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SYSTEMATIC REVIEW

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The role of bariatric surgery in hypertension control: a systematic review and meta-analysis with extended benefits on metabolic factors

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Abstract

Background By 2025, global obesity rates are projected to reach 16% in men and 21% in women, imposing a significant public health burden. Obesity is a major contributor to hypertension (HTN), exacerbating cardiovascular risks. This review and meta-analysis evaluated the effectiveness of non-surgical treatments versus bariatric surgery in managing hypertension among obese individuals.

Methods We searched PubMed, Scopus, Embase, and Cochrane databases up to May 2024. Randomized controlled trials (RCTs) comparing bariatric surgery (e.g., Roux-en-Y Gastric Bypass (RYGB), Sleeve gastrectomy (SG), Laparoscopic adjustable gastric banding (LAGB), Duodenal-jejunal bypass liner/Biliopancreatic diversion (DJBL/BPD)) with non-surgical interventions (e.g., lifestyle modifications, medications) in hypertensive obese patients were included. Primary outcomes were changes in systolic and diastolic blood pressure. Secondary outcomes included changes in fasting blood sugar (FBS), HbA1c, and lipid profiles. Data were synthesized using a random-effects model, with heterogeneity and publication bias assessed.

Results From 7,187 records, 29 studies involving 2,548 patients met the inclusion criteria. Bariatric surgery resulted in greater reductions in systolic (MD: -4.506 mmHg; 95% CI: -6.999 to -2.013) and diastolic (MD: -3.040 mmHg; 95% CI: -4.765 to -1.314) blood pressure compared to non-surgical interventions. Roux-en-Y gastric bypass had the most significant impact. Bariatric surgery also led to substantial reductions in FBS (MD: -30.444 mg/dl; 95% CI: -41.288 to -19.601), HbA1c (MD: -1.108%; 95% CI: -1.414 to -0.802), and triglycerides (MD: -39.746 mg/dl; 95% CI: -54.458 to -25.034), and increased HDL levels (MD: 7.387 mg/dl; 95% CI: 5.056 to 9.719). The quality of evidence was high for most outcomes, supporting these findings.

Conclusion Bariatric surgery is superior to non-surgical treatments in managing obesity-related hypertension and metabolic disorders. Reductions in blood pressure, glycemic indexes, and lipid profiles highlight bariatric surgery's critical role in improving cardiovascular health and metabolic outcomes in obese hypertensive patients.

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Graphical abstract

Keywords Bariatric surgery, Hypertension, Obesity, Blood pressure reduction

Introduction

By 2025, it's estimated that 16% of adult men and 21% of adult women worldwide will be obese. This will impact the global economy by costing 2.5% of the total GDP. Additionally, obesity rates are not expected to drop in any country during this decade [1].

There is strong evidence indicating that significant weight gain and increased visceral fat are primary contributors to hypertension (HTN) [2, 3]. Excess adipose tissue plays a role in developing hypertension through various mechanisms. These include the physical compression of the kidneys impairing renal-pressure natriuresis, increased sympathetic activity, activation of the renin-angiotensin-aldosterone system, and insulin resistance, among other factors [4, 5].

The coexistence of obesity and hypertension significantly elevates cardiovascular risks and imposes a substantial health burden. Obesity increases cardiac output and stroke volume, while hypertension elevates total peripheral resistance, together creating a "double burden" on the heart. This dual impact increases the likelihood of congestive heart failure, coronary heart disease, and other cardiovascular complications [6]. Additionally, the co-occurrence of obesity and hypertension is linked with elevated risks of diabetes, dyslipidemia, and metabolic syndrome. This combination intensifies health risks and complicates the management of these conditions [7].

Effective strategies to manage these conditions include weight loss through lifestyle modifications and pharmacological or surgical interventions [8]. While new medications and lifestyle modifications for obesity provide a more promising outlook for success, maintaining long-term treatment for obesity remains a challenge. Bariatric surgery, however, may offer more effective long-term management of obesity and its associated conditions [8–10].

Considering the variability in results from previous studies [11–16], which demonstrated differences in both the extent and durability of blood pressure reduction and hypertension remission following bariatric surgery—ranging from significant short-term improvements with gradual attenuation over time to sustained long-term remission in select patient populations— and the emergence of targeted randomized controlled trials like The GATEWAY trial [17], which focuses on comparing bariatric surgery with medical therapy for hypertension

Table 1 Baseline characteristics of the included studies

NUM	Study ID	Country	Group	*N*, group	Follow-up (months)	Age (years) (mean ± Sd)	Female %	BMI (kg/m²) (mean ± Sd)	Body Weight (kg) (mean ± Sd)	Waist Circumference (cm) (mean ± Sd)	SBP (mmHg) (mean ± Sd)	DBP (mmHg) (mean ± Sd)	HT rate (%)	DM rate (%)	FBS (mg/mL) (mean ± Sd)	HbA1c (%) (mean ± Sd)	LDL Cholesterol (mg/dL) (mean ± Sd)	HDL Cholesterol (mg/dL) (mean ± Sd)	Total Cholesterol (mg/dL) (mean ± Sd)	Triglycerides (mg/dL) (mean ± Sd)
1	F. R. Azevedo, (2018)	Brazil	SG + TB Plus SMT	10	24	45 ± 10	NA	33.4 ± 2.6	102.2 ± 12.2	112 ± 8	NA	NA	90%	100%	217 ± 103	9.3 ± 2.1	86 ± 17	33 ± 8	183 ± 45	369 ± 25
			SMT	10	24	56 ± 7	NA	30.3 ± 2.1	88.5 ± 11.7	106 ± 6	NA	NA	100%	100%	145 ± 71	8 ± 1.5	95 ± 33	41 ± 10	172 ± 45	202 ± 185
2	A. P. Courcoulas, (2020)	America	RYGB + LLLI	20	60	45.4 ± 7.5	80%	35.7 ± 2.7	99.3 ± 13.4	110.6 ± 8.2	139.7 ± 12.3	81.3 ± 9.6	50%	100%	191.5 ± 82	8.6 ± 2.1	124.3 ± 3.8	41.8 ± 8.7	200.2 ± 40.3	169.7 ± 27.16
			LAGB + LLLI	21	60	47.7 ± 7	80.9%	35.6 ± 3.4	100.2 ± 14	114.5 ± 11.9	134.5 ± 17	77.1 ± 8.6	61.9%	100%	180 ± 85.4	7.9 ± 2.2	107.4 ± 29.7	40 ± 9.3	189.5 ± 5.8	221.9 ± 44.4
			ILWLI	20	60	48.9 ± 4.7	85%	35.7 ± 3.3	102 ± 14.3	118 ± 9.5	132 ± 17.9	76.3 ± 9.6	65%	100%	142.1 ± 28	7 ± 0.8	105.5 ± 33.3	44.1 ± 17.1	182 ± 39	161.2 ± 24.52
3	Abu Dayyeh, B.K., (2022)	America	ESG + LSM	77	13	47.3 ± 9.3	88%	35.5 ± 2.6	98.4 ± 12.3	110.3 ± 10.4	134.2 ± 15.2	82.4 ± 9.3	49%	23%	101.7 ± 26.4	5.8 ± 0.8	115.0 ± 37.3	54.5 ± 15.5	193.8 ± 41.0	120.8 ± 63.1
			LSM	110	13	45.7 ± 10	83%	35.7 ± 2.6	99.1 ± 12.8	109.7 ± 12.5	131.6 ± 15.2	80.9 ± 11.2	52.7%	32%	98.6 ± 28.4	5.8 ± 0.8	111.9 ± 31.8	54.9 ± 14	192 ± 37.3	123.3 ± 51.5
4	David E. Cummings (2016)	America	RYGB	15	12	52 ± 8.3	80%	38 ± 3.7	108.8 ± 14.9	121.7 ± 10.2	129.3 ± 20.6	77 ± 10.2	80%	NA	145.8 ± 46.8	7.7 ± 1	92.8 ± 27.7	42.54 ± 11.6	166.28 ± 38.67	150.58 ± 62
			Intensive lifestyle and medical intervention	17	12	54.6 ± 6.3	58%	37.1 ± 3.5	112.8 ± 16.5	120.8 ± 10	120.1 ± 9.6	74.8 ± 7.5	94%	NA	153 ± 46.8	7.3 ± 0.9	85.07 ± 23.2	42.54 ± 7.734	170.15 ± 30.936	203.7 ± 132.86
5	J. B. Dixon, (2008)	Australia	LAGB + conventional diabetes care	30	24	46.6 ± 7.4	50%	37 ± 2.7	105.6 ± 13.8	114.1 ± 10.2	136.4 ± 15.6	86.6 ± 9.4	93%	NA	156.7 ± 38.5	7.8 ± 1.2	NA	47.1 ± 10.1	201.8 ± 32.7	190.6 ± 106.6
			Conventional diabetes therapy with a focus on weight loss by lifestyle change	30	24	47.1 ± 8.7	56%	37.2 ± 2.5	105.9 ± 14.2	116 ± 10	135.3 ± 14.4	84.5 ± 9.8	90%	NA	158 ± 48.7	7.6 ± 1.4	NA	48.1 ± 11.1	198.2 ± 56.7	188.7 ± 111.8
6	J. B. Dixon, (2012)	Australia	LAGB	30	24	47.4 ± 8.8	43%	46.3 ± 6	134.9 ± 22.1	136.1 ± 13.1	137.6 ± 18.7	83.1 ± 8.2	50%	41%	107.4 ± 30.6	6.25 ± 1.1	NA	44.8 ± 10.4	194.4 ± 42.2	163.7 ± 83.1
			conventional weight loss	30	24	50 ± 8.2	40%	43.8 ± 4.9	126 ± 19.3	126.6 ± 13.1	142.2 ± 16.9	86.8 ± 8.8	56%	33%	103.7 ± 23.5	6.26 ± 1.1	NA	43.6 ± 10.4	192.2 ± 36.1	195.6 ± 96.9
7	F. Halperin, (2014)	America	RYGB	19	12	50.7 ± 7.6	68%	36 ± 3.5	104.6 ± 15.5	117.8 ± 14.9	132.8 ± 10.5	81.7 ± 7.4	NA	100%	132.3 ± 49.7	8.24 ± 1.42	88.1 ± 27.7	43.6 ± 9.7	154.2 ± 34	120 ± 66
			intensive lifestyle and medical management (WhyWAIT)	19	12	52.6 ± 4.3	52%	36.5 ± 3.4	102.7 ± 17	114.1 ± 12.2	126.3 ± 14.7	76.6 ± 8.8	NA	100%	162.2 ± 53.8	8.83 ± 1.01	98.9 ± 29.3	39.1 ± 9.9	162.5 ± 38.6	156 ± 76
8	P. Koehestanie, (2014)	Netherlands	Endoscopic DJBL + dietary intervention	38	12	49.5 ± 12.3	34%	34.6 ± 4.3	105.4 ± 13.7	NA	147 ± 13	92 ± 10.7	NA	100%	198.2 ± 49.9	8.3 ± 1	88.9 ± 35.7	42.5 ± 14.8	170.1 ± 32.5	150.6 ± 136.3
			dietary intervention	39	12	49 ± 8.4	35%	36.8 ± 7.2	110.8 ± 22.5	NA	152 ± 16.9	90 ± 10.7	NA	100%	198.2 ± 52.6	8.3 ± 1	92.8 ± 35.7	46.4 ± 11.9	170.1 ± 50.6	177.1 ± 109
9	Z. Liang (2013)	China	RYGB	31	12	50.8 ± 5.4	29%	30.5 ± 0.9	82 ± 3.5	NA	160.8 ± 7.8	88.6 ± 5.5	NA	NA	169.4 ± 20.9	10.5 ± 1.2	148.5 ± 24.4	34.4 ± 6.6	201.5 ± 21.3	300.3 ± 104.5
			usual care with Exenatide therapy	34	12	50.9 ± 5.9	29%	30.3 ± 1.4	81.8 ± 3.7	NA	159.9 ± 8.6	85.8 ± 11	NA	NA	168.6 ± 23.1	10.5 ± 1.5	143.9 ± 24.7	34.8 ± 5	205.3 ± 35.6	315.3 ± 95.7
			usual care without Exenatide therapy	36	12	51.8 ± 6.7	33%	30.3 ± 2	81.3 ± 5	NA	156.6 ± 11.8	87.8 ± 6.8	NA	NA	169.2 ± 25.9	10.9 ± 1.4	143.9 ± 16.2	34 ± 5.8	194.5 ± 39.4	309.1 ± 116.9

