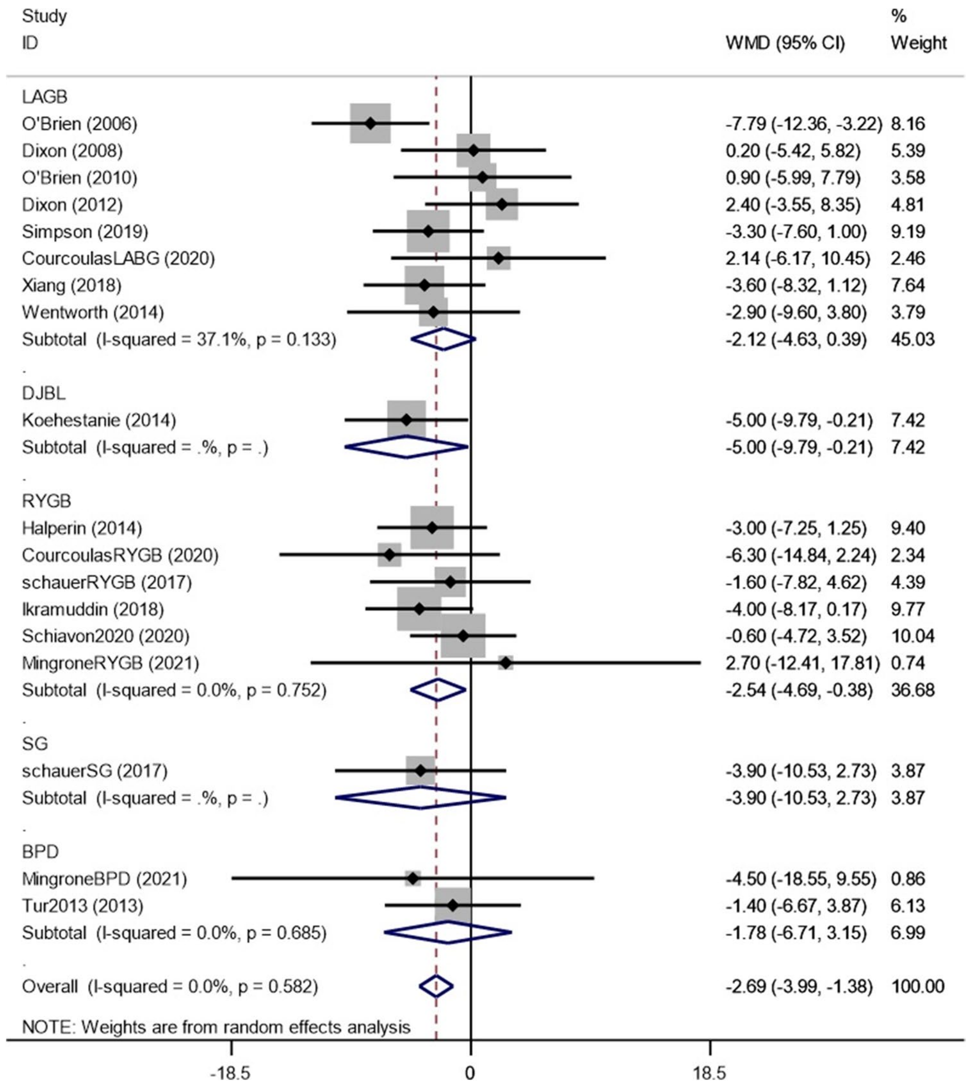
Change of Antihypertensives

The endpoint of antihypertensives in the surgery group and the control group was mentioned in eleven studies. Palikhe (2014) [24], Halperin (2014) [26], Schauer (2017) [29], Schiavon (2020) [14], and Mingrone (2021) [12] reported the number of antihypertensives taken per capita at baseline and endpoint. Cummings' (2016) [32] study suggested that patients in surgery groups took fewer antihypertensives than those in the control group at the endpoint, but did not report baseline status. Meta-analysis of above studies showed that patients in the surgical group reduce 0.912 (CI95%: – 1.493 to – 0.331, p = 0.002, I^2 = 82.4%) per capita antihypertensives (Fig. 4A). Whereas no antihypertensives were reduced in the control group (p = 0.776 in Fig. 4B), Dixon (2008) [20], Palikhe (2014) [24], Ikramuddin (2018) [31], and Wentworth (2014) [34] reported the number of patients receiving anti-hypertension drugs at the beginning and the endpoint; the medicine rate of surgery group decreased from 67.3 (CI95%: 59.2 to 75.3%) to 37.3% (CI95%: 29.0 to 45.6%), compared to control group from 70.9 (CI95%: 63.1 to 78.7%) to 68.4% (CI95%: 60.3 to 76.5%). However, Dixon (2012) [22] and Koehestanie (2014) [25] only reported changes in antihypertensive drugs were not statistically significant .

