CLINICAL RESEARCH STUDY

THE AMERICAN JOURNAL of MEDICINE®

Weight and Type 2 Diabetes after Bariatric Surgery: Systematic Review and Meta-analysis

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ABSTRACT

BACKGROUND: The prevalence of obesity-induced type 2 diabetes mellitus is increasing worldwide. The objective of this review and meta-analysis is to determine the impact of bariatric surgery on type 2 diabetes in association with the procedure performed and the weight reduction achieved.
METHODS: The review includes all articles published in English from January 1, 1990, to April 30, 2006.
RESULTS: The dataset includes 621 studies with 888 treatment arms and 135,246 patients; 103 treatment arms with 3188 patients reported on resolution of diabetes, that is, the resolution of the clinical and laboratory manifestations of type 2 diabetes. Nineteen studies with 43 treatment arms and 11,175 patients reported both weight loss and diabetes resolution separately for the 4070 diabetic patients in these studies. At baseline, the mean age was 40.2 years, body mass index was 47.9 kg/m^2, 80% were female, and 10.5% had previous bariatric procedures. Meta-analysis of weight loss overall was 38.5 kg or 55.9% excess body weight loss. Overall, 78.1% of diabetic patients had complete resolution, and diabetes was improved or resolved in 86.6% of patients. Weight loss and diabetes resolution were greatest for patients undergoing biliopancreatic diversion/duodenal switch, followed by gastric bypass, and least for banding procedures. Insulin levels declined significantly postoperatively, as did hemoglobin A1c and fasting glucose values. Weight and diabetes parameters showed little difference at less than 2 years and at 2 years or more.
CONCLUSION: The clinical and laboratory manifestations of type 2 diabetes are resolved or improved in the greater majority of patients after bariatric surgery; these responses are more pronounced in procedures associated with a greater percentage of excess body weight loss and is maintained for 2 years or more.
 • *The American Journal of Medicine (2009) 122, 248-256*

KEYWORDS: Bariatric surgery; Biliopancreatic diversion/duodenal switch; Gastric bypass; Gastroplasty; Laparoscopic adjustable gastric banding; Meta-analysis; Type 2 diabetes

A remarkable effect of bariatric surgery is the profound and durable resolution of the clinical manifestations of type 2 diabetes. In our 2004 meta-analysis of 134 studies that reported comorbidity resolution (2738 citations), based on reports of the experience with 22,094 patients from January 1, 1990 to June 5, 2003, we found that bariatric surgery is followed by resolution of type 2 diabetes in 48% of patients who underwent laparoscopic adjustable gastric banding, 84% of patients who underwent gastric bypass, and 98% of patients who underwent biliopancreatic diversion/duodenal switch.[1]

Laparoscopic adjustable gastric banding involves the placement of a percutaneous adjustable band constricting the upper stomach; gastric bypass consists of division of the stomach into a small upper pouch and a gastric remnant, the upper pouch drained by a Roux limb of proximal jejunum; the biliopancreatic diversion/duodenal switch involves performance of a subtotal gastrectomy and dividing the small intestine into an enteric limb carrying food, a biliopancreatic

Funding: This work was supported by Ethicon Endo-Surgery, Inc, a Johnson & Johnson Company, Cincinnati, Ohio.

Conflict of Interest: None of the authors have any conflicts of interest associated with the work presented in this manuscript.

Authorship: All authors had access to the data and played a role in writing this manuscript.

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0002-9343/$ -see front matter
doi:10.1016/j.amjmed.2008.09.041

limb carrying bile and pancreatic juice, and an ultra-short distal common channel after anastomosis of the 2 proximal limbs.

To explore these findings further, we updated the 2004 meta-analysis to include all studies on banding, gastroplasty, gastric bypass, and biliopancreatic diversion/duodenal switch published between January 1, 1990, and April 30, 2006. We report on the total (<2 years) and long-term (≥2 years) resolution and improvement of the clinical manifestation of type 2 diabetes after bariatric surgery, substantiated by metabolic data of insulin levels, percentage of hemoglobin A1c (HgA1c), and fasting glucose levels for those studies containing pure diabetic populations. We examined the effect of surgery on diabetes and overall weight reduction relative to the categories of bariatric surgery performed.

CLINICAL SIGNIFICANCE

- Type 2 diabetes was resolved in 78% and resolved or improved in 87% of patients undergoing bariatric surgery.
- There was a progressive relationship of diabetes resolution and weight loss achieved as a function of the operation performed: laparoscopic adjustable gastric banding, gastroplasty, gastric bypass, and biliopancreatic diversion/duodenal switch.
- Clinical findings were substantiated by the laboratory parameters of serum insulin, HbA1c, and glucose.
- These findings were maintained for 2 years or more.

MATERIALS AND METHODS

Search Strategy for Identification of Studies

We conducted a comprehensive review of all studies published in the English literature containing data on weight loss and type 2 diabetes-related outcomes for patients treated with any form of bariatric surgery. We performed an electronic search in MEDLINE, Current Contents, and the Cochrane Library for interventional or observational studies published from January 1, 1990, to April 30, 2006. Search terms used were as follows: obesity/surgery (MeSH) OR gastric bypass OR gastroplasty OR bariatric OR gastric banding OR anastomosis, Roux-en-Y (MeSH) OR biliopancreatic diversion (MeSH) OR jejunoileal bypass (MeSH) OR ([gastric pacing OR gastric stimulation] AND obes*). To supplement the electronic search, we also reviewed PubMed for the prior 6 months with no limits and Current Contents for the prior year. In addition, manual reference checks were performed of bibliographies of accepted articles and reviews published within the last 2 years.

Selection of Studies

The studies were selected for further review, and data extraction was based on protocol-defined criteria. Only English language studies or studies abstracted or translated into English were included. Multiple publications of the same or overlapping series of patients were identified and grouped together as "kinned" citations. The parent study was most often the more recent publication. Data from kin studies were counted only once to avoid double-counting of patients.

Assessment of Methodological Quality

All the studies were assigned a level of evidence using the schema of evidence assignment developed by the Centre for Evidence-based Medicine in Oxford, United Kingdom (Table 1, online).[2] In addition, randomized controlled trials also were rated for quality on the basis of the Jadad scoring method.[3]

Data Collection and Analysis

Study, patient, and treatment data were summarized using simple counts and means. Efficacy outcomes collected for weight loss were absolute weight, body mass index (BMI), and percentage of excess body weight lost. Diabetes-related outcomes were expressed as the percentage of patients with their clinical and laboratory manifestations of diabetes resolved (off diabetes medications with normal fasting blood glucose [<100 mg/dL] or HgA1c [<6%]), improved (decreased dosage of diabetes medications or more normal fasting blood glucose [100-125 mg/dL]), resolved or improved, unchanged, and worsened. Diabetes-related laboratory values obtained were insulin levels, HgA1c, and fasting blood glucose.

Mean patient characteristics were synthesized by calculating raw weighted means. Because the reporting of baseline characteristics is often incomplete, the denominators used for creating percentages and means vary by the individual characteristics reported.

Weight loss was calculated at the time for which data were available on at least 50% of the initial patient population. Groups with 50% or more patient follow-up were divided according to whether the time point was less than 2 years or 2 years or more. Results for diabetes resolution and diabetes-related laboratory data were grouped for annual time points after surgery. The outcomes for groups with less than 2 years follow-up and 2 years or more were analyzed separately. The diabetes resolution outcomes are given only for patients in each cohort who had diabetes before surgery, as are insulin, HgA1c, and fasting glucose values. The definition of diabetes at times varied among authors; as a rule, however, overt diabetes was defined as a fasting blood glucose greater than 125 mg/dL or an HgA1c greater than 7%.