Table 1 (continued)

NUM	Study ID	Country	Group	N, group	Follow-up (months)	Age (years) (mean ± Sd)	Female %	BMI (kg/m²) (mean ± Sd)	Body Weight (kg) (mean ± Sd)	Waist Circumference (cm) (mean ± Sd)	SBP (mmHg) (mean ± Sd)	DBP (mmHg) (mean ± Sd)	HT rate (%)	DM rate (%)	FBS (mg/mL) (mean ± Sd)	HbA1c (%) (mean ± Sd)	LDL Cholesterol (mg/dL) (mean ± Sd)	HDL Cholesterol (mg/dL) (mean ± Sd)	Total Cholesterol (mg/dL) (mean ± Sd)	Triglycerides (mg/dL) (mean ± Sd)
10	G. Mingrone, (2021)	Italy	RYGB	120	20	43.9 ± 7.6	10%	44.2 ± 5.2	128.7 ± 21.3	129 ± 14.9	145.8 ± 20.5	91.5 ± 14.2	NA	NA	171.2 ± 59.5	8.6 ± 1.4	108.3 ± 34.8	42.5 ± 7.7	177.9 ± 38.7	150.6 ± 79.7
			BPD	120	20	43.6 ± 8.2	8%	44.4 ± 9	128 ± 28.7	139.5 ± 22.3	154.5 ± 29.7	95.9 ± 12.9	NA	NA	174.8 ± 61.3	8.9 ± 1.7	135.3 ± 50.3	38.7 ± 7.7	212.7 ± 58	194.9 ± 79.7
			medical therapy plus lifestyle interventions	120	20	43.5 ± 7.3	8%	44.6 ± 5.7	137 ± 19	127 ± 13.8	155.2 ± 34.2	96 ± 17.5	NA	NA	178.4 ± 61.3	8.5 ± 1.2	154.7 ± 54.1	38.7 ± 7.7	235.9 ± 61.9	221.4 ± 70.9
11	Nordstrand N, et al. (2012)	Norway	RYGB	49	12	44.4 ± 9.5	67%	45/5 ± 5/5	134 ± 22	NA	150 ± 18	83 ± 10	NA	28%	NA	NA	NA	NA	NA	NA
			ILI	41	12	47.5 ± 10.6	70%	42/3 ± 4	122 ± 14	NA	146 ± 20	79 ± 9	NA	31%	NA	NA	NA	NA	NA	NA
12	Tur JJ, et al. (2013)	Spain	BPD	37	12	44.1 ± 9.8	70%	49.2 ± 5.9	132/8 ± 24.4	NA	132.6 ± 14.4	82.8 ± 8.9	NA	24%	110.4 ± 26.9	6.3 ± 0.8	118 ± 28.9	40.2 ± 6.2	178.8 ± 38	136.5 ± 63.9
			COT	46	12	46.7 ± 10.3	63%	46.8 ± 4.6	126 ± 17.9	NA	136.1 ± 14	86.6 ± 10	NA	23%	116.4 ± 40.6	7.8 ± 1.7	119.2 ± 23	44.1 ± 9.1	194.4 ± 31.8	151.4 ± 66.7
			ILI	60	12	47.8 ± 11.5	71%	45.8 ± 5	122.2 ± 20.1	NA	131.9 ± 18.7	86.8 ± 10	NA	25%	122.1 ± 40.1	6.7 ± 1.7	121.8 ± 31.8	49.4 ± 10.4	202.8 ± 37.2	162.1 ± 62.4
13	Wentworth JM, et al. (2014)	Australia	LAGB + MDC	25	24	53 ± 6	76%	29 ± 1	81 ± 10	NA	130 ± 18	83 ± 10	NA	NA	133.3 ± 37.8	6.9 ± 1.2	NA	47.9 ± 15.2	187.2 ± 46	135 ± 99
			MDC	26	24	53 ± 7	65%	29 ± 1	83 ± 12	NA	131 ± 11	84 ± 9	NA	NA	147.7 ± 41.4	7.2 ± 1.1	NA	44 ± 15.2	195 ± 61.6	164.7 ± 49.5
14	Xiang AH, et al. (2018)	USA	gastric banding	44	24	47 ± 10	77%	35.7 ± 2.9	97.5 ± 12.2	NA	127.1 ± 10.5	78.3 ± 7.5	NA	43%	111.7 ± 12.6	5.9 ± 2.6	104.4 ± 27.1	46.4 ± 11.6	174 ± 27.1	116.9 ± 137.55
			metformin	44	24	51 ± 9	79%	35 ± 2.9	96.1 ± 10.9	NA	126.4 ± 10	75.9 ± 8.1	NA	40%	111.7 ± 14.4	5.8 ± 2.6	104.4 ± 30.9	46.4 ± 11.6	174 ± 34.8	108.9 ± 158.2
15	Ikramuddin et al. (2015)	USA	Roux-en-Y	60	24	49 ± 9	63%	34.9 ± 3	NA	114 ± 10	127 ± 15	78 ± 12	70%	100%	205.2 ± 52.2	9.6 ± 1	104.4 ± 35	42.5 ± 1	181.7 ± 39	186.3 ± 79.8
			intensive lifestyle and medical management	59	24	49 ± 8	57%	34.3 ± 3	NA	113 ± 12	132 ± 14	79 ± 10	69%	100%	214.2 ± 57.6	9.6 ± 1	104.4 ± 43	42.5 ± 8	189.5 ± 46	194.1 ± 79.8
16	Ikramuddin et al. (2013)	USA	Roux-en-Y	60	12	49 ± 9	63%	34.9 ± 3	98.8 ± 3.6	114 ± 10	127 ± 15	78 ± 12	70%	100%	222 ± 73.5	9.6 ± 1	104.4 ± 35	42.5 ± 1	181.7 ± 39	186.3 ± 1
			Medical management	60	12	49 ± 8	56%	34.3 ± 3	97.9 ± 4.2	113 ± 12	132 ± 14	79 ± 10	68%	98%	207 ± 56.1	9.6 ± 1	104.4 ± 43	42.5 ± 8	189.5 ± 46	194.1 ± 1
17	Ikramuddin et al. (2018)	USA	Roux-en-Y	55	60	49 ± 9	67%	34.9 ± 3	98 ± 17	114 ± 10	127 ± 15	78 ± 12	NA	NA	222 ± 75	9.6 ± 1	102 ± 35	41 ± 11	181 ± 38	200 ± 105
			Medical management	43	60	48 ± 8	72%	34.4 ± 3	99 ± 14	113 ± 12	132 ± 14	79 ± 10	NA	NA	205 ± 54	9.6 ± 1	102 ± 41	41 ± 8	186 ± 42	211 ± 112
18	Schavion et al. (2018)	Brazil	Roux-en-Y + Medical management	50	12	43 ± 9	72%	37.4 ± 2	102 ± 14	112.2 ± 8	123 ± 12	77.6 ± 7	100%	8%	99.8 ± 18	5.7 ± 1	121.5 ± 30	46.4 ± 15	NA	166.8 ± 104.8
			Medical management	50	12	45 ± 9	68%	36.4 ± 3	100.1 ± 14	111 ± 9	122.8 ± 13	78 ± 9	100%	8%	99.7 ± 20	5.7 ± 1	120.8 ± 35	48.3 ± 13	NA	154.7 ± 68
19	Simonson (2019)	USA	LAGB	18	36	51 ± 12.7	50%	36.4 ± 3	106.8 ± 10.4	115.9 ± 7.1	128.5 ± 7.4	79.1 ± 5.3	NA	NA	167.4 ± 63.8	8.41 ± 1.1	92.3 ± 26.6	36.7 ± 9.4	155.3 ± 33.9	175.9 ± 119.3
			Control	22	36	51.6 ± 7.5	40%	36.7 ± 4.2	111.6 ± 17.9	114.4 ± 9.4	126.2 ± 13	80.9 ± 8.1	NA	NA	154.7 ± 47.8	8.08 ± 1.23	91.5 ± 26.6	42 ± 12	160.6 ± 28.6	145.1 ± 104.3
20	Schiavon (2019)	Brazil	RYGB	50	12	43.1 ± 9.2	82%	37.4 ± 2.4	102 ± 13.6	NA	126 ± 40.2	106.4 ± 25	100%	8%	NA	NA	NA	NA	NA	NA
			Control	50	12	44.6 ± 9.2	70%	36.4 ± 2.9	100.1 ± 14	NA	124.6 ± 28.1	108.6 ± 25.6	100%	8%	NA	NA	NA	NA	NA	NA
21	Schiavon (2024)	Brazil	RYGB	50	60	43.6 ± 9.2	60%	37.3 ± 3.67	101.95 ± 14.44	112.23 ± 10.47	122.98 ± 15.75	77.6 ± 10.83	100%	6%	98.36 ± 19.66	5.7 ± 0.72	119.1 ± 43.9	45.01 ± 14.01	NA	154.56 ± 80.2
			Control	50	60	45.6 ± 8.5	46%	36.4 ± 3.67	100.09 ± 14.43	111.13 ± 10.4	122.76 ± 15.75	77.34 ± 10.83	100%	2%	98.89 ± 18.96	5.73 ± 0.7	115.5 ± 41.59	46.56 ± 14.06	NA	144.43 ± 72.9