Table 3 Subgroup analysis of mean change in systolic blood pressure and diastolic blood pressure

		Mean change in systolic blood pressure						Mean change in diastolic blood pressure					
Subgroups	Range	Groups	WMD	95% CI		P	I^2	groups	WMD	95% CI		P	I^2
Age (years)	< 45	6	− 2.228	− 5.852	1.397	0.228	0.00%	6	− 2.426	− 5.655	0.804	0.141	34.20%
	> 45	14	− 4.756	− 7.265	− 2.248	< 0.001	0.00%	12	− 2.726	− 4.28	− 1.172	0.001	0.00%
BMI (kg/m^2)	> 40	15	− 4.427	− 6.62	− 2.235	< 0.001	0.00%	13	− 3.259	− 4.683	− 1.834	< 0.001	0.00%
	< 40	5	− 0.172	− 6.251	5.907	0.956	0.00%	5	0.268	− 2.979	3.516	0.871	0.00%
Body weight (kg)	< 100	6	− 4.963	− 8.318	− 1.609	0.004	0.00%	5	− 4.917	− 7.235	− 2.6	< 0.001	0.00%
	100–120	9	− 4.121	− 7.201	− 1.042	0.009	8.30%	8	− 2.251	− 4.057	− 0.445	0.015	0.00%
	> 120	5	− 0.172	− 6.251	5.907	0.956	0.00%	5	0.268	− 2.979	3.516	0.871	0.00%
Waist circumference (cm)	< 115	8	− 2.914	− 5.847	0.019	0.051	0.00%	8	− 2.846	− 5.11	− 0.582	0.014	24.10%
	> 115	8	− 4.01	− 9.218	− 9.218	0.131	37.30%	8	− 1.87	− 4.16	0.419	0.109	0.00%
SBP (mmHg)	< 130	5	− 2.625	− 7.704	2.454	0.311	45.00%	4	− 1.991	− 4.355	0.373	0.099	0.00%
	> 130	15	− 4.743	− 7.29	-2.196	< 0.001	0.00%	14	− 2.995	− 4.56	− 1.431	< 0.001	0.00%
DBP (mmHg)	> 80	7	− 2.028	− 5.649	1.593	0.272	21.00%	6	− 3.041	− 4.773	− 1.308	0.001	0.00%
	< 80	13	− 5.523	− 8.299	− 2.747	< 0.001	0.00%	12	− 2.212	− 4.209	− 0.216	0.03	0.80%
FPG (mmol/L)	< 7.0	6	− 2.6	− 5.77	0.57	0.108	0.00%	6	− 2.021	− 4.955	0.913	0.177	49.20%
	> 7.0	14	− 4.919	− 7.635	− 2.203	< 0.001	0.00%	12	− 2.986	− 4.675	− 1.297	0.001	0.00%
HbA1C (%)	< 7.0	5	− 2.904	− 6.588	0.78	0.122	0.00%	7	− 2.154	− 4.722	0.413	0.1	39.20%
	> 7.0	13	− 4.978	− 7.809	− 2.148	0.001	2.60%	11	− 2.992	− 4.737	− 1.246	0.001	0.00%
TC (mmol/L)	< 4.5	5	− 4.957	− 11.914	1.999	0.163	60.90%	4	− 3.122	− 5.52	− 0.724	0.011	0.00%
	> 4.5	12	− 4.341	− 7.137	− 1.546	0.002	0.00%	11	− 2.719	− 4.747	− 0.692	0.009	15.90%
TG (mmol/L)	< 1.8	11	− 5.649	− 9.281	− 2.018	0.002	18.80%	10	− 3.487	− 5.302	− 1.672	< 0.001	0.00%
	> 1.8	9	− 2.597	− 5.335	0.14	0.063	0.00%	8	− 1.837	− 3.714	0.039	0.055	0.00%
HDL (mmol/L)	< 1.2	15	− 3.798	− 6.471	− 1.124	0.005	13.30%	14	− 2.239	− 3.745	− 0.733	0.004	0.00%
	> 1.2	4	− 4.6	− 8.617	− 0.582	0.025	0.00%	4	− 3.831	− 7.227	− 0.436	0.027	39.10%
LDL (mmol/L)	< 2.6	7	− 5.156	− 9.314	− 0.999	0.015	22.00%	6	− 3.083	− 5.133	− 1.033	0.003	0.00%
	2.6–3.4	7	− 2.91	− 6.407	0.587	0.103	0.00%	7	− 2.521	− 4.675	− 0.367	0.022	0.00%
	> 3.4	3	− 5.998	− 10.754	− 1.242	0.013	0.00%	2	− 7.475	− 11.818	− 3.132	0.001	0.00%
Operation type	LAGB	8	− 2.535	− 5.69	0.62	0.115	0.00%	8	− 2.122	− 4.633	0.39	0.098	37.10%
	RYGB	8	− 5.751	− 10.104	− 1.398	0.01	40.80%	6	− 2.536	− 4.69	− 0.382	0.021	0.00%
	DJBL	1	− 5	− 14.921	4.921	0.323	-	1	− 5	− 9.789	− 0.211	0.041	-
	SG	1	− 4.3	− 15.056	6.456	0.433	-	1	− 3.9	− 10.529	2.729	0.249	-
	BPD	2	− 5.599	− 16.137	4.94	0.298	0.00%	2	− 1.782	− 6.715	3.152	0.479	0.00%