Meta-analysis

Restricted, maximum-likelihood, random-effects meta-analyses were conducted for each procedure group and each

study characteristic and subgroup of interest.[4,5] These random-effects meta-analyses take into account both the study sample size and the estimate of heterogeneity in the selected studies. The higher the between-study variation (ie, the more heterogeneous the study results are), the less impact the study sample size had in weighting the studies in the analysis.

Tests of heterogeneity were conducted using Cochran's Q statistic,[6] and the percentage of variation in meta-analyzed outcomes that could be attributed to sources other than sampling error (I^2) also was calculated. When the I^2 estimate was equal to 25%, 50%, and 75%, this can be interpreted as indicating the presence of low, moderate, and high heterogeneity, respectively.[7]

Sensitivity analyses stratified by the level of evidence (levels I and II vs levels II-IV evidence) and by the percentage of patients followed up were conducted for resolution of diabetes in the overall group. In addition, sensitivity analyses stratified by the percentage of patients followed up also were performed for percentage of excess body weight loss in the overall group.

A meta-regression approach was used to evaluate whether baseline BMI or percentage of excess body weight loss at the last time point reported had an effect on diabetes resolution. Calculations were done using SAS software version 8.1 (SAS Inc, Cary, NC) and SPSS software version 14.0 (SPSS Inc, Chicago, Ill).

RESULTS

Systematic Review

Search Yields. Initially, a total of 4402 citations were screened and 1817 full publications were retrieved, yielding 621 primary studies that met criteria for inclusion in the extractable and analyzable dataset (Figure 1). These primary studies were associated with an additional 558 kin studies, which occasionally contributed additional data of interest, such as data on subgroups.

Study Characteristics. The dataset consists of 621 studies with 888 treatment arms and 135,246 patients; 103 arms with 3188 patients reported on the resolution of the clinical and laboratory manifestations of type 2 diabetes. Nineteen studies with 43 treatment arms and 11,175 patients reported both weight loss and diabetes resolution outcomes separately for the 4070 diabetic patients in these studies.

Table 2 presents study level characteristics according to procedure. A few studies with mixed treatment groups or other bariatric procedures are not represented. Most studies were performed in Europe (44%) or North America (43%). Seventy-three percent of the studies were single-arm series with 58% of those being retrospective. Only 4.7% of the studies were randomized clinical trials, with only 10 studies (1.6%) contributing class I evidence. Multicenter studies made up 11% of the dataset. By Jadad scoring, 27 of the 29 randomized controlled trials had a quality score of 1 to 3 and 2 trials had a score of 4 to 5.

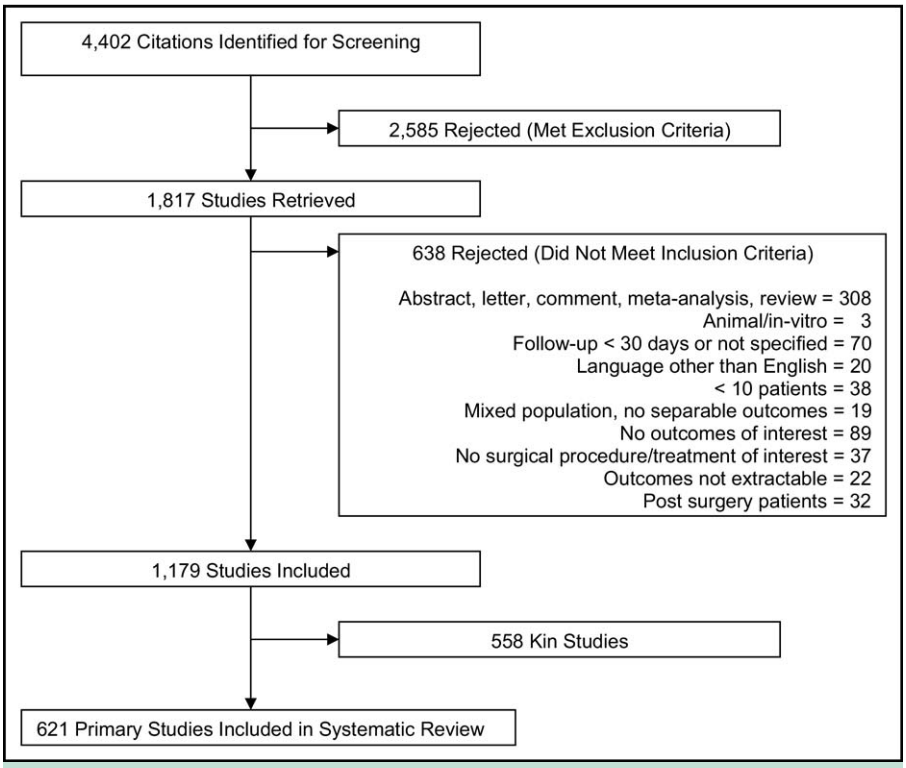

Figure 1 Study screening and data extraction process.

Table 2 Study Characteristics

	Total[a]				Gastric Banding			Gastroplasty			Gastric Bypass			Biliopancreatic Diversion/ Duodenal Switch		
	k	t	n	%	k	t	n	k	t	n	k	t	n	k	t	n
Totals	621	888	135,246		158	192	32,908	159	186	17,198	221	287	55,106	48	64	8670
Publication Year																
1990-1994	75	110	10,325	12.1%	5	7	654	34	46	3025	20	22	3544	1	2	228
1995-1999	97	150	16,306	15.6%	19	22	2995	45	52	4353	26	32	3497	9	10	1431
2000-2001	85	123	14,207	13.7%	29	38	2145	32	36	4781	20	25	4847	3	3	226
2002-2003	129	176	30,994	20.8%	38	46	11,538	20	22	1157	52	70	13,989	11	17	2112
2004-2005	193	264	55,431	31.1%	58	66	13,863	24	26	3712	77	102	23,728	22	29	4525
2006	42	65	7983	6.8%	9	13	1713	4	4	170	26	36	5501	2	3	148
Study Location																
Europe	275	390	45,749	44.4%	106	131	21,921	89	98	9889	39	47	4015	32	39	2469
North America	268	391	77,167	43.2%	25	29	5121	46	61	4017	160	211	49,285	13	22	5857
South America	19	24	2701	3.1%	1	1	29	3	3	1423	12	15	1147	1	1	40
Australia/New Zealand	22	29	3838	3.5%	10	12	2433	4	5	196	4	4	236	1	1	134
Asia	9	11	1029	1.5%	1	1	14	7	7	875	1	2	80	—	—	—
Middle East	28	43	4762	4.5%	15	18	3390	10	12	798	5	8	343	1	1	170
Study Design[b]																
RCT	29	65	3360	4.7%	10	15	564	12	17	522	13	22	947	—	—	—
nRCT prospective	49	89	6554	7.9%	16	21	1182	13	16	465	21	28	1618	3	4	55
Comparative retrospective	60	126	13,601	9.7%	19	29	3852	16	17	1673	33	52	5142	6	8	1047
UCS prospective	187	224	21,186	30.2%	38	43	6301	60	62	3607	52	65	8615	21	28	1761
Single-arm retrospective	266	343	75,348	42.7%	71	80	20,762	55	70	10,412	86	101	28,341	14	17	5247
Observational	25	33	14,436	4.0%	2	2	151	1	1	17	15	18	10,410	3	6	473
Case-control	2	3	84	0.3%	1	1	44	1	2	40	—	—	—	—	—	—
Level of Evidence																
I	10	20	1172	1.6%	7	10	713	3	3	120	2	3	137	—	—	—
II	79	147	14,085	12.7%	22	30	1430	24	32	859	37	52	7253	4	5	171
III	233	337	35,508	37.6%	45	56	6673	66	70	4516	87	121	17,780	30	41	2734
IV	296	379	83,804	47.6%	83	95	24,040	65	80	11,241	94	110	29,903	13	17	5678
Institutional Setting																
Single	540	760	109,979	86.9%	140	170	25,588	140	162	14,701	192	250	48,828	40	49	7294
Multicenter	70	107	23,386	11.3%	18	22	7320	17	21	2259	26	33	6212	4	7	661
NR	11	21	1881	1.8%	—	—	—	2	3	238	3	4	66	4	8	715

k = number of studies; t = number of treatment groups; n = number of patients; RCT = randomized controlled trial; nRCT = nonrandomized controlled trial; UCS = uncontrolled case series; NR = not reported.