Table 1 (continued)

NUM	Study ID	Country	Group	N, group	Follow-up (months)	Age (years) (mean ± Sd)	Female %	BMI (kg/m²) (mean ± Sd)	Body Weight (kg) (mean ± Sd)	Waist Circumference (cm) (mean ± Sd)	SBP (mmHg) (mean ± Sd)	DBP (mmHg) (mean ± Sd)	HT rate (%)	DM rate (%)	FBS (mg/mL) (mean ± Sd)	HbA1c (%) (mean ± Sd)	LDL Cholesterol (mg/dL) (mean ± Sd)	HDL Cholesterol (mg/dL) (mean ± Sd)	Total Cholesterol (mg/dL) (mean ± Sd)	Triglycerides (mg/dL) (mean ± Sd)
22	Schiavon (2020)	Brazil	RYGB	50	36	43 ± 9.1	72%	37.4 ± 3.43	102 ± 13.89	112.2 ± 9.2	123 ± 11.6	77.6 ± 7	100%	8%	98.4 ± 9.39	5.7 ± 0.63	121.5 ± 32.49	46.4 ± 14.42	NA	152.5 ± 79.21
			Control	50	36	44.9 ± 9.2	56%	36.4 ± 3.43	100.1 ± 13.72	111.1 ± 9.2	122.8 ± 12.9	78 ± 9.3	100%	4%	98.6 ± 8.91	5.73 ± 0.62	120.8 ± 32.49	48.3 ± 14.42	NA	143.9 ± 72.89
23	O'Brien (2006)	Australia	"laparoscopic adjustable gastric band"	39	24	41.8 ± 6.4	76%	33.7 ± 1.8	96.1 ± 11.2	103.3 ± 10	131.4 ± 14	83.2 ± 11.7	23%	NA	95.4 ± 34.2	NA	135.1 ± 52.1	50.2 ± 15.8	208.8 ± 62.7	128.3 ± 75.2
			"very-lowcalorie diets, pharmacotherapy, and lifestyle change"	40	24	40.7 ± 7	77%	33.5 ± 1.4	93.6 ± 11.9	99.4 ± 9.4	130.3 ± 13.5	81 ± 9.1	17%	NA	90.1 ± 10.8	NA	135.1 ± 65.6	54.1 ± 25.9	215.7 ± 62.8	123.9 ± 79.6
24	O'Brien (2010)	Australia	"Laparoscopic Adjustable Gastric"	25	24	16.5 ± 1.4	64%	42.3 ± 6.1	120.7 ± 25.3	120.8 ± 14.2	122 ± 13.9	72.4 ± 7.5	NA	NA	89 ± 20	NA	NA	46 ± 12	173 ± 27	124 ± 44
			optimal lifestyle program	25	24	16.6 ± 1.2	72%	40.4 ± 3.1	115.4 ± 14	118.1 ± 10.6	132.8 ± 15.9	76.5 ± 10.5	NA	NA	82 ± 7.2	NA	NA	46 ± 8	178 ± 27	141 ± 141
25	Ospanov (2021)	Australia	"unstapled laparoscopic one anastomosis gastric bypass with an obstructive stapleless pouch and anastomosis"	20	12	38.6 ± 6.89	90%	39.88 ± 5.8	108.95 ± 15.69	NA	135.8 ± 6.93	92.25 ± 3.97	NA	35%	117.18 ± 35.82	5.71 ± 5.36	NA	NA	209.97 ± 20.10	178.02 ± 42.5
			"stapled laparoscopic mini-gastric bypass-one anastomosis gastric bypass"	20	12	48.7 ± 8.54	75%	45.91 ± 5.5	128.95 ± 23.71	NA	142.4 ± 25.11	93.9 ± 4.15	NA	35%	106.02 ± 13.86	5.84 ± 0.61	NA	NA	200.31 ± 33.25	160.31 ± 63.7
			"nonsurgical weight loss therapy via a hypocaloric diet with energy restriction"	20	12	47.25 ± 9.85	65%	36.51 ± 8.1	101.13 ± 26.09	NA	138.9 ± 14.03	92.95 ± 3.24	NA	30%	108.9 ± 17.82	5.81 ± 0.7	NA	NA	213.07 ± 27.45	163.85 ± 43.3
26	Parikh (2014)	USA	bypass, sleeve or band	29	6	46.8 ± 8.1	79%	32.8 ± 1.7	81.96 ± 7.71	106.3 ± 10.1	126.4 ± 16.6	77 ± 13.3	NA	NA	149.6 ± 45.5	7.7 ± 1.4	101.8 ± 88.2	47.2 ± 15.5	193.4 ± 61.7	196.9 ± 188.2
			intensive medical weight management	28	6	53.9 ± 8.4	78%	32.4 ± 1.8	83.68 ± 10.79	106.7 ± 7.7	129.1 ± 19	75.3 ± 8.1	NA	NA	143.6 ± 46.9	7.9 ± 1.3	116.1 ± 55.9	46.4 ± 13.2	193.9 ± 66.6	156.5 ± 69.1

Table 1 (continued)