Fig. 3 Overall estimate and subgroup analysis by surgical type of mean change in diastolic blood pressure after bariatric surgery versus control groups. Standard deviations (SD) were imputed by taking the median SD of the LABG groups for Xiang (2018). Standard deviations (SD) were imputed by taking the median SD of the RYGB groups for Cummings (2026) and Liang (2013). Standard deviations (SD) were imputed by taking the median SD of the BPD groups for Tur (2013)



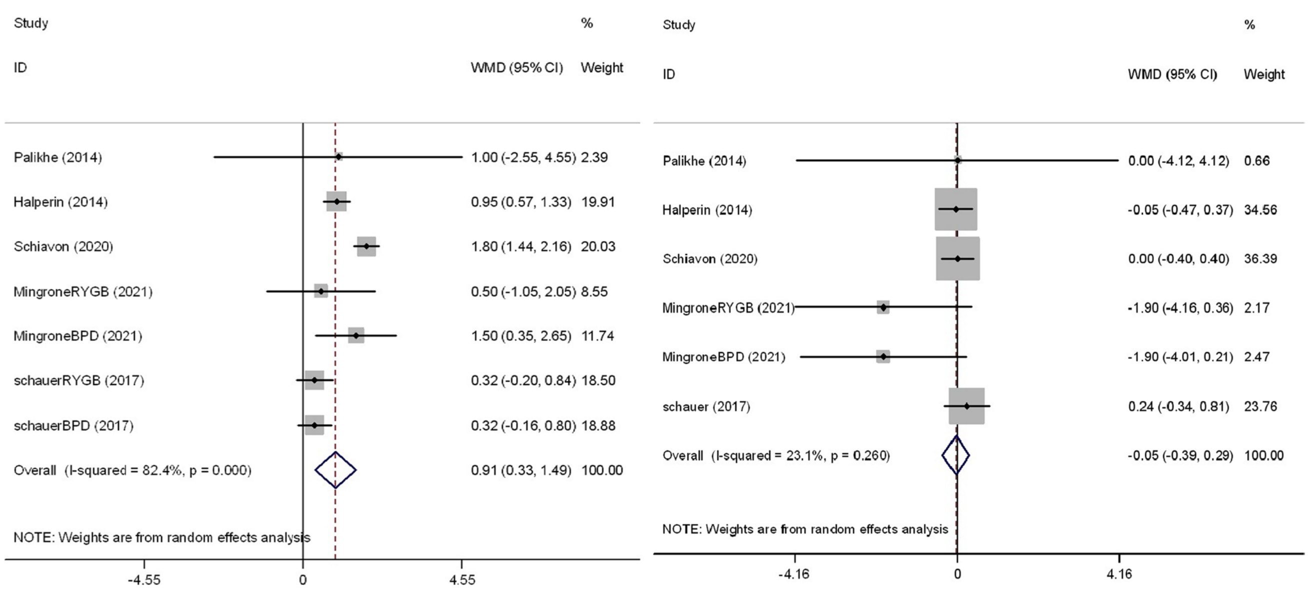


Fig. 4 Antihypertensives change per capita in surgical group (**A**) and control group (**B**)