Total study characteristics may be greater or lesser than the sum of the 4 individual procedures because there were comparative studies of more than 1 procedure that were counted only once in the total, and the total includes procedures that could not be characterized as 1 of the 4 listed procedures.

[a]Total column includes studies with mixed surgery types, revisions/reparations and other surgery types not shown (including biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, sleeve gastrectomy, and unspecified bariatric surgery).

[b]Does not include studies without efficacy and safety data (including guidelines and health economic studies).

Table 3 Surgery Characteristics

Surgery Type[a]	Open				Laparoscopic			
	k	t	n	%	k	t	n	%
Total	296	365	42,455		242	285	56,201	
Gastric banding	22	28	1655	3.9%	130	151	29,749	52.9%
Gastroplasty	123	144	12,538	29.5%	19	19	1669	3.0%
Gastric bypass	116	144	21,115	49.7%	86	108	24,179	43.0%
Biliopancreatic diversion/duodenal switch	35	49	7147	16.8%	7	7	604	1.1%

k = number of studies; t = number of treatment groups; n = number of patients.
[a]Table does not include studies having mixed/unspecified surgical techniques.

Table 3 divides surgery type by laparoscopic and open procedures. The majority (85%) of the banding studies were laparoscopic, whereas 87% of the gastroplasty (partitioning of the stomach into a small, upper pouch and the gastric remnant), 57% of the gastric bypass, and 83% of the biliopancreatic diversion/duodenal switch procedures were open.

Patient Characteristics. The mean age of the patients at baseline was 40.2 years with a range of 16 to 65 years (Table 4). The mean BMI at baseline was 47.9 kg/m^2. Approximately 80% of the patients were female, and approximately 10.5% had undergone previous bariatric surgical procedures. Of the overall population, 22.3% had type 2 diabetes.

Efficacy Meta-analyses and Heterogeneity

Heterogeneity of Results. As would be expected from such a large dataset encompassing a wide range of accrual years and various study types, with the inclusion of multiple procedures, the data on weight loss were heterogeneous. Weight loss data among the 16 diabetes-only studies were less heterogeneous. Similarly, data on diabetes resolution were for the most part highly heterogeneous (>75%) for the entire dataset but was slightly less heterogeneous (<75%) for some surgery groups in the pure diabetic population. Although the values for the I^2 statistic were often more than 80%, indicating significantly more between-study than within-study heterogeneity, the results across studies were substantially consistent with rates more than 65% in all but the smallest studies. Thus, meta-analytic pooling of the results was believed to be appropriate.

Weight Loss by Procedure. Total weight loss (all procedures) at the time point for which data are available for at least 50% of study patients was 38.5 kg or 55.9% of excess body weight loss (Table 5). Total weight loss at less than 2 years was 36.6 kg or 53.8% excess body weight loss. Weight loss at 2 years or more follow-up was 41.6 kg or 59% excess body weight loss. Weight loss was greatest for the biliopancreatic diversion/duodenal switch groups followed by gastric bypass, gastroplasty, and laparoscopic adjustable gastric banding. The relative effectiveness of the procedures was consistent at both less than 2 years and 2 years or more.

Weight Loss by Procedure—Diabetic Patients Only. For diabetic patients only, the total weight loss (all procedures) at the time point for which data are available for at least 50% of study patients was 40.6 kg or 64.4% of excess body weight loss (Table 6, online). The weight loss results again appear to last more than 2 years, with a weight loss of 38.2 kg or 67.1% excess body weight at less than 2 years and 42.9 kg or 58.0% excess body weight at 2 years or more.

Diabetes Resolution by Procedure. In the 621 studies, the diabetic patients had an overall 78.1% resolution of their clinical manifestations of diabetes, and diabetes was improved or resolved in 86.6% (Table 7, online). Diabetes resolution was greatest for patients undergoing biliopancreatic diversion/duodenal switch (95.1% resolved), followed by gastric bypass (80.3%), gastroplasty (79.7%), and then laparoscopic adjustable gastric banding (56.7%). The proportion of patients with diabetes resolution or improvement was fairly constant at time points less than 2 years and 2 years or more. Postoperative insulin levels decreased significantly, as did HgA1c and fasting glucose values. Sensitivity analyses for the overall results (all procedures) revealed no effect of level of evidence ($P > .10$) or follow-up duration ($P > .10$) on resolution of diabetes. Table 8 represents an overview of the progressive relationship of weight loss per operative classification for overall, less than 2 years, and 2 years or more resolution of diabetes.

Diabetes Resolution for Pure Diabetic Populations. Overall, there were 12 treatment groups reporting categoric outcomes for diabetes with 79.3% of diabetic patients having resolution of their clinical and laboratory manifestations of diabetes and 98.9% having resolution or improvement (Table 9, online). Again, the observation of greater resolution for biliopancreatic diversion/duodenal switch procedures followed by bypass and then banding held true. Results were fairly homogeneous with I^2 values of 0%, 49%, and 21% for the biliopancreatic diversion/duodenal switch, gastric bypass, and banding groups, respectively. Metaregression revealed evidence of an impact of mean change in BMI on diabetes resolution ($P < .01$). Substantively, the same association held true at the time points of less than 2 years and 2 years or more. The laboratory parameters of