NUM	Study ID	Country	Group	N, group	Follow-up (months)	Age (years) (mean ± Sd)	Female %	BMI (kg/m^2) (mean ± Sd)	Body Weight (kg) (mean ± Sd)	Waist Circumference (cm) (mean ± Sd)	SBP (mmHg) (mean ± Sd)	DBP (mmHg) (mean ± Sd)	HT rate (%)	DM rate (%)	FBS (mg/mL) (mean ± Sd)	HbA1c (%) (mean ± Sd)	LDL Cholesterol (mg/dL) (mean ± Sd)	HDL Cholesterol (mg/dL) (mean ± Sd)	Total Cholesterol (mg/dL) (mean ± Sd)	Triglycerides (mg/dL) (mean ± Sd)
27	Ruban (2021)	UK	"Duodenal-Jejunal Bypass Liner and intensive medical care"	85	24	51.6 ± 7.9	45%	36.8 ± 5	107.9 ± 17.1	118.7 ± 12.3	130.3 ± 11.6	82 ± 9.7	58%	NA	NA	8.9 ± 0.9	95.5 ± 32.8	44.3 ± 9.6	175.6 ± 37.05	178.9 ± 96.5
			intensive medical care	85	24	51.9 ± 8.5	45%	35.8 ± 4.2	104.2 ± 14.9	117.8 ± 16	133.3 ± 15	83.5 ± 10.6	62%	NA	NA	8.7 ± 0.9	93.9 ± 35.1	44.3 ± 11.5	170.6 ± 38.6	163.9 ± 72.6
28	Philip R. Schauer (2014)	USA	MEDICAL THERAPY	40	36	50.3 ± 7.51	67%	36.4 ± 2.99	113.3 ± 9.33	113.3 ± 9.33	135.3 ± 17.35	82.08 ± 11.15	65%	100%	157 ± 64.8	9 ± 1.4	100.9 ± 36.1	48.8 ± 12.95	NA	162 ± 107.3
			RYGB	48	36	48 ± 8.45	58%	37.1 ± 3.39	116.6 ± 9.25	116.6 ± 9.25	135 ± 19.05	81.85 ± 10.18	73%	100%	193 ± 72.5	9.3 ± 1.4	92.4 ± 29.03	45.4 ± 13.01	NA	179 ± 102.3
			SG	49	36	47.8 ± 8.08	77%	36.1 ± 3.91	113.6 ± 10.21	113.6 ± 10.21	135.8 ± 18.82	82.18 ± 11.59	61%	59%	164 ± 71	9.5 ± 1.7	105.8 ± 39.5	44.5 ± 12.01	NA	160 ± 70.2
29	Philip R. Schauer (2012)	USA	MEDICAL THERAPY	50	12	49.7 ± 7.4	62%	36.8 ± 3	106.5 ± 14.7	114.5 ± 9.4	135.5 ± 17	82.6 ± 11	52%	82%	155 ± 65.6	8.9 ± 1.4	101 ± 37.3	48.4 ± 13.1	NA	166 ± 103
			RYGB	50	12	48.3 ± 8.4	58%	37 ± 3.3	106.7 ± 14.8	116.4 ± 9.2	134.6 ± 18.7	81.8 ± 10.2	70%	100%	193 ± 68.7	9.3 ± 1.4	91.8 ± 28.8	46.2 ± 13.4	NA	167 ± 100
			SG	50	12	47.9 ± 8	44%	36.2 ± 3.9	100.8 ± 16.4	114 ± 10.4	135.8 ± 18.8	82.2 ± 11.6	60%	98%	164 ± 70.2	9.5 ± 1.7	105.8 ± 39.5	44.5 ± 12	NA	160 ± 69.4

List of Abbreviations and Their Full Forms

SG + TB Plus SMT: Sleeve Gastrectomy + Transit Bipartition Plus Standard Medical Therapy

SMT: Standard Medical Therapy

RYGB + LLLI: Roux-en-Y Gastric Bypass + Low-Level Lifestyle Intervention

LAGB + LLLI: Laparoscopic Adjustable Gastric Banding + Low-Level Lifestyle Intervention

ILWLI: Intensive Lifestyle and Weight Loss Intervention

ESG + LSM: Endoscopic Sleeve Gastroplasty + Lifestyle Modifications

LSM: Lifestyle Modifications

RYGB: Roux-en-Y Gastric Bypass

DJBL: Duodenal-Jejunal Bypass Liner

BPD: Bilio-Pancreatic Diversion

LAGB + MDC: Laparoscopic Adjustable Gastric Banding + Multidisciplinary Diabetes Care

MDC: Multidisciplinary Diabetes Care

ILI: Intensive Lifestyle Intervention

MEDICAL THERAPY: Medical Therapy

COT: Conventional Obesity Therapy

WhyWAIT: Why Wait? Trial

SG: Sleeve Gastrectomy

remission and blood pressure reduction in obese patients, we conducted an extensive systematic review and meta-analysis to evaluate the comparative effectiveness of non-surgical treatment versus bariatric surgery in managing hypertension in obese individuals with this condition.

Methods

This systematic review was conducted based on a predefined protocol with explicit criteria for study selection, data extraction, and analysis. The protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) (PROSPERO ID: CRD42024562295). The review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [18].

Search strategy

We comprehensively searched four electronic databases—PubMed, Scopus, Embase, and Cochrane—up to May 2, 2024. We utilized the following keywords and Medical Subject Headings (MeSH) terms: "Hypertension" AND ("Bariatric Surgery" OR "Gastric Bypass" OR "Gastroplasty") AND ("Myocardial Infarction" OR "Stroke" OR "Heart Failure" OR "Coronary Artery Disease" OR "Peripheral Arterial Disease" OR "Myocardial Ischemia" OR "Death, Sudden, Cardiac" OR "Mortality"). Additional studies were identified through reference lists of articles and pertinent reviews. The specific search queries for each database are provided in the Supplemental Material file.

Eligibility criteria

Eligible studies were randomized controlled trials (RCTs) focusing on two groups: the first group comprised individuals undergoing bariatric surgeries (such as laparoscopic adjustable gastric banding (LAGB), Roux-en-Y gastric bypass (RYGB), sleeve gastrectomy (SG), or duodenal-jejunal bypass liner with biliopancreatic diversion (DJBL/BPD)) alongside anti-hypertensive medications, with or without lifestyle modifications. The second group included individuals who did not undergo any surgical interventions but received anti-hypertensive medications or engaged in lifestyle modifications like diet, weight-loss drugs, and other lifestyle changes.

The included studies needed to report changes in blood pressure, as the primary outcomes included mean changes in systolic and/or diastolic blood pressure. Secondary outcomes encompassed changes in fasting blood sugar (FBS), glycosylated hemoglobin (HbA1c), fasting plasma triglycerides (TG), total cholesterol (TC), and concentrations of high-density and low-density lipoproteins (HDL and LDL). The presence of secondary outcome data was not mandatory for inclusion; primary outcomes were sufficient. No restrictions were placed on the participants' age, gender, ethnicity, socioeconomic status, or concurrent metabolic disorders.

Study selection

To identify and remove duplicates, citations were managed using online reference management systems, Rayyan and EndNote 21. Two reviewers (P.D. and H.S.) independently screened titles and abstracts for eligibility, followed by full-text reviews of potentially eligible studies by two other reviewers (M.P and M.M). Disagreements were resolved by consensus or, if necessary, through arbitration by a third reviewer (K.H).

Risk of bias assessment

Two reviewers (S.S. and P.P.) independently assessed the quality of the included studies using the Cochrane Risk of Bias Assessment Tool for Randomized Trials (RoB 2.0) [19]. This tool evaluates various bias domains through a series of signaling questions, such as trial design, conduct, and reporting. Each domain's risk of bias was judged as 'Low,' 'High,' or 'Some concerns'. The quality of the evidence was appraised using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) methodology [20].

Data extraction

Two authors (D.N. and F.O.) independently extracted data using a pre-designed format. The information extracted included the publication year, study design, inclusion/exclusion criteria, sample size, baseline characteristics, and outcomes (Table 1). Additionally, we attempted to contact the corresponding authors of the included studies to obtain missing data. However, in cases where crucial data remained unavailable, the respective parameters were excluded from the analysis. Moreover, Discrepancies were resolved through discussion with a third author (H.S).

Data synthesis

We extracted the mean change and standard deviation (SD) from baseline to the last follow-up for both intervention and control groups. The mean difference (MD) and 95% confidence interval (CI) were calculated to compare effect sizes. Studies reporting medians and interquartile ranges (IQR) or medians and ranges were converted to means and SDs using methods by Luo et al. and Wan et al. [21].

If the SD of the mean change was not reported, it was calculated using the formula [22]:

$$SD\ change = \sqrt{\begin{array}{l}\left(SD^2_{baseline} + SD^2_{final}\right) \\ \quad - \left(2 \times\ r \times\ SD_{baseline} \times\ SD_{final}\right)\end{array}}$$

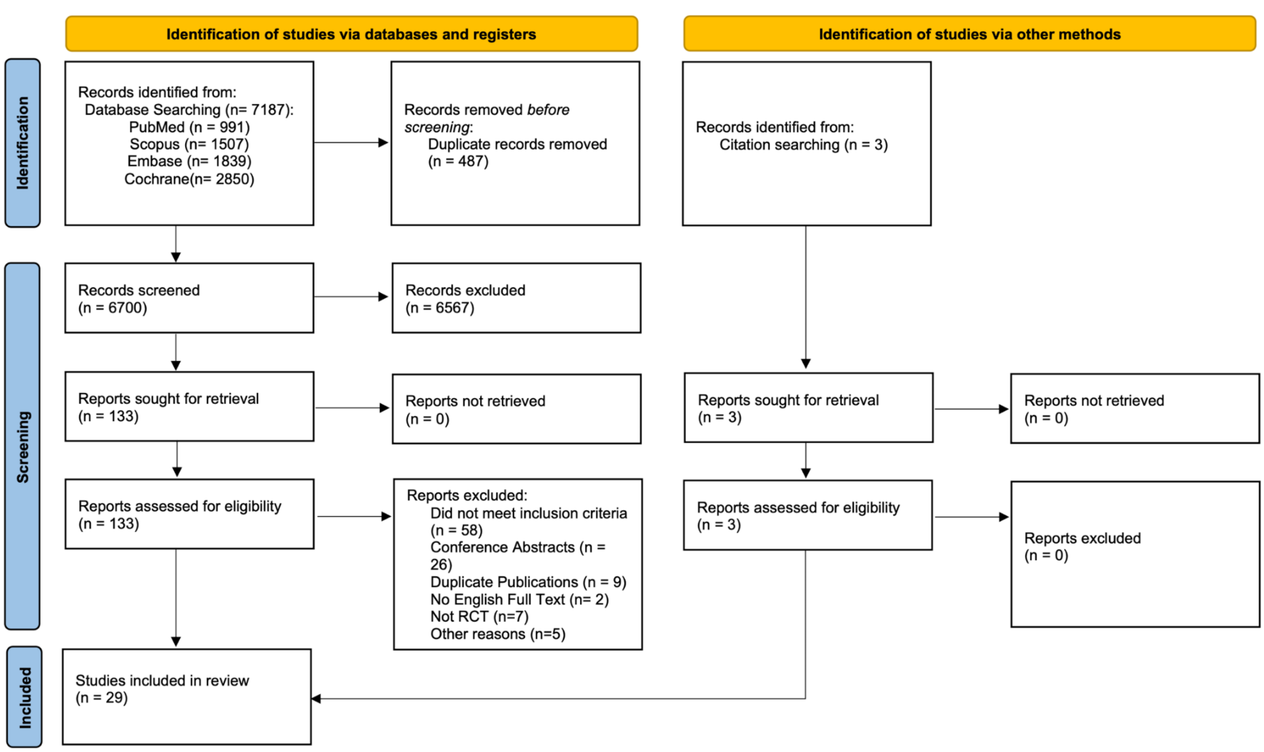
The correlation coefficient (r=.6) was calculated as the mean correlation coefficient from studies that reported the SD of the change scores, using the following standard imputation formula:

$$r = \frac{SD_{baseline}^2 + SD_{final}^2 - SD_{change}^2}{2 \times SD_{baseline} \times SD_{final}}$$

Meta-analyses were conducted using a random-effects model with restricted maximum likelihood estimation. Heterogeneity among studies was assessed using Cochrane's Q statistic and I^2 statistic [23], with I^2 values classified as low (< 25%), moderate (25–50%), or high (> 50%) heterogeneity. Subgroup analyses were performed based on time trends (≤ 1 year, > 1 and ≤ 2 years, > 2 years) and also the type of surgery (sleeve gastrectomy, RYGB, LAGB, DJBL/BPD). Visual and statistical assessments for publication bias were conducted using funnel plots and Begg's and Egger's tests [24]. Furthermore, the "trim and fill" method was used to investigate the potential missing studies due to publication bias [25]. Sensitivity analyses using leave-one-out and fixed-effects model were conducted to evaluate the robustness of findings. Moreover, since studies with larger sample sizes usually have more statistical power, further analyses were performed, limiting the included studies to RCTs with more than 50 cases in each arm. Meta-regression analysis was conducted for variables reported in more than ten studies, including year of publication, follow-up duration, sample size, age, and BMI. All statistical analyses were performed using R Statistical Software (v4.1.2; R Core Team 2021).

Results

After the initial search, 7,187 records were identified across PubMed, Scopus, Embase, and Cochrane. Following the removal of 487 duplicate studies, 6,567 articles were excluded based on their titles and abstracts, leaving 133 studies for full-text assessment. Subsequently, 117 studies were excluded for various reasons, as detailed in Fig. 1. Consequently, 26 articles were included in the review, along with 3 articles identified through citation search. Ultimately, 29 articles were selected for inclusion in the current meta-analysis and systematic review. The articles included in the review were published between 2004 and 2024. The majority of the studies were conducted in the USA (12 studies), followed by Australia (6 studies) and Brazil (5 studies). In total, this review analyzed data from 2,548 patients, with 1,249 patients in the surgical groups and 1,158 in the non-surgical groups. Detailed information about the included articles can be found in Table 1.



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Fig. 1 PRISMA Flow diagram of search strategy and trial selection

Quality assessment of included articles

The quality assessment of the included articles was conducted using the ROB2 tool, which evaluates the risk of bias across five domains: bias from the randomization process (Domain 1), deviations from intended interventions (Domain 2), missing outcome data (Domain 3), measurement of outcomes (Domain 4), and selection of reported results (Domain 5). Most studies (19 in total) exhibited a low risk of bias. Eight studies raised some concerns, primarily in Domains 1, 2, and 5. Common issues in Domain 1 included unclear allocation concealment, while in Domain 2, incomplete descriptions of how deviations from intended interventions were addressed were noted. For Domain 5, discrepancies between prespecified and reported outcomes were identified. Two studies were rated as high risk of bias due to substantial issues across these same domains. A detailed domain-specific assessment of all studies is provided in S1 Fig.

Meta-analysis of changes in blood pressure after bariatric surgery versus non-surgical intervention

Twenty-six RCTs were included in the analysis, comparing systolic blood pressure changes between surgical and non-surgical interventions. The heterogeneity was relatively high (I^2 = 66.7%). Patients in the surgical arms experienced a significantly greater reduction in SBP compared to those in the non-surgical arms (MD: -4.506 mmHg; 95% CI: -6.999 to -2.013; P=.001) (see Fig. 2 and S2.1-2.3 Figs). Sensitivity analyses using leave-one-out and fixed-effect methods also indicated significant differences in SBP changes between the surgical and non-surgical groups (S2 Table and S18 Fig). However, sensitivity analysis with ten studies that had more than 50 patients in each arm did not show a significant difference between the interventions (MD: -2.939 mmHg; 95% CI: -7.199 to 1.321; P=.15) (S2 Table).

Subgroup analyses based on the duration of follow-up and type of bariatric surgery showed that the superiority of surgical intervention in reducing SBP remained significant in studies with ≤ 1-year or > 2-year follow-ups. However, the difference was non-significant in studies with > 1-year but ≤ 2-year follow-up (MD: -0.649 mmHg; 95% CI: -5.157 to 3.858; P=.15) (S1 Table). The heterogeneity between studies with more than 2 years of follow-up was low (I^2 = 11.4%), while the observed heterogeneities were high in all other groups. Additionally, only Roux-en-Y gastric bypass surgery significantly reduced SBP (MD: -6.805 mmHg; 95% CI: -11.348 to -2.261; P<.01), while other types of bariatric surgery did not show significant differences compared to non-surgical interventions (S3 Fig).

A meta-regression analysis was conducted using variables such as year of study publication, duration of follow-up, sample size, mean age, and mean BMI. The results were non-significant for all variables except for sample size, which accounted for 47.54% of the between-study heterogeneity (S3 Table). The moderator test for sample size was significant (P=.01), and a bubble plot indicated that studies with larger sample sizes demonstrated a smaller mean difference in SBP reduction between surgical and non-surgical groups (S26 Fig). The funnel plot of 26 included articles seemed symmetrical, and no missing study was found using trim and fill methods (S27 Fig). The Egger test also confirmed the non-significant risk of publication bias (P=.29).

A meta-analysis comparing the reduction in diastolic blood pressure between surgical and non-surgical interventions was performed with 25 RCTs. High between-study heterogeneity (I^2 = 73.4%) was observed. The reduction in DBP was significantly greater in the surgical groups compared to the non-surgical groups (MD: -3.040 mmHg; 95% CI: -4.765 to -1.314; P=.001) (see Fig. 2 and S4.1-4.2 Figs). This result was robust in sensitivity analyses using the leave-one-out method, fixed-effect method, and analyses limited to studies with more than 50 patients per arm (S2 Table and S19 Fig). Subgroup analyses showed significant differences in DBP changes between the surgical and non-surgical arms in studies with ≤ 1-year or > 2-year follow-ups (S1 Table). Similar to the SBP analysis, RYGB surgery was significantly better at reducing DBP compared to non-surgical interventions (MD: -3.955 mmHg; 95% CI: -6.504 to -1.406; P<.01) (S5 Fig).

Meta-regression analysis revealed no significant associations between the pooled effect size of DBP mean difference and variables such as year of study publication, duration of follow-up, sample size, mean age, and mean BMI (S3 Table). An investigation of the risk of publication bias based on the 25 selected studies, using visual inspection and the Egger test (P=.70), revealed no source of publication bias in the DBP meta-analysis (S28 Fig).

Meta-analysis of changes in glycemic indexes after bariatric surgery versus non-surgical intervention

A total of 21 RCTs comparing the mean fasting blood sugar changes after surgical and non-surgical interventions were selected for meta-analysis. Using the random-effects method, surgical interventions were significantly more effective in reducing FBS compared to non-surgical treatments (MD: -30.444 mg/dl; 95% CI: -41.288 to -19.601; P<.001) (Fig. 3) despite high between-study heterogeneity (I^2 = 81.2%). Subgroup analyses based on follow-up duration and type of surgery showed that bariatric surgery was significantly superior to non-surgical treatments in reducing FBS in all groups, except for those with > 1-year but ≤ 2-year follow-up time and the DJBL/BPD surgery group (S1 Table and S6-7 Figs). The between-study heterogeneity remained high in all