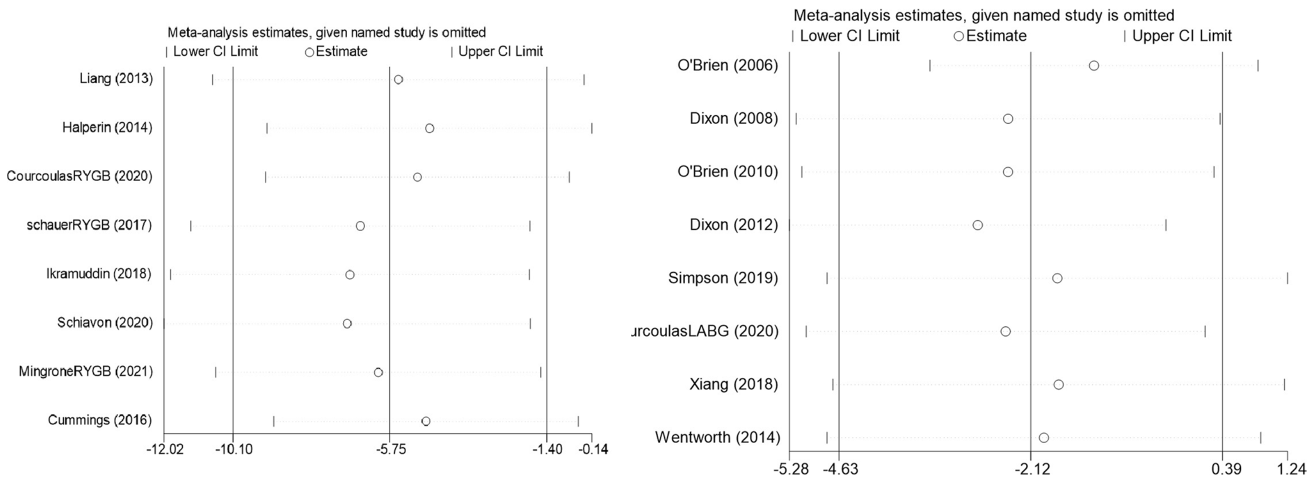


Fig. 5 Sensitivity analysis of SBP in RYGB groups (left) and DBP in LAGB groups

Sensitivity Analysis and Meta-Regression Analysis

To further study the source of heterogeneity, we performed sensitivity analyses to evaluate the impact of small sample studies in RYGB group on SBP and LAGB group on DBP (Fig. 5), which proved its stability and reliability. We also performed meta-regression analyses to assess the confounding impact of age, body mass index, waist circumference, fasting plasma glucose, and blood lipids. Meta-regression analyses showed that triglycerides (regression coefficient: – 21.95; P = 0.015) explained some of the heterogeneity for SBP in RYGB group. BMI (regression coefficient: – 11.30; P = 0.036) and body weight (regression coefficient: – 8.66; P = 0.014) explained some of the heterogeneity for DBP in LAGB group. No significance was observed for the other confounders. Meta-regression analyses indicated that the change in blood pressure was negatively associated with increases in triglycerides and body weight. We also conducted meta-analyses after lowering the weight of moderate-quality evidence. I^2 overall and in all operation subgroups were lower (Appendix Figs. 13 and 14), while the mean change in systolic blood pressure and diastolic blood pressure was still significant (P = 0.013 and P = 0.003).

Secondary Outcome Analyses

Overall estimate and subgroup analyses by surgical type of secondary outcomes are pooled in Table 4 and Appendix Figs. 1 to 12, including the mean changes in body weight, body mass index, waist circumference, fasting blood lipids, fasting blood glucose, glycosylated hemoglobin, body weight, body mass index, waist circumference, renal function, resting heart rates and 6-min walking test. We also respectively evaluate change in metabolic syndrome, HOMA-IR, hsCRP, lipid-lowering drugs, and antidiabetic drugs in the surgery group and control group in Table 5.

Adverse

Adverse events are listed in Supplementary S2. During the following time, 603 (0.28/per person per year) adverse events were reported in the surgery group, and 393 (0.23/per person per year) adverse events were reported in the control group. Four deaths were reported, two persons in the control group died of fatal myocardial infarction, and one person in the control group was sudden death after coronary artery bypass grafting surgery. One person's death cause was not identified in the surgery group.