Table 4 Patient Characteristics

Baseline Characteristics	Total[a]			Gastric Banding			Gastroplasty			Gastric Bypass			Biliopancreatic Diversion/Duodenal Switch		
	t	N	Mean (Range)	t	N	Mean (Range)	t	N	Mean (Range)	t	N	Mean (Range)	t	N	Mean (Range)
Mean age (y)	671	101,043	40.17 (16.00-65.00)	153	28,202	39.92 (16.00-64.00)	134	11,101	36.19 (17.00-50.00)	214	38,181	40.92 (16.00-65.00)	53	6594	40.95 (27.00-52.00)
Mean BMI (kg/m^2)	669	89,312	47.86 (29.90-154.00)	156	26,306	44.97 (37.00-54.20)	133	10,602	46.72 (32.20-142.00)	205	30,688	49.55 (41.00-154.00)	55	6828	50.46 (36.20-69.60)
	t	n/N	%	t	n/N	%	t	n/N	%	t	n/N	%	t	n/N	%
Gender:															
Male	660	19,470/97,814	19.9%	144	4736/26,344	18.0%	132	2184/10,409	21.0%	206	6631/37,785	17.5%	60	1737/7146	24.3%
Female	660	77,828/97,814	79.6%	144	21,584/26,344	81.9%	132	8057/10,409	77.4%	206	31,019/37,785	82.1%	60	5370/7146	75.1%
Prior bariatric surgery	206	3513/33,509	10.5%	27	178/4516	3.9%	32	17/3983	0.4%	66	1177/15,405	7.6%	14	311/4381	7.1%
Comorbid conditions															
Degenerative joint disease	120	9795/23,844	41.1%	20	1304/3434	38.0%	17	413/1265	32.6%	51	7081/16,042	44.1%	13	384/885	43.4%
Hypertension	220	14,557/35,468	41.0%	41	1856/5443	34.1%	35	885/2610	33.9%	86	9115/20,806	43.8%	24	1335/2828	47.2%
GERD	71	6060/15,959	38.0%	9	333/1186	28.1%	10	90/687	13.1%	41	5416/13,350	40.6%	3	25/262	9.5%
Dyslipidemia	73	3262/9138	35.7%	17	823/2339	35.2%	13	691/1403	49.3%	26	1019/3818	26.7%	7	122/263	46.4%
Hypercholesterolemia	46	3649/13,062	27.9%	6	42/1081	3.9%	6	78/322	24.2%	16	2555/8582	29.8%	11	583/1760	33.1%
Sleep apnea	148	6768/26,691	25.4%	23	579/4302	13.5%	18	140/1124	12.5%	69	5263/17,736	29.7%	19	521/1711	30.5%
Hypertriglyceridemia	22	777/3175	24.5%	2	5/21	23.8%	2	18/64	28.1%	5	291/938	31.0%	5	180/686	26.2%
Depression	39	2911/12,694	22.9%	6	371/2013	18.4%	3	54/330	16.4%	24	2352/9533	24.7%	2	27/230	11.7%
Type II diabetes	257	8088/36,233	22.3%	55	980/6013	16.3%	33	383/2497	15.3%	97	4973/21,306	23.3%	31	753/2502	30.1%
Asthma	45	542/3571	15.2%	6	37/479	7.7%	6	45/346	13.0%	21	232/1482	15.7%	5	170/602	28.2%
Cardiovascular problems	40	664/6385	10.4%	2	101/164	61.6%	10	130/1050	12.4%	18	233/4033	5.8%	2	7/107	6.5%
Heart disease	19	72/1595	4.5%	4	19/440	4.3%	5	12/240	5.0%	4	32/532	6.0%	2	8/243	3.3%
CHF	6	9/386	2.3%	1	1/11	9.1%	—	—	—	—	—	—	—	—	—

t = number of treatment groups reporting characteristic; n = number of patients with this characteristic; N = number of patients evaluated in studies reporting characteristic; % = percent of patients with characteristic in studies reporting it; BMI = body mass index; GERD = gastroesophageal reflux disease; CHF = congestive heart failure.

[a]Total column includes studies with mixed surgery types, revisions/reparations, and other surgery types not shown (including biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, sleeve gastrectomy, and unspecified bariatric surgery).

Table 5 Efficacy Outcomes for Weight Reduction: Meta-Analyses*

Outcome Measures[b]	Total[a] t (N)	Mean Change (95% CI)	Q-pval	I^2	Gastric Banding t (N)	Mean Change (95% CI)	Q-pval	I^2
Absolute weight (kg)	300 (23,380)	**−38.49 (−40.36, −36.63)**	<.001	99%	77 (4726)	**−31.97 (−35.14, −28.80)****	<.001	99%
BMI (kg/m^2)	428 (37,587)	**−13.97 (−14.51, −13.43)**	<.001	98%	112 (11,692)	**−10.62 (−11.36, −9.89)****	<.001	98%
% EBWL	319 (34,329)	**55.92 (54.06, 57.78)**	<.001	99%	66 (8599)	**46.17 (43.14, 49.19)****	<.001	99%
Treatment Arms with Outcome at <2 y								
Absolute weight (kg)	191 (12,483)	**−36.60 (−38.67, −34.54)****	<.001	99%	46 (2141)	**−27.41 (−30.26, −24.56)****	<.001	94%
BMI (kg/m^2)	262 (18,272)	**−13.61 (−14.32, −12.91)****	<.001	98%	66 (6128)	**−9.63 (−10.46, −8.79)****	<.001	97%
% EBWL	188 (20,556)	**53.82 (51.27, 56.37)**	<.001	100%	37 (5090)	**43.85 (40.25, 47.46)****	<.001	98%
Treatment Arms with Outcome at ≥2 y								
Absolute weight (kg)	108 (10,830)	**−41.60 (−45.15, −38.04)**	<.001	99%	31 (2585)	**−38.30 (−44.13, −32.47)****	<.001	99%
BMI (kg/m^2)	166 (19,315)	**−14.51 (−15.35, −13.68)**	<.001	99%	46 (5564)	**−12.01 (−13.24, −10.78)****	<.001	98%
% EBWL	131 (13,773)	**59.00 (56.40, 61.60)****	<.001	99%	29 (3509)	**48.98 (44.00, 53.96)****	<.001	98%

Outcome Measures[b]	Gastroplasty t (N)	Mean Change (95% CI)	Q-pval	I^2	Gastric Bypass t (N)	Mean Change (95% CI)	Q-pval	I^2
Absolute weight (kg)	84 (3922)	**−36.07 (−39.75, 32.38)****	<.001	99%	71 (7190)	**−44.65 (−48.35, −40.95)****	<.001	100%
BMI (kg/m^2)	95 (5423)	**−13.81 (−14.86, −12.76)****	<.001	97%	111 (11,081)	**−16.33 (−17.08, −15.58)****	<.001	96%
% EBWL	55 (2929)	**55.53 (51.33, 59.73)****	<.001	99%	116 (15,560)	**59.53 (56.47, 62.59)**	<.001	100%
Treatment Arms with Outcome at <2 y								
Absolute weight (kg)	52 (1724)	**−35.50 (−38.36, −32.65)****	<.001	89%	58 (6592)	**−45.36 (−49.71, −41.01)****	<.001	100%
BMI (kg/m^2)	53 (1709)	**−13.14 (−14.39, −11.88)****	<.001	93%	89 (8324)	**−16.36 (−17.14, −15.58)****	<.001	94%
% EBWL	25 (954)	**54.58 (46.70, 62.46)****	<.001	99%	82 (11,406)	**58.03 (54.25, 61.81)**	<.001	100%
Treatment Arms with Outcome at ≥2 y								
Absolute weight (kg)	32 (2198)	**−36.97 (−45.35, −28.58)****	<.001	99%	13 (598)	**−41.41 (−47.10, −35.72)****	<.001	93%
BMI (kg/m^2)	42 (3714)	**−14.57 (−16.31, −12.83)****	<.001	98%	22 (2757)	**−16.17 (−18.27, −14.07)****	<.001	98%
% EBWL	30 (1975)	**56.48 (52.47, 60.49)****	<.001	96%	34 (4154)	**63.25 (58.39, 68.10)****	<.001	98%

Outcome Measures[b]	Biliopancreatic Diversion/Duodenal Switch t (N)	Mean Change (95% CI)	Q-pval	I^2
Absolute weight (kg)	21 (2284)	**−43.53 (−47.53, −39.53)****	<.001	90%
BMI (kg/m^2)	35 (3224)	**−18.72 (−21.17, −16.27)****	<.001	97%
% EBWL	23 (3127)	**63.61 (57.52. 69.70)****	<.001	99%
Treatment Arms with Outcome at <2 y				
Absolute weight (kg)	13 (764)	**−38.27 (−41.94, −34.59)****	<.001	76%
BMI (kg/m^2)	16 (834)	**−20.04 (−25.01, −15.07)****	<.001	98%
% EBWL	13 (1562)	**56.04 (47.91, 64.17)****	<.001	97%
Treatment Arms with Outcome at ≥2 y				
Absolute weight (kg)	8 (1520)	**−49.81 (−53.48, −46.15)****	<.001	87%
BMI (kg/m^2)	19 (2390)	**−17.59 (−19.30, −15.88)****	<.001	95%
% EBWL	10 (1565)	**73.72 (69.02, 78.42)****	<.001	98%

t = number of treatment groups; N = number of patients evaluated; CI = confidence interval; Q-pval = *P* value for test of homogeneity of effects; I^2 = the percentage of total variation across studies that is due to heterogeneity rather than chance; BMI = body mass index; EBWL = excess body weight lost.