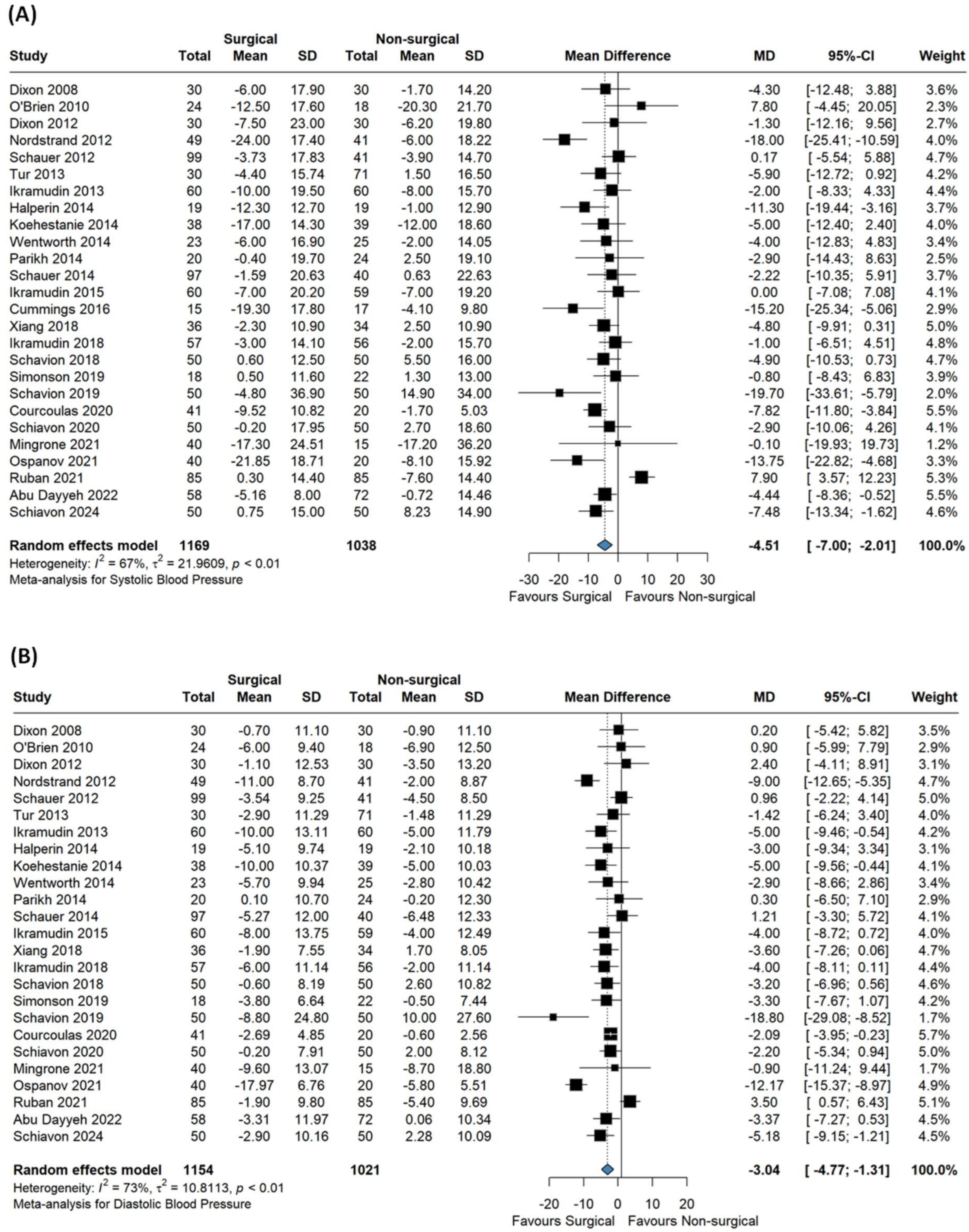


Fig. 2 Forest plot illustrating the subgroup analysis of surgical versus non-surgical methods focusing on (**A**) systolic blood pressure (**B**) Diastolic blood pressure

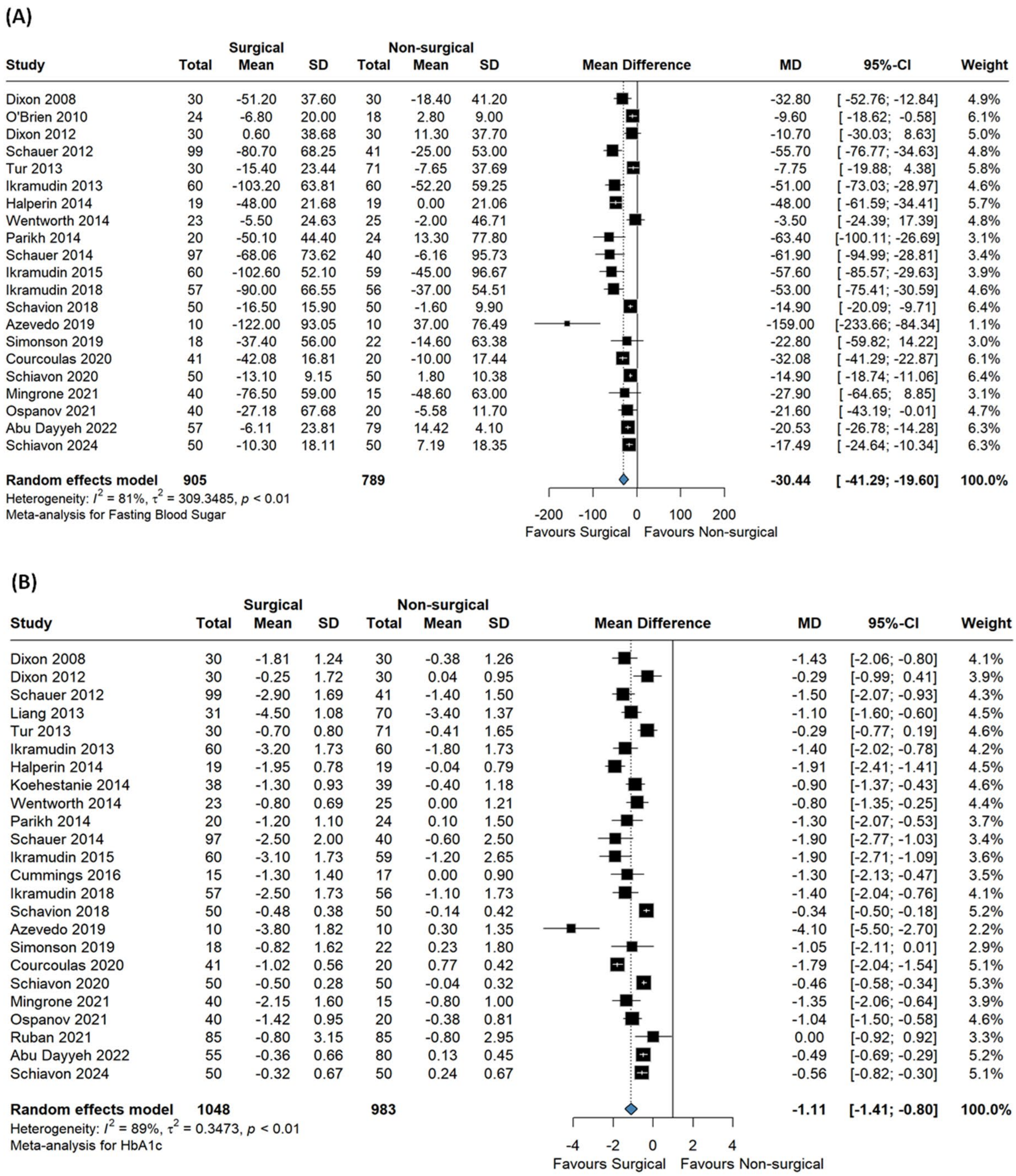


Fig. 3 Forest plot illustrating the subgroup analysis of surgical versus non-surgical methods focusing on (**A**) Fasting blood sugar (**B**) glycated haemoglobin (HbA1c)

subgroups except the subgroup of >2 years follow-up (I^2 = 0.0%).

The mean changes in HbA1c were reported in 24 RCTs. Patients who underwent bariatric surgery had a significantly greater reduction in HbA1c compared to those treated non-surgically (MD: -1.108%; 95% CI: -1.414 to -0.802; P<.001) (Fig. 3). The included studies were significantly heterogeneous (I^2 = 89.4). Subgroup analysis by follow-up duration revealed a greater reduction in HbA1c in the surgical groups across all subgroups (S1 Table). Although the DJBL/BPD surgery group did not show a significant difference from non-surgical treatments, the superiority of surgical intervention remained significant for all other types of surgery (S8-9 Figs).

Sensitivity analyses confirmed the robustness of the findings for both FBS and HbA1c meta-analyses (S2

Table and S20-21 Figs). Meta-regression analysis using continuous variables such as the year of study publication, duration of follow-up, sample size, mean age and mean BMI did not show any significant association with the overall pooled estimates for FBS or HbA1c reduction (S3 Table). Funnel plots for glycemic indexes, including FBS (21 studies) and HbA1c (24 studies), appeared asymmetrical, primarily due to the results of Azevedo's study (S29-30 Figs). The Egger test confirmed a probable risk of publication bias for FBS (P=.001) and HbA1c (P=.002). We applied the trim and fill method to explore the impact of potential missing studies further. For FBS, adjusting for publication bias by adding seven hypothetical studies resulted in an estimated effect size of -18.9170 [-33.5884; -4.2456], with a p-value of 0.134 and heterogeneity of 84.6% (S29 Fig). Similarly, for HbA1c, the inclusion of ten additional studies adjusted the effect size to -0.5852 [-0.9969; -0.1734], with a p-value of 0.006 and heterogeneity of 93.0% (S30 Fig).

Meta-analysis of changes in lipid profiles after bariatric surgery versus non-surgical intervention

Twenty-five RCTs were included in a meta-analysis to assess mean triglyceride level changes between surgical and non-surgical treatments. The studies were heterogeneous (I^2 = 74.5%). The pooled results indicated that surgical interventions were more effective in reducing TG levels compared to non-surgical treatments (MD: -39.746 mg/dl; 95% CI: -54.458 to -25.034; P<.001). Subgroup analysis revealed that only patients in the RYGB and LAGB surgery groups experienced significant reductions in TG levels, while other types of bariatric surgery did not show significant superiority over non-surgical treatments (S17 Fig). However, in subgroup analyses based on follow-up duration, all groups demonstrated the superiority of surgical interventions (S1 Table and S16 Fig).