Publication Bias

Publication bias calculated for overall estimates (Fig. 6). There was a low probability of publication bias for comparisons of systolic blood pressure and diastolic blood pressure between surgery groups and control groups, as reflected by Begg's test (P = 0.871 and 0.363, respectively) and Egger's test (P = 0.814 and 0.282, respectively). Similarly, there was no observable publication bias for the overall comparisons of TG (P for Egger' test: 0.473), TC (P = 0.161), HDL (P = 0.297), FPG (P = 0.200), BMI (P = 0.687), BW (P = 0.921), and WC (P = 0.294).

Discussion

The objective of this meta-analysis is to evaluate the efficacy of bariatric surgery on blood pressure. Via a meta-analysis of the data from 19 randomized clinical trials and on 1353 patients, we found that bariatric surgery can effectively decrease systolic blood pressure and diastolic blood pressure and reduce antihypertensives, antidiabetic drugs, and lipid-lowering drugs. Besides that, patients after surgery tend to lose more weight; decrease more waist circumference, fasting plasma glucose, glycosylated hemoglobin, triglycerides concentration, and hsCRP; increase more high-density lipoprotein cholesterol concentration; and had a better remission of metabolic syndrome. However, no significant differences were found in total cholesterol, low-density lipoprotein cholesterol concentration, renal function, resting heart rates, and 6-min walking experiment.

Obesity-related hypertension is mainly due to obesity leading to sympathetic nervous system activation, insulin resistance, and renin-angiotensin system activation [35, 36]. Bariatric surgery can inhibit the activation of the RAS system and renal sympathetic nerve by reducing kidney compression [37–39], strengthening water and sodium excretion [40], improving insulin resistance [41], hemodynamics disorder[42], and improve nocturnal hypoxemia state of OSAHS patients [22, 43].

However, it is worth mentioning that through the subgroup analyses, Roux-en-Y gastric bypass, as the most extensive bariatric surgery in clinical practice, has the most significant positive effect on improving blood pressure, blood lipids, blood plasma glucose, and other endpoints. Probably due to its additional regulation of gut hormones and intestinal flora, it can induce changes in appetite [44, 45]. Whereas laparoscopic adjustable gastric banding (LAGB) was designed as a purely restrictive operation, it was not as effective in reducing blood pressure as other operation types. In SG surgery, BPD surgery, and DJBL surgery subgroup analyses, our sample size was insufficient to provide significant results on blood pressure changing. Other than that, we also found that people with poor control of hypertension and diabetes, non-severe obesity, age > 45 years, and less waist circumference had better efficacy.

Secondary endpoint analyses, same as many studies before [13, 46], bariatric surgery was more efficient than non-surgical treatment in weight loss, diabetes control, metabolic syndrome remission, triglycerides, and high-density lipoprotein cholesterol improvement. However, changes in total cholesterol and low-density lipoprotein cholesterol concentration were not significant, mainly because of its diversity in lipid-lowering drugs usage. Due to other influencing factors and insufficient studies,

Table 4 Overall estimate and subgroup analysis by surgical type of secondary outcome between surgery group and non-surgical group

Overall estimate of secondary outcome							Subgroup analysis by operation type (WMD)				
Outcome	Groups	Wmd	95% CI		P	I^2	LAGB	RYGB	DJBL	SG	BPD
Body weight (kg)	19	−18.466	−22.999	−13.932	<0.001	92.8%	−14.827*	−21.363*	−2.800	−16.323*	−33.58*
Body mass index (kg/m2)	14	−4.788	−7.921	−1.656	0.003	97.7%	−0.442	−8.121*	−0.900*	−8.000*	−11.951*
Waist circumference (cm)	14	−14.491	−17.572	−11.410	<0.001	72.3%	−12.490*	−17.605*	-	−12.632*	−15.900*
TG (mmol/L)	19	−0.625	−1.005	−0.245	0.001	93.7%	−0.269*	−0.537*	0.745	−2.569*	−0.230
TC (mmol/L)	14	−0.135	−0.441	0.170	0.385	72.4%	0.007	0.198	-	−0.907	−0.856*
HDL (mmol/L)	19	0.189	0.125	0.254	<0.001	57.0%	0.180*	0.254*	0.181	0.259*	0.009
LDL (mmol/L)	17	−0.115	−0.401	0.172	0.433	79.1%	−0.010	−0.138	0.905	0.005	−0.937*
FPG (mmol/L)	18	−0.674	−1.255	−0.093	0.023	79.3%	−0.008	−1.522*	−1.371	−4.532	−0.526
HbA1c (%)	17	−1.160	−1.526	−0.794	<0.001	77.0%	−0.936*	−1.197*	−0.900*	−2.212	−0.936
Resting heart rates (bpm)	4	−4.652	−9.673	0.369	0.069	44.3%	−1.647	−11.700*	-	-	−2.450
6-min walking test (m)	3	−5.947	−39.983	28.090	0.732	54.6%	−3.488	−9.900	-	-	-
Scr (umol/L)	5	−4.227	−9.828	1.374	0.139	0.0%	−5.304	−5.121	-	5.304	-
GFR (ml/min)	5	7.153	−8.691	22.997	0.376	80.4%	-	14.261	-	−2.100	−2.100