[a]Total column includes studies with mixed surgery types, revisions/reparations and other surgery types not shown (including biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, sleeve gastrectomy, and unspecified bariatric surgery).

[b]Outcomes reported at latest time point in which greater than 50% of the patient population were followed up.

BOLD font indicates a statistically significant preoperative versus postoperative difference within the surgery category. **P* value <.10 for test of heterogeneity of outcome. ***P* <.01 for test of heterogeneity of outcome.

diabetes declined significantly ($P < .001$): insulin levels 97.9 mU/L, HbA1c 2.1%, and fasting glucose 44.4 mmol/L.

DISCUSSION

The prevalence of type 2 diabetes has markedly increased in the last decade in the United States[8-10] and globally.[11-13] These data are correlated with a comparably steep increase in the prevalence of obesity.[14-17] The primary risk factor for type 2 diabetes is obesity, and 90% of all patients with type 2 diabetes are overweight or obese.[18,19] The National Health and Nutrition Examination Survey III (1988-1994) data showed that the risk for chemical diabetes is approximately 50% at a BMI of 30 kg/m^2 or more and more than 90% at a BMI of 40 kg/m^2 or more.[20] The Nurses' Health Study of 84,941 women (1980-1996) showed that the relative risk of diabetes increased approximately 40-fold as the BMI in-

Table 8 Overview of Weight Loss, Surgical Procedure, and Diabetes Resolution

	Total	Gastric Banding	Gastroplasty	Gastric Bypass	BPD/DS
% EBWL	55.9	46.2	55.5	59.7	63.6
% Resolved overall	78.1	56.7	79.7	80.3	95.1
% Resolved <2 y	80.3	55.0	81.4	81.6	94.0
% Resolved ≥2 y	74.6	58.3	77.5	70.9	95.9

%EBWL = percent excess body weight loss; BPD/DS = biliopancreatic diversion/duodenal switch.

creased from less than 23 kg/m^2 to more than 35 kg/m.[21,22] Virtually all morbidly obese adults have a measurably impaired glucose tolerance; 36% of individuals with impaired glucose tolerance will progress to type 2 diabetes within 10 years.[23] Even in the preclinical state, the steady-state plasma glucose concentration is statistically significantly correlated with the BMI.[24]

Morbid obesity has been defined by the National Institutes of Health (NIH) as a BMI of 40 kg/m^2 or more or 35 kg/m^2 or more in the presence of obesity comorbidities.[25] It has been estimated that in the United States there are 23 million people with a BMI of 35 kg/m^2 or more and 8 million people with a BMI of 40 kg/m^2 or more.[26] It is in this latter group that marked weight loss is associated with resolution and improvement in the clinical and laboratory manifestations of type 2 diabetes.[1,27-29]

This review summarizes the best available evidence on the effect of bariatric surgery on type 2 diabetes. There are a number of limitations to the present study, the most important being the high attrition of patients available for follow-up, the diversity of reporting formats for diabetes outcomes, and the lack of information on specific subpopulations such as different ethnic groups. All meta-analyses include the publication bias of availability. A literature review can capture only what has been published. Because the pattern of results for key outcomes in this meta-analysis are so consistent across studies, the amount of publication bias necessary to substantially change the inferences made in this article would have to be considerable. The accepted patient follow-up percentage in the literature is 50%, and data for more than 50% are scarce or unavailable.

On the other hand, a meta-analysis based on a systematic, cumulative review offers certain advantages of assessment: The dataset is global, comprehensive, and as inclusive as possible, limited only by a predetermined time span or cutoff date. The selection criteria are independent of outcomes and, therefore, to a large extent, eliminate selection bias. The derived meta-analytic data are weighted by the number of study patients, as well as by the variability among studies.

This study clearly demonstrated that bariatric surgery can cause resolution of the clinical manifestations of type 2 diabetes, as well as improvement, and that this resolution is verified by serum insulin levels, HgA1c, and fasting blood glucose determinations. Other studies have shown that type 2 diabetic patients also have fewer disease complications[28] and live longer after bariatric surgery-induced diabetes resolution.[30,31]

This study also showed that the resolution or improvement in type 2 diabetes is related to the weight loss achieved by morbidly obese diabetic patients. There are, however, data that do not allow the assumption of an absolute cause-and-effect relationship between body weight and type 2 diabetes. The simplest contradictory evidence is that 10% of type 2 diabetic patients are thin[18,19] and that approximately three quarters of the morbidly obese are not diabetic (Table 4).

Additional evidence that weight and type 2 diabetes are not in a direct cause-and-effect relationship is the observation that the manifestations of type 2 diabetes can totally clear within days after gastric bypass, before there is any significant weight loss,[27,32,33] and after the immediate effect of postoperative starvation on the blood glucose level has dissipated.[34] This finding would suggest that changes in the gut hormonal milieu after bypass of the distal stomach, duodenum, and proximal jejunum can influence the mechanism of type 2 diabetes. Substantiation of this hypothesis comes from the studies of Rubino et al,[35] who demonstrated that a bypass of the duodenum and upper jejunum in lean diabetic rats would return them to euglycemia, even though they maintained normal weight. Further, Arguelles and associates[36] recently reported a small series of lean diabetic patients who experienced remission of their diabetes with a modification of the Rubino procedure.

The available information on nonfatal adverse effects of the bariatric surgery procedures is so heterogenous, sparse, and poorly reported that it does not allow for a meta-analytic evaluation or even a systematic meaningful review. With respect to the mortality of bariatric surgery, we recently published a meta-analysis of early and late mortality.[37] The overall 30 days or less mortality for all bariatric surgery procedures was 0.28%, placing these procedures in the lowest category of operative mortality of operations performed in the United States.[38]

CONCLUSIONS

This systematic review and meta-analysis demonstrates that bariatric surgery has a powerful treatment effect in morbidly obese persons with type 2 diabetes. In the studies reporting only diabetic patients, 82% of patients had resolution of the clinical and laboratory manifestations of diabetes in the first 2 years after surgery, and 62% remained free of diabetes more than 2 years after surgery (80% and 75% for the total

group). Randomized clinical trials comparing surgery and medical therapies for type 2 diabetes are urgently needed. Considering the potential benefits for millions of people, such trials should assess the risk/benefit ratio of surgery in less obese (BMI 30-35 kg/m^2) populations, as well as in the morbidly obese (BMI $\geq$35 kg/m^2) population.