Changes in HDL levels were pooled from 25 studies, which also showed high heterogeneity (I^2 = 73.1%). Individuals in the surgical arms had a greater increase in HDL levels compared to those in the non-surgical arms (MD: 7.387 mg/dl; 95% CI: 5.056 to 9.719; P<.001). Similar to the TG analysis, only the RYGB and LAGB surgery groups showed significant differences in mean HDL changes compared to non-surgical treatments (S11 Fig). Additionally, all follow-up duration subgroups indicated significant superiority of surgical interventions (S1 Table and S10 Fig).

Leave-one-out sensitivity analyses for both TG and HDL meta-analyses revealed that removing any included study did not significantly change the pooled effects of each analysis (S22-25 Figs). Separate meta-analyses using a fixed-effect model and studies with more than 50 cases per arm confirmed the robustness of our findings in both TG and HDL analyses (S2 Table). Meta-regression analyses for TG and HDL levels did not identify any significant variables contributing to heterogeneity or affecting the pooled results (S3 Table). The funnel plot of 25 articles in the TG meta-analysis appeared symmetrical, representing the absence of publication bias risk, confirmed by the Egger test (P=.98). Moreover, the trim and fill methods suggested no missing study (S34 Fig). Despite the symmetrical funnel plot of 25 articles in the HDL meta-analysis and the non-significant results of the Egger test (P=.41), three missing studies were suggested based on the trim and fill method (S31 Fig).

Mean changes in LDL levels were available from 21 articles. The change in LDL levels was not significantly different between surgical and non-surgical treatments (MD: -7.744 mg/dl; 95% CI: -16.783 to 1.293; P=.089), with extreme between-study heterogeneity (I^2 = 91.8%). Subgroup analysis also showed non-significant differences between treatments across all follow-up duration groups (S1 Table and S12 Fig). The observed heterogeneity was high in all subgroups except for >1-year but ≤2-year follow-up subgroup studies (I^2=0.0%). None of the bariatric surgery groups were significantly superior to non-surgical interventions in reducing LDL levels (S13 Fig). Leave-one-out analysis revealed that excluding Parikh's study made the mean LDL reduction in surgical arms significantly higher than in non-surgical arms (S23 Fig). However, further sensitivity analyses using a fixed-effect model or studies with more than 50 cases per arm did not demonstrate the superiority of bariatric surgery (S2 Table). The Egger test (P=.13) and funnel plots did not indicate publication bias or asymmetry in the analysis of LDL, including 21 studies. However, the trim and fill method represented three missing studies, potentially due to publication bias (S32 Fig).

Twenty studies reporting mean total cholesterol changes for surgical and non-surgical interventions were included. Despite high heterogeneity (I^2 = 90.8%), the meta-analysis revealed that the mean difference between the two arms was not statistically significant (MD: -8.635 mg/dl; 95% CI: -19.847 to 2.576; P=.12). Subgroup analyses based on follow-up duration or type of surgery also showed non-significant differences in MD between surgical and non-surgical treatments (S2 Table, S14-15 Figs). The heterogeneity was moderate in subgroups of studies with >1-year but ≤2-year and more than 2 years follow-up duration (I^2=47.8% and 44.1%, respectively). Sensitivity analysis showed that omitting any included study did not significantly change the pooled result (S24 Fig). However, further analysis using a fixed-effect model showed that the mean TC change in the surgery group was more pronounced than in non-surgical groups (MD: -4.461 mg/dl; 95% CI: -7.352 to -1.570; P=.002). Meta-analysis of studies with more than 50 cases per arm did not reveal a significant difference (S2 Table). No potential source of risk of publication bias was found in the TC meta-analysis using funnel plot and the Egger test (P=.28). Moreover, no missing study was reported by trim and fill methods (S33 Fig).

Meta-regression analyses for LDL and TC levels, using the same variables previously described, showed that none of the variables were significantly associated with the pooled results of the analysis (S3 Table).

Grading the quality of evidence and the strength of recommendations using the GRADE approach

S4 Table presents the GRADE summary of findings. The certainty of the pooled results was high for most of the reported variables. However, the certainty for the TC and LDL analyses was moderate and low, respectively. In terms of the importance of the findings, the HbA1c result was categorized as critical. The result for total cholesterol was considered non-important, while all other results were deemed important based on the GRADE system.

Discussion

This systematic review and meta-analysis aimed to compare the efficacy of different bariatric surgery modalities to non-surgical treatments, such as medications, diet, lifestyle modifications, or a combination of these approaches. Through a meta-analysis of 29 randomized clinical trials involving 2548 patients, we found that the combined results significantly favored bariatric surgery in terms of reducing both systolic and diastolic blood pressure, our primary outcomes. Furthermore, bariatric surgery proved to be more effective than non-surgical treatments in reducing fasting blood glucose, hemoglobin A1C, and triglyceride levels. Patients who underwent bariatric surgery also demonstrated higher HDL levels. However, the two treatments had no significant difference in reducing LDL and total cholesterol levels.

The primary outcome of this study was the significant reduction in systolic and diastolic blood pressure. Previous systematic reviews have primarily focused on changes in body weight, fasting plasma glucose, and other factors, thus underestimating the efficacy of bariatric surgery in lowering blood pressure, an important risk factor for several health issues. Our meta-analysis indicated that the results significantly favored bariatric surgery over non-surgical treatments in reducing blood pressure values. Subgroup analysis showed that the Roux-en-Y gastric bypass procedure, which is the most commonly performed bariatric surgery in both clinical practice and our study population, had the most significant positive effect on reducing both systolic and diastolic blood pressure. Other modalities, such as laparoscopic adjustable gastric banding (LAGB), biliopancreatic diversion with duodenal switch (BPD/DS), duodenal-jejunal bypass liner (DJBL), and sleeve gastrectomy, also demonstrated greater reductions in blood pressure in the surgical group compared to the non-surgical group. However, these differences were not statistically significant, possibly due to the smaller populations undergoing these procedures, resulting in insufficient data to produce a significant outcome.

The mean reductions in SBP and DBP observed in our study (-4.506 mmHg and −3.040 mmHg, respectively) are clinically meaningful, particularly when contextualized within the broader literature on cardiovascular risk reduction. Evidence from large-scale studies demonstrates that even modest reductions in BP can significantly lower the risk of major cardiovascular events. For instance, a 5-mmHg reduction in SBP has been associated with a 10% decrease in the risk of cardiovascular events, including stroke, heart failure, ischemic heart disease, and cardiovascular mortality [26–28]. Similarly, a 3-mmHg reduction in DBP has been shown to yield proportional risk reductions across various age groups, with the greatest benefits observed in younger populations [27]. Antihypertensive medications achieve varying degrees of BP reduction depending on the drug class, dose, and treatment intensity. For instance, ACE inhibitors typically lower BP by -8/-5 mmHg at half the maximum recommended dose, while dual alpha and beta receptor blockers reduce BP by -6/-4 mmHg in patients with mild to moderate hypertension [29, 30]. Similarly, hydrochlorothiazide exhibits a dose-dependent effect, with reductions ranging from −4/-2 mmHg at 6.25 mg/day to -11/-5 mmHg at 50 mg/day [31]. More intensive regimens, such as those involving more versus less intense BP-lowering treatment, achieve greater reductions, with mean SBP/DBP differences of -11.1/-5.6 mmHg [32]. In comparison, bariatric surgery achieves BP reductions that are slightly lower than those of high-intensity pharmacotherapy but comparable to monotherapy or low-dose combinations. Importantly, bariatric surgery offers additional benefits beyond BP control, including sustained weight loss and improvements in metabolic parameters, which may further reduce cardiovascular risk.

Furthermore, the duration of follow-up played an important role in the significance of our primary outcome. Studies with less than one year of follow-up and those with over two years of follow-up showed significant results favoring bariatric surgery in reducing both systolic and diastolic blood pressure. In contrast, studies with follow-up periods between 12 and 24 months, although favoring the surgical method, did not demonstrate statistically significant results. This difference could be due to the rapid weight loss experienced soon after bariatric surgery, significantly impacting blood pressure within the first year. Over time, as weight loss stabilizes, its immediate effects may diminish. Additionally, the long-term lifestyle changes adopted by patients after surgery might take longer to fully impact blood pressure, including improved diet and increased physical activity, leading to significant outcomes only in studies with extended follow-up periods.

Many of the included patients, in addition to obesity and hypertension, also suffered from diabetes. The coexistence of obesity, hypertension, and diabetes significantly decreases the quality of life and plays an important role as a risk factor for several critical health issues, such as cardiovascular disease [33–36]. In this context, we also observed bariatric surgeries' statistically significant superiority in FBS and HbA1C values. Unlike our primary outcome of blood pressure, not only the Roux-en-Y gastric bypass but also sleeve gastrectomy and laparoscopic adjustable gastric banding demonstrated statistically significant reductions in FBS and HbA1C. However, while the duodenal-jejunal bypass liner and biliopancreatic diversion procedures showed greater reductions in these values, the results were not statistically significant. Regarding the duration of follow-up, the patterns observed in our primary outcomes were repeated: studies with follow-ups of less than one year and those with over two years had statistically significant results, while studies with follow-up periods between 12 and 24 months did not show significant results.