*Stand for $P < 0.05$

Table 5 Change in metabolic syndrome, HOMA-IR, hsCRP, lipid-lowering drugs, diabetes drugs in surgery group and control group

	Change in surgery group						Change in non-surgical group					
Outcome	**Groups**	**RR**	**95% CI**		**P**	**I²**	**groups**	**RR**	**95%CI**		**P**	**I²**
Metabolic syndrome	5	0.364	0.262	0.507	< 0.001	40.6%	4	0.821	0.704	0.959	0.013	28.8%
Use of metformin	6	0.464	0.247	0.872	0.017	94.90%	5	0.979	0.808	1.186	0.826	64.10%
Use of insulin	13	0.345	0.229	0.520	< 0.001	41.6%	9	0.933	0.748	1.163	0.535	0.0%
Use of other diabetes medication	9	0.549	0.420	0.719	< 0.001	51.4%	7	0.891	0.797	0.995	0.040	3.9%
Use lipid-lowering drug	5	0.508	0.409	0.633	< 0.001	44.3%	4	0.955	0.762	1.196	0.687	75.9%
Outcome	**Groups**	**WMD**	**95% CI**		**P**	**I²**	**groups**	**WMD**	**95%CI**		**P**	**I²**
hs-CRP(mg/ml)	5	−4.867	−7.796	−1.938	0.001	91.3%	4	−0.155	−0.633	0.322	0.523	0.0%
HOMA-IR	10	−3.406	−4.429	−2.382	< 0.001	94.4%	10	−0.293	−0.457	−0.129	< 0.001	0.0%

the effects of bariatric surgery on renal function and physical activity were still uncertain.

Several possible limitations should be acknowledged. First, the patient sample was mainly from Europe and the USA, only including two studies from East Asia and one study from India, which made it lack external authenticity among the Asian population. Secondly, the risk of reporting bias was high for some studies due to lacking of negative results, such as changes of antihypertensive drugs in Dixon (2012) [22] and Koehestanie (2014) [25]; it may overestimate the efficacy of bariatric surgery. Besides, the attrition bias was high in several studies due to the high rate of loss follow-up. Because patients with better improvement have higher follow-up rates, it may underestimate the efficacy of bariatric surgery. Furthermore, the qualified trials of this meta-analysis span more than 16 years. During this period, more drugs such as GLP-1 analogs had been put into clinical use, which were more effective than traditional treatment. However, with the studies including newer class of medications as comparators, obesity surgery is still a more effective way of lowering blood pressure [19, 23, 24]. Lastly, we observed moderate to strong evidence of heterogeneity in some second endpoint analyses, which was similar to several meta-analyses before [13, 46–48].

To the authors' knowledge, this study is the most comprehensive meta-analysis of RCT to assess the comparison of bariatric surgery with non-surgical treatment in terms of controlling blood pressure. Most system reviews before mainly focus on changes in body weight, fasting plasma glucose, and other aspects and therefore underestimated the efficacy in blood pressure. Few system reviews compared bariatric surgery with lifestyle modifications, exercise, and pharmacological therapy. Only two system reviews in 2013 and 2016 found no extra benefits in reducing blood pressure [13, 46], and one system review compared pre-operative and post-operative in type1 diabetes mellitus which found a significant difference in dropping blood pressure [48].