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Table 1 Levels of Evidence for Primary Research Question[a,c]

	Types of Studies			
	Therapeutic Studies—Investigating the Results of Treatment	Prognostic Studies—Investigating the Effect of a Patient Characteristic on the Outcome of Disease	Diagnostic Studies—Investigating a Diagnostic Test	Economic and Decision Analyses—Developing an Economic or Decision Model
Level I	☐ High-quality randomized controlled trial with statistically significant difference or no statistically significant difference but narrow confidence intervals ☐ Systematic review[b] of Level I randomized controlled trials (studies were homogeneous)	☐ High-quality prospective study[d] (all patients were enrolled at the same point in their disease with ≥ 80% follow-up of enrolled patients) ☐ Systematic review[b] of Level I studies	☐ Testing of previously developed diagnostic criteria in series of consecutive patients (with universally applied reference "gold" standard) ☐ Systematic review[b] of Level I studies	☐ Sensible costs and alternatives; values obtained from many studies; multiway sensitivity analyses ☐ Systematic review[b] of Level I studies
Level II	☐ Lesser-quality randomized controlled trial (eg, <80% follow-up, no blinding, or improper randomization) ☐ Prospective[d] comparative study[e] ☐ Systematic review[b] of Level II studies or Level I studies with inconsistent results	☐ Retrospective[f] study ☐ Untreated controls from a randomized controlled trial ☐ Lesser-quality prospective study (eg, patients enrolled at different points in their disease or < 80% follow-up) ☐ Systematic review[b] of Level II studies	☐ Development of diagnostic criteria on basis of consecutive patients (with universally applied reference "gold" standard) ☐ Systematic review[b] of Level II studies	☐ Sensible costs and alternatives; values obtained from limited studies; multiway sensitivity analyses ☐ Systematic review[b] of Level II studies
Level III	☐ Case-control study[g] ☐ Retrospective[f] comparative study[e] ☐ Systematic review[b] of Level III studies	☐ Case-control study[g]	☐ Study of nonconsecutive patients (without consistently applied reference "gold" standard) ☐ Systematic review[b] of Level III studies	☐ Analyses based on limited alternatives and costs; poor estimates ☐ Systematic review[b] of Level III studies
Level IV	Case series[h]	Case series	☐ Case-control study ☐ Poor reference standard	☐ No sensitivity analyses
Level V	Expert opinion	Expert opinion	Expert opinion	Expert opinion

[a]A complete assessment of the quality of individual studies requires critical appraisal of all aspects of the study design.

[b]A combination of results from ≥ 2 prior studies.

[c]Studies provided consistent results.

[d]Study was started before the first patient enrolled.

[e]Patients treated one way (eg, with cemented hip arthroplasty) compared with patients treated another way (eg, with cementless hip arthroplasty) at the same institution.

[f]Study was started after the first patient enrolled.

[g]Patients identified for the study on the basis of their outcome (eg, failed total hip arthroplasty), called "cases," are compared with those who did not have the outcome (eg, had a successful total hip arthroplasty), called "controls."

[h]Patients treated one way with no comparison group of patients treated another way.

This chart was adapted from material published by the Centre for Evidence-Based Medicine, Oxford, United Kingdom. For more information, please see www.cebm.net.

Table 6 Efficacy Outcomes for Weight Reduction in Diabetic Patients: Meta-Analyses

	Total				Gastric Banding			
	t (N)	Mean Change (95% CI)	Q-pval	I^2	t (N)	Mean Change (95% CI)	Q-pval	I^2
Total Diabetic Patients[b]								
Absolute weight (kg)	9 (452)	**−40.55 (−51.92, −29.19)****	<.001	87%	3 (23)	**−17.28 (−26.65, −7.92)**	.702	0%
BMI (kg/m^2)	11 (723)	**−13.57 (−17.00, −10.15)****	<.001	95%	4 (111)	**−8.34 (−10.61, −6.08)**	.167	41%
% EBWL	7 (540)	**64.42 (58.96, 69.89)****	<.001	94%	1 (88)	**51.90 (48.35, 55.45)**	—	—
Treatment Arms with Outcome at <2 y								
Absolute weight (kg)	5 (147)	**−38.22 (−54.18, −22.21****	<.001	81%	2 (6)	**−22.03 (−37.42, −6.63)**	.721	0%
BMI (kg/m^2)	7 (344)	**−13.99 (−18.71, −9.26)****	<.001	90%	2 (6)	**−7.61 (−11.44, −3.78)**	.785	0%
% EBWL	5 (421)	**67.10 (62.27, 71.93)****	<.001	91%	—	—	—	—
Treatment Arms with Outcome at ≥2 y								
Absolute weight (kg)	4 (305)	**−42.88 (−61.35, −24.42)****	<.001	92%	1 (17)	**−14.50 (−26.28, −2.72)**	—	—
BMI (kg/m^2)	4 (379)	**−12.86 (−8.33, −7.38)****	<.001	98%	2 (105)	**−8.37 (−11.94, −4.79)***	.04	76%
% EBWL	2 (119)	**58.01 (45.48, 70.54)****	<.001	91%	1 (88)	**51.90 (48.35, 55.45)**	—	—

	Gastric Bypass[a]				Biliopancreatic Diversion/Duodenal Switch			
	t (N)	Mean Change (95% CI)	Q-pval	I^2	t (N)	Mean Change (95% CI)	Q-pval	I^2
Total Diabetic Patients[b]								
Absolute weight (kg)	3 (161)	**−42.65 (−50.94, −34.35)***	.05	67%	3 (268)	**−56.30 (−66.41, −46.18)****	.009	79%
BMI (kg/m^2)	4 (341)	**−16.14 (−16.86, −15.42)**	.826	0%	3 (271)	**−16.47 (−26.06, −6,89)****	<.001	95%
% EBWL	6 (452)	**66.74 (62.58, 70.89)****	<.001	88%	—	—	—	—
Treatment Arms with Outcome at <2 y								
Absolute weight (kg)	2 (130)	**−38.71 (−55.37, −22.06)***	.016	83%	1 (11)	**−65.50 (−81.63, −49.37)**	—	—
BMI (kg/m^2)	3 (310)	**−16.04 (−16.81, −15.26)**	.813	0%	2 (28)	**−15.56 (−32.22, 1.10)****	<.001	97%
% EBWL	5 (421)	**67.10 (62.27, 71.93)****	<.001	91%	—	—	—	—
Treatment Arms with Outcome at ≥2 y								
Absolute weight (kg)	1 (31)	**−46.20 (−49.89, −42.51)**	—	—	2 (257)	**−53.79 (−65.05, −42.53)***	.016	83%
BMI (kg/m^2)	1 (31)	**−16.80 (−18.80, −14.80)**	—	—	1 (243)	**−18.10 (−19.12, −17.08)**	—	—
% EBWL	1 (31)	**64.70 (58.26, 71.14)**	—	—	—	—	—	—

t = number of treatment groups; N = number of patients evaluated; CI = confidence interval; Q-pval = *P* value for test of homogeneity of effects; I^2 = the percentage of total variation across studies that is due to heterogeneity rather than chance; BMI = body mass index; EBWL = excess body weight lost.

BOLD font indicates a statistically significant preoperative versus postoperative difference within the surgery category:

[a]Two treatment arms perform gastric bypass with an additional Silastic ring gastroplasty.

[b]Outcomes reported at latest time point in which greater than 50% of the patient population were followed up.