Other secondary outcomes include HDL, LDL, total cholesterol, and triglycerides. It is quite safe and straightforward to interpret that people with obesity who need surgery or medication to achieve a healthy body weight and BMI often have impaired lipid profiles [37]. They typically exhibit high levels of LDL, triglycerides, and total cholesterol, along with low levels of HDL [38]. These impairments alone can significantly increase the risk of cardiovascular diseases [39]. When combined with previously discussed issues like hypertension and diabetes, these factors can lead to a substantially higher risk of irreversible events in patients' lives [40, 41]. Our analysis demonstrated significant results for both HDL and Tg markers. HDL levels were significantly higher in the surgery group, while Tg levels were higher in the non-surgical treatment group. Among the surgical methods, RYGB stood out as a dominant and solid option, showing statistically significant better results compared to non-surgical methods. However, although bariatric surgery was favored in reducing LDL and Tc values, the results were not statistically significant in the overall pooled analysis of LDL and total cholesterol.

The significant improvements in blood pressure and metabolic outcomes observed in our study may be partially mediated by changes in adipokine profiles following bariatric surgery. One such adipokine, omentin-1, has been shown to play a key role in improving insulin sensitivity, glucose metabolism, and cardiovascular function. Omentin-1 is secreted by visceral fat, and its levels are inversely correlated with waist circumference and insulin resistance. In obese patients undergoing bariatric surgery, increased serum omentin-1 levels have been associated with improved diastolic cardiac function and reduced cardiovascular risk [42].

In recent years, bariatric surgery has become increasingly prevalent due to the rising rates of obesity and associated metabolic disorders [43, 44]. This surge in surgical interventions is driven by the significant benefits observed, such as substantial weight loss and improvements in conditions like hypertension, diabetes, and dyslipidemia [45, 46]. While bariatric surgery is increasingly recognized for its significant benefits, non-surgical treatments remain a critical component of obesity management, particularly for patients who are not candidates for surgery or prefer less invasive options [47]. Non-surgical treatments for obesity include pharmacological therapies, dietary interventions, lifestyle modifications, and behavioral counseling. Pharmacological agents, such as orlistat, liraglutide, and semaglutide, have effectively achieved weight loss and improved metabolic parameters, particularly in patients with obesity and type 2 diabetes [48]. However, the long-term sustainability of these results often depends on continued medication use. Dietary and lifestyle interventions, such as low-calorie diets combined with regular physical activity, remain foundational approaches for obesity management. However, the extent of weight loss achieved with these methods is typically modest, with adherence posing a significant challenge. Behavioral interventions aim to support sustained lifestyle changes, though their long-term efficacy can vary depending on individual patient factors [49]. While non-surgical methods are less invasive and may benefit patients with mild to moderate obesity, they are generally less effective in achieving substantial and sustained weight loss or resolving comorbidities, particularly in patients with severe obesity or those who fail initial therapy. Combining these strategies, such as pairing pharmacotherapy with lifestyle changes, may enhance outcomes but still falls short of the efficacy observed with bariatric surgery [15]. However, it is crucial to acknowledge the potential risks associated with bariatric surgery, including surgical complications [50], so it is of utmost importance that the medical care team of the patient have all the data on trials on this matter so far included in one study to have a better vision In making the decision to allocate each patient to what modality of treatment.

The broader literature highlights important risks associated with bariatric surgery that should be considered in clinical decision-making. Bariatric surgery has been associated with higher rates of gastrointestinal complications, such as anastomotic leaks, ulcers, and internal hernias, as well as nutritional deficiencies, including iron deficiency and hypovitaminosis B12 [4, 51, 52]. For example, a cohort study of 1,888 patients with severe obesity found that bariatric surgery was associated with a 16% increased risk of gastrointestinal surgery, a 4.7% increased risk of gastroduodenal ulcers, and a 14% increased risk of iron deficiency compared to medical treatment [52]. Similarly, randomized trials have reported hospitalization rates of up to 11% following gastric bypass, primarily due to complications such as abscesses, ulcers, and cholelithiasis [51].

Despite these risks, bariatric surgery is generally considered safe, with mortality rates as low as 0.1% in-hospital and 0.3% at 30 days, reflecting improvements in surgical techniques and patient care protocols [4]. The most common causes of mortality include sepsis, cardiac events, and pulmonary embolism, while morbidity is often driven by cardiovascular events, pulmonary issues, and gastrointestinal complications. Nutritional deficiencies, particularly after malabsorptive procedures like biliopancreatic diversion, remain a significant concern and require long-term monitoring and supplementation [4].

Given the significance of this topic, numerous studies have been conducted, though their results have not always been consistent. In a study by L. Sjöström et al., bariatric surgery led to significant long-term weight loss and improved cardiovascular risk factors. However, there were no significant differences in blood pressure changes between the surgical and non-surgical groups over the 10-year follow-up period [11]. In another study, Although bariatric surgery greatly enhanced metabolic parameters and facilitated weight loss, Wu and colleagues found that it did not show significant differences in blood pressure changes compared to non-surgical methods over five years [12]. Additionally, Mingrone and colleagues discovered that over a ten-year follow-up period, metabolic surgery was more effective at managing type 2 diabetes and aiding weight loss compared to conventional medical therapy. However, there were no significant differences in blood pressure changes between the groups undergoing surgical and medical treatments [15]. On the other hand, multiple observational studies and secondary analyses of randomized trials have indicated that subjects who undergo bariatric surgery exhibit higher remission rates of hypertension compared to those who do not have the surgery [13, 14, 16].

These inconsistencies may stem from differences in study designs, populations, and follow-up durations. Furthermore, variability in non-surgical treatment protocols, the inclusion of patients with different comorbidities, and different surgical techniques likely contribute to these divergent results.

Thus, it is crucial to reach a firm conclusion on this matter. The importance of this study lies in its comprehensive analysis, which includes a larger number of patients compared to previous research. This extensive sample size enhances the reliability of the results, making the findings more robust and generalizable. Consequently, the study offers valuable insights for the patient's care team, facilitating informed decisions about treatment options. The significant patient inclusion and rigorous methodology make this study one of the most impactful in the field, providing clear evidence that supports the superior efficacy of bariatric surgery in managing obesity and related comorbidities.

Limitations

Several limitations should be acknowledged. First, the study population was predominantly from Europe and the USA, which may limit the generalizability of our findings to other populations, particularly those in Asia, the Middle East, and Africa. Future studies should focus on multi-ethnic populations to improve the external validity of these results. Additionally, the inclusion criteria may have restricted real-world observational data, leading to potential selection bias. While our analysis was based solely on randomized controlled trials to ensure methodological rigor, observational studies can provide valuable insights into long-term outcomes in broader patient populations. Second, the wide range of publication years for the included studies means that the medications used in non-surgical groups have evolved, with newer medications being more effective. However, even in recent studies, bariatric surgery remains a more effective option compared to non-surgical methods for achieving the desired outcomes [17, 53]. Third, we observed moderate to strong evidence of heterogeneity in analyses of some of our endpoints, which is consistent with the issue reported in several previous meta-analyses [54–56]. Fourth, our study lacks reported data on complications and adverse events, such as malnutrition, dumping syndrome, and surgical mortality, in the included RCTs. This restricts our ability to compare the risks of bariatric surgery with non-surgical interventions. Lastly, there was a lack of studies addressing the quality of life of the patients, which could have connected various factors and biomarkers to the day-to-day experiences of those suffering from obesity, hypertension, and other comorbidities. Further trials and studies reporting not only factors like blood pressure, blood glucose, and lipid profiles but also measures of quality of life are needed to enhance decision-making.

Conclusion

In conclusion, this systematic review and meta-analysis of 29 randomized clinical trials underscores the superior efficacy of bariatric surgery over non-surgical treatments in managing obesity and associated metabolic disorders. Our findings indicate that bariatric surgery significantly reduces systolic and diastolic blood pressure, fasting blood glucose, hemoglobin A1C, and triglyceride levels while increasing HDL levels. Among the various surgical modalities, Roux-en-Y gastric bypass demonstrated the most significant impact on these outcomes. The extensive sample size of this study provides robust and generalizable evidence, offering valuable insights for patient care teams. These findings affirm the critical role of bariatric surgery in managing obesity and improving related health conditions such as hypertension, diabetes, and dyslipidemia, supporting its use as an effective treatment option.

Supplementary Information

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Supplementary Material 1

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Not applicable.

Author contributions

P. D. conceptualized the study, collected data, and drafted the manuscript. SM. P. collected data, conducted statistical analysis for the meta-analysis, and contributed to data interpretation. H. S., M. M., S. S., D. ND., and MM. M., P. PR., F. OS., P. E., MA. F., were involved in data collection, quality assessment of included studies, and writing and editing the manuscript. K. H. provided expert consultation on systematic review methodology, meta-analysis, and research project management. H. S. served as the principal investigator, supervised the entire project, developed the systematic review protocol, ensured methodological rigor, and was responsible for the final approval of the manuscript.

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Data availability

This study is a systematic review and meta-analysis, relying on data already provided by previously published studies. All datasets and materials used in this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable. This study is a systematic review and meta-analysis that utilized previously published and peer-reviewed material. Therefore, no ethical approval or consent to participate was required.

Consent for publication

Not applicable. As this study relied solely on previously published data, no individual person's data, images, or videos were included that would require consent for publication.

Competing interests

The authors declare no competing interests.

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