Conclusion

Bariatric surgery is more effective than non-surgical treatment in controlling patients' blood pressure. Roux-en-Y gastric bypass surgery has the most certain efficacy on blood pressure reduction among all surgeries and should be the first choice operation type for patients with obesity and hypertension. Laparoscopic adjustable gastric banding surgery has no advantage in blood pressure control compared to non-surgical treatment. Other operation type needs more clinical evidence.

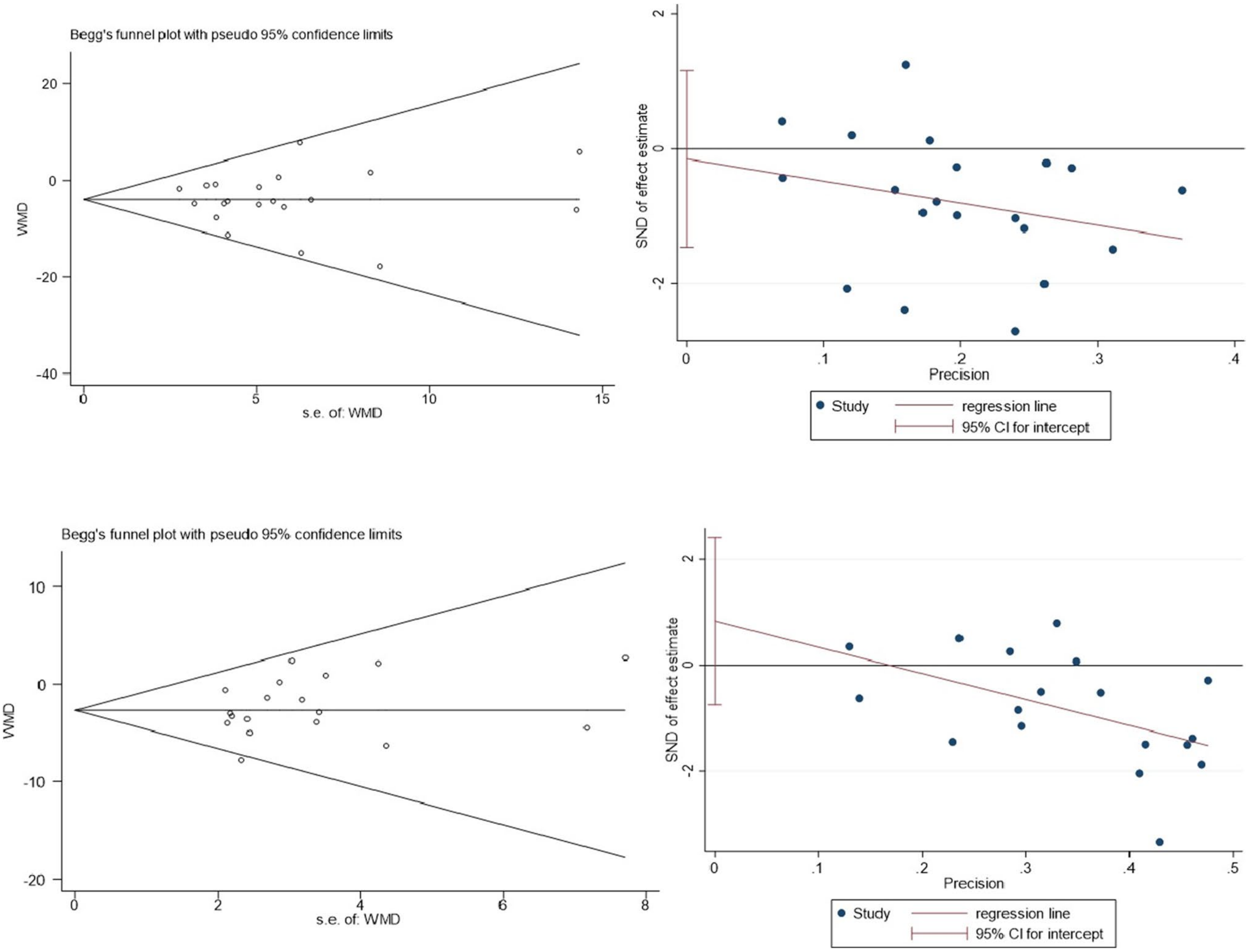


Fig. 6 SBP Begg's test (upper left) and Egger's test (upper right), DBP Begg's test (lower left) and Egger's test (lower right)

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11695-021-05671-9.

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Declarations

Ethics Approval As all analyses were based on previously published studies, ethics approval was not required for this systematic review.

Conflict of Interest The authors declare no competing interests.

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