*$P < .10$ for test of heterogeneity of outcome;

**$P < .01$ for test of heterogeneity of outcome.

Table 7 Efficacy for Improvement in Diabetes Outcomes by Surgical Procedure: Meta-Analyses

	Total[a]				Gastric Bypass			
	t (N)	Mean (95% CI)	Q-pval	I^2	t (N)	Mean (95% CI)	Q-pval	I^2
Total								
% Patients' diabetes resolved[b]	103 (3188)	78.07 (73.80, 82.34)	<.001	83%	22 (553)	56.73 (46.68, 66.78)	<.001	75%
% Patients' diabetes resolved or improved	52 (2170)	86.61 (81.64, 91.57)	<.001	87%	14 (522)	80.62 (69.73, 91.51)	<.001	90%
% Patients' diabetes improved	50 (2107)	37.40 (28.82, 45.98)	<.001	95%	14 (522)	38.10 (23.25, 52.95)	<.001	94%
% Patients' diabetes unchanged	37 (934)	14.29 (9.22, 19.35)	<.001	80%	11 (333)	18.08 (9.42, 26.75)	<.001	75%
% Patients' diabetes worsened	14 (3590)	1.14 (0.00, 2.37)**	<.001	94%	3 (894)	3.79 (0.00, 11.08)**	<.001	98%
Treatment Arms with Outcome at <2 y								
% Patients' diabetes resolved[b]	60 (1878)	80.27 (75.07, 85.47)	<.001	81%	9 (257)	54.99 (44.23, 65.75)	.017	57%
% Patients' diabetes resolved or improved	27 (1637)	86.00 (79.70, 92.31)	<.001	87%	9 (371)	82.29 (71.44, 93.14)	<.001	85%
% Patients' diabetes improved	27 (1637)	48.66 (37.47, 59.85)	<.001	96%	9 (371)	51.63 (33.95, 69.32)	<.001	94%
% Patients' diabetes unchanged	16 (462)	12.02 (4.39, 19.66)	<.001	86%	4 (124)	7.75 (0.00, 18.53)	.002	80%
% Patients' diabetes worsened	6 (2395)	0.38 (0.13, 0.63)	.893	0%	1 (271)	0.37 (0.00, 1.09)	—	—
Treatment Arms with Outcome at ≥2 y								
% Patients' diabetes resolved[b]	43 (1310)	74.59 (67.25, 81.93)	<.001	85%	13 (296)	58.29 (42.23, 74.35)**	<.001	82%
% Patients' diabetes resolved or improved	25 (533)	87.24 (79.18, 95.31)**	<.001	86%	5 (151)	78.69 (53.77, 100.00)**	<.001	91%
% Patients' diabetes improved	23 (470)	19.39 (11.63, 27.16)**	<.001	77%	5 (151)	14.71 (5.35, 24.06)*	.019	66%
% Patients' diabetes unchanged	21 (472)	16.09 (9.26, 22.92)**	<.001	70%	7 (209)	24.70 (15.50, 33.91)*	.048	53%
% Patients' diabetes worsened	8 (1195)	2.79 (0.00, 6.02)**	<.001	93%	2 (623)	5.85 (0.00, 17.59)**	<.001	98%

	Gastroplasty				Gastric Bypass			
	t (N)	Mean (95% CI)	Q-pval	I^2	t (N)	Mean (95% CI)	Q-pval	I^2
Total								
% Patients' diabetes resolved[b]	16 (281)	79.74 (67.32, 92.17)**	<.001	85%	30 (1311)	80.28 (74.43, 86.14)**	<.001	79%
% Patients' diabetes resolved or improved	11 (104)	87.21 (75.68, 98.73)*	.011	56%	18 (1314)	84.53 (76.08, 92.99)	<.001	90%
% Patients' diabetes improved	11 (104)	38.48 (16.86, 60.10)**	<.001	73%	16 (1251)	46.34 (30.26, 62.43)	<.001	97%
% Patients' diabetes unchanged	9 (97)	12.03 (1.34, 22.72)*	.074	44%	8 (350)	21.15 (8.43, 33.88)**	<.001	92%
% Patients' diabetes worsened	—	—	—	—	3 (1649)	0.31 (0.04, 0.57)	.989	0%
Treatment Arms with Outcome at <2 y								
% Patients' diabetes resolved[b]	8 (70)	81.44 (63.80, 99.08)**	<.001	73%	25 (1256)	81.60 (75.24, 87.95)**	<.001	82%
% Patients' diabetes resolved or improved	4 (31)	89.02 (71.72, 100.00)	.366	5%	11 (1204)	83.95 (72.94, 94.96)	<.001	93%
% Patients' diabetes improved	4 (31)	45.79 (3.99, 87.59)*	.035	65%	11 (1204)	50.64 (31.79, 69.48)	<.001	98%
% Patients' diabetes unchanged	2 (22)	22.75 (4.69, 40.81)	.435	0%	5 (279)	20.62 (3.56, 37.69)**	<.001	95%
% Patients' diabetes worsened	—	—	—	—	3 (1649)	0.31 (0.04, 0.57)	.989	0%
Treatment Arms with Outcome at ≥2 y								
% Patients' diabetes resolved[b]	8 (211)	77.46 (58.19, 96.73)**	<.001	89%	5 (55)	70.90 (58.78, 83.02)	.498	0%
% Patients' diabetes resolved or improved	7 (73)	84.38 (66.34, 100.00)**	.003	70%	7 (110)	85.32 (70.91, 99.72)**	.003	70%
% Patients' diabetes improved	7 (73)	33.00 (7.58, 58.41)**	<.001	78%	5 (47)	27.56 (8.12, 47.00)*	.037	61%
% Patients' diabetes unchanged	7 (75)	10.10 (0.00, 21.88)*	.03	57%	3 (71)	22.37 (0.00, 45.12)*	.098	57%
% Patients' diabetes worsened	—	—	—	—	—	—	—	—

	Biliopancreatic Diversion/Duodenal Switch			
	t (N)	Mean (95% CI)	Q-pval	I^2
Total				
% Patients' diabetes resolved[b]	18 (491)	95.05 (91.05, 99.05)**	<.001	81%
% Patients' diabetes resolved or improved	6 (135)	98.96 (96.88, 100.00)	.997	0%
% Patients' diabetes improved	6 (135)	14.03 (1.76, 26.29)**	<.001	78%
% Patients' diabetes unchanged	5 (122)	1.86 (0.00, 4.44)	.951	0%
% Patients' diabetes worsened	—	—	—	—
Treatment Arms with Outcome at <2 y				
% Patients' diabetes resolved[b]	10 (231)	94.00 (86.27, 100.00)**	<.001	87%
% Patients' diabetes resolved or improved	3 (31)	100.00 (93.22, 100.00)	1	0%
% Patients' diabetes improved	3 (31)	32.06 (15.24, 48.87)	.496	0%
% Patients' diabetes unchanged	2 (15)	0.00 (0.00, 11.59)	1	0%
% Patients' diabetes worsened	—	—	—	—
Treatment Arms with Outcome at ≥2 y				
% Patients' diabetes resolved[b]	8 (260)	95.85 (91.87, 99.84)*	.034	54%
% Patients' diabetes resolved or improved	3 (104)	98.86 (96.62, 100.00)	.893	0%
% Patients' diabetes improved	3 (104)	5.02 (0.00, 11.58)	.156	46%

Table 7 Continued

	Gastroplasty				Gastric Bypass			
	t (N)	Mean (95% CI)	Q-pval	I^2	t (N)	Mean (95% CI)	Q-pval	I^2
% Patients' diabetes unchanged	3 (107)	1.96 (0.00, 4.67)	.754	0%				
% Patients' diabetes worsened	—	—	—	—				

t = number of treatment groups; N = number of patients evaluated; CI = confidence interval; Q-pval = *P* value for test of homogeneity of effects; I^2 = the percentage of total variation across studies that is due to heterogeneity rather than chance. **BOLD** font indicates a statistically significant preoperative versus postoperative difference within the surgery category:

[a]Total column includes studies with mixed surgery types, revisions/reparations and other surgery types not shown (including biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, sleeve gastrectomy, and unspecified bariatric surgery).

[b]Diabetes resolved = discontinued treatment, Diabetes improved = reduced treatment.

*$P < .10$ for test of heterogeneity of outcome;

**$P < .01$ for test of heterogeneity of outcome.

Table 9 Efficacy for Improvement in Diabetes Outcomes by Surgical Procedures in Studies Reporting Only Diabetic Patients: Meta-Analyses

	Total				Gastric Banding			
	t (N)	Mean (95% CI)	Q-pval	I^2	t (N)	Mean (95% CI)	Q-pval	I^2
Total Diabetic Patients								
% Patients' diabetes resolved[b]	12 (963)	79.29 (70.15, 88.43)	<.001	92%	4 (169)	62.71 (55.39, 70.03)	.284	21%
% Patients' diabetes resolved or improved	5 (422)	98.91 (96.50, 100.00)	<.001	89%	2 (103)	95.69 (85.98, 100.00)	.018	82%
% Patients' diabetes improved	5 (422)	23.64 (17.52, 29.75)	.088	51%	2 (103)	30.09 (21.16, 39.02)	.379	0%
% Patients' diabetes unchanged	5 (608)	1.48 (0.00, 4.33)	<.001	89%	2 (103)	4.31 (0.00, 14.02)	.018	82%
Insulin	5 (51)	**−97.98 (−146.69, −49.28)****	<.001	85%	2 (6)	−99.60 (−312.51, 113.30)	.18	44%
HbA1C (%)	5 (345)	**−2.13 (−2.63, −1.63)****	<.001	87%	1 (17)	−1.40 (−3.20, 0.40)	—	—
Fasting glucose (mmol/L)	12 (670)	**−4.36 (−5.25, −3.48)****	<.001	95%	2 (6)	−2.49 (−5.78, 0.80)	.421	0%
Treatment Arms with Outcome at <2 y								
% Patients' Diabetes Resolved[b]	10 (915)	81.81 (72.76, 90.85)	<.001	92%	3 (152)	65.13 (57.54, 72.72)	.976	0%
% Patients' Diabetes Resolved or Improved	4 (391)	98.56 (95.30, 100.00)	<.001	91%	2 (103)	95.69 (85.98, 100.00)	.018	82%
% Patients' diabetes improved	4 (391)	24.45 (17.32, 31.59)	.049	62%	2 (103)	30.09 (21.16, 39.02)	.379	0%
% Patients' diabetes unchanged	5 (608)	1.48 (0.00, 4.33)	<.001	89%	2 (103)	4.31 (0.00, 14.02)	.018	82%
Insulin	4 (37)	**−89.46 (−161.79, −17.12)****	<.001	88%	2 (6)	−99.60 (−312.51, 113.30)	.18	44%
HbA1C (%)	3 (297)	**−2.24 (−2.94, −1.54)****	<.001	93%	—	—	—	—
Fasting glucose (mmol/L)	9 (382)	**−3.91 (−4.82, −3.00)****	<.001	85%	2 (6)	**−2.49 (5.78, 0.80)**	.421	0%
Treatment Arms with Outcome at ≥2 y								
% Patients' diabetes resolved[b]	2 (48)	62.08 (23.47, 100.00)**	.006	87%	1 (17)	41.18 (17.78, 64.57)	—	—
% Patients' diabetes resolved or improved	1 (31)	100.00 (95.57, 100.00)	—	—	—	—	—	—
% Patients' diabetes improved	1 (31)	19.35 (5.45, 33.26)	—	—	—	—	—	—
% Patients' diabetes unchanged	—	—	—	—	—	—	—	—
Insulin	1 (14)	**−115.30 (−132.93, −97.67)**	—	—	—	—	—	—
HbA1C (%)	2 (48)	**−1.94 (−2.50, −1.38)**	.535	0%	1 (17)	−1.40 (−3.20, 0.40)	—	—
Fasting glucose (mmol/L)	3 (288)	**−5.47 (−7.11, −3.83)****	<.001	95%	—	**—**	—	—

	Gastric Banding				Biliopancreatic Diversion/Duodenal Switch			
	t (N)	Mean (95% CI)	Q-pval	I^2	t (N)	Mean (95% CI)	Q-pval	I^2
Total Diabetic Patients								
% Patients' diabetes resolved[b]	6 (477)	80.51 (74.79, 86.23)*	.08	49%	2 (317)	99.35 (98.31, 100.00)	.91	0%
% Patients' diabetes resolved or improved	3 (319)	100.00 (99.36, 100.00)	1	0%	—	—	—	—
% Patients' diabetes improved	3 (319)	20.44 (14.34, 26.54)	.234	31%	—	—	—	—
% Patients' diabetes unchanged	2 (200)	0.00 (0.00, 0.99)	1	0%	1 (305)	0.66 (0.00, 1.56)	—	—
Insulin	1 (20)	**−40.20 (−76.07, −4.33)**	—	—	2 (25)	**−125.00 (−139.57, −110.42)**	.124	58%
HbA1C (%)	4 (328)	**−2.18 (−2.71, −1.65)****	<.001	90%	—	—	—	—
Fasting glucose (mmol/L)	6 (379)	**−3.91 (−4.96, −2.85)****	<.001	90%	4 (285)	**−5.39 (−6.68, −4.10)****	<.001	93%
Treatment Arms with Outcome at <2 y								
% Patients' diabetes resolved[b]	5 (446)	81.19 (73.99, 88.38)*	.044	59%	2 (317)	99.35 (98.31, 100.00)	.91	0%
% Patients' diabetes resolved or improved	2 (288)	100.00 (99.35, 100.00)	1	0%	—	—	—	—
% Patients' diabetes improved	2 (288)	20.89 (12.66, 29.12)*	.089	65%	—	—	—	—
% Patients' diabetes unchanged	2 (200)	0.00 (0.00, 0.99)	1	0%	1 (305)	0.66 (0.00, 1.56)	—	—
Insulin	1 (20)	**−40.20 (−76.07, −4.33)**	—	—	1 (11)	**−130.70 (−139.32, −122.08)**	—	—
HbA1C (%)	3 (297)	**−2.24 (−2.94, −.54)****	<.001	93%	—	—	—	—
Fasting glucose (mmol/L)	5 (348)	**−3.86 (−5.13, −2.59)****	<.001	92%	2 (28)	**−4.54 (−5.64, −3.44)**	.394	0%
Treatment arms with outcome at ≥2 y								
% Patients' diabetes resolved[b]	1 (31)	80.65 (66.74, 94.55)	—	—	—	—	—	—
% Patients' diabetes resolved or improved	1 (31)	100.00 (95.57, 100.00)	—	—	—	—	—	—
% Patients' diabetes improved	1 (31)	19.35 (5.45, 33.26)	—	—	—	—	—	—
% Patients' diabetes unchanged	—	—	—	—	—	—	—	—
Insulin	—	**—**	—	—	1 (14)	**−115.30 (−132.93, −97.67)**	—	—
HbA1C (%)	1 (31)	**−2.00 (−2.58, −1.42)**	—	—	—	—	—	—
Fasting glucose (mmol/L)	1 (31)	**−4.20 (−5.47, −2.93)**	—	—	2 (257)	**−6.01 (−7.97, −4.05)****	—	—

t = number of treatment groups; N = number of patients evaluated; CI = confidence interval; Q-pval = *P* value for test of homogeneity of effects; I^2 = the percentage of total variation across studies that is due to heterogeneity rather than chance; HbA1C = hemoglobin A1C.

BOLD font indicates a statistically significant preoperative versus postoperative difference within the surgery category:

[a]Two treatment arms perform gastric bypass with an additional Silastic ring gastroplasty.

[b]Diabetes resolved = discontinued treatment, Diabetes improved = reduced treatment.

*$P < .10$ for test of heterogeneity of outcome;

**$P < .01$ for test of heterogeneity of outcome.