REVIEW

Bariatric Surgery
A Systematic Review and Meta-analysis

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Context About 5% of the US population is morbidly obese. This disease remains largely refractory to diet and drug therapy, but generally responds well to bariatric surgery.

Objective To determine the impact of bariatric surgery on weight loss, operative mortality outcome, and 4 obesity comorbidities (diabetes, hyperlipidemia, hypertension, and obstructive sleep apnea).

Data Sources and Study Selection Electronic literature search of MEDLINE, Current Contents, and the Cochrane Library databases plus manual reference checks of all articles on bariatric surgery published in the English language between 1990 and 2003. Two levels of screening were used on 2738 citations.

Data Extraction A total of 136 fully extracted studies, which included 91 overlapping patient populations (kin studies), were included for a total of 22 094 patients. Nineteen percent of the patients were men and 72.6% were women, with a mean age of 39 years (range, 16-64 years). Sex was not reported for 1537 patients (8%). The baseline mean body mass index for 16 944 patients was 46.9 (range, 32.3-68.8).

Data Synthesis A random effects model was used in the meta-analysis. The mean (95% confidence interval) percentage of excess weight loss was 61.2% (58.1%-64.4%) for all patients; 47.5% (40.7%-54.2%) for patients who underwent gastric banding; 61.6% (56.7%-66.5%), gastric bypass; 68.2% (61.5%-74.8%), gastroplasty; and 70.1% (66.3%-73.9%), biliopancreatic diversion or duodenal switch. Operative mortality (≤30 days) in the extracted studies was 0.1% for the purely restrictive procedures, 0.5% for gastric bypass, and 1.1% for biliopancreatic diversion or duodenal switch. Diabetes was completely resolved in 76.8% of patients and resolved or improved in 86.0%. Hyperlipidemia improved in 70% or more of patients. Hypertension was resolved in 61.7% of patients and resolved or improved in 78.5%. Obstructive sleep apnea was resolved in 85.7% of patients and was resolved or improved in 83.6% of patients.

Conclusions Effective weight loss was achieved in morbidly obese patients after undergoing bariatric surgery. A substantial majority of patients with diabetes, hyperlipidemia, hypertension, and obstructive sleep apnea experienced complete resolution or improvement.

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THE WORLD EPIDEMIC OF OVERweight (body mass index [BMI], calculated as weight in kilograms divided by the square of the height in meters, ≥25) and obesity (BMI ≥30) is estimated to encompass about 1.7 billion individuals,[1-3] and the percentage of overweight adults is highest in the United States.[4-7] Approximately two thirds of individuals living in the United States are overweight, and of those, almost half are obese.[7] The BMI subgroups experiencing the most rapid growth are 35 or higher (23 million) and 40 or higher (8 million).[8,9]

The rise in the prevalence of obesity is associated with increases in the prevalence of obesity comorbidities (eg, type 2 diabetes, hyperlipidemia, hypertension, obstructive sleep apnea, heart disease, stroke, asthma, back and lower extremity weight-bearing degenerative problems, several forms of cancer, depression, etc).[10-12] These comorbidities are responsible for more than 2.5 million deaths per year worldwide.[10] The loss of life expectancy due to obesity is profound—in comparison with a normal-weight individual, a 25-year-old morbidly obese man has a 22% reduction in expected remaining lifespan, representing an approximate loss of 12 years of life.[13]

Unfortunately, diet therapy, with and without support organizations, is relatively ineffective in treating obesity in the long term.[14,15] There are currently no truly effective pharmaceutical agents to treat obesity, especially morbid obesity.[14,15] In 1991, the National Institutes of Health established guidelines for the surgical therapy of morbid obesity (BMI ≥40 or BMI ≥35 in the presence of significant comorbidities), now referred to as bariatric surgery.[16]

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The literature on postoperative weight loss and the problems associated with various bariatric surgical procedures is extensive and has been summarized elsewhere.[17] The literature with respect to comorbidity outcomes of bariatric surgery is also extensive, but has not been systematically reviewed and subjected to meta-analysis. We have conducted a systematic review of published observational and interventional trials that focus on bariatric surgery. The subsequent meta-analysis has concentrated on the impact of bariatric surgery on 4 selected obesity comorbidities: diabetes, hyperlipidemia, hypertension, and obstructive sleep apnea. For consistency, meta-analyses of weight loss outcomes were confined to the studies qualifying for the categories selected for assessment.

METHODS

We used a comprehensive and current database to catalog the bariatric surgery literature. The catalog was developed as an online, navigable research adjunct. The evidence database for the catalog was assembled using established systematic review methods.[18,19]

The main objectives of this study were to analyze the impact of bariatric surgery on diabetes, hyperlipidemia, hypertension, and obstructive sleep apnea, as well as on health care economics and disease impact; to analyze weight reduction efficacy outcomes in the studies selected for the comorbid conditions; and to summarize operative mortality outcomes.

Data Sources

A broad search of the English-language literature was performed incorporating both electronic and manual components. The electronic search was performed using MEDLINE, Current Contents, and the Cochrane Library databases. MEDLINE (1990-2003, cutoff date June 5, 2003) was searched using the following search terms: *obesity/surgery, gastric bypass*, *gastroplasty*, *bariatric*, *gastric banding*, "*anastomosis, Roux-en-Y*," *biliopancreatic diversion* (including duodenal switch), or *jejunoileal bypass*. Prior to 1990, the literature offered little to no clinical data on the impact of bariatric surgery weight loss on diabetes, hyperlipidemia, hypertension, and obstructive sleep apnea. The complete bibliography of accepted and rejected studies is available by request to the corresponding author.

Two strategies were used to identify recently published articles that may not have been indexed on MEDLINE by the search cutoff date. First, a search was performed that included a keyword search for the prior 6 months with no limit. Next, Current Contents was searched for the prior year using an analogous approach. Finally, manual reference checks of accepted papers in recent reviews (within the past 2 years) were performed to supplement the above electronic searches. The cutoff date for the retrieval of articles from libraries was July 2003.

Literature Screening and Catalog Construction

Study selection was accomplished through 2 levels of study screening. At level 1 screening, abstracts were reviewed for the following exclusion criteria: publication of abstracts only, case reports, letters, comments, and reviews; animal or in vitro studies; fewer than 10 patients in the study; follow-up of less than 30 days; languages other than English; no surgical intervention for obesity; and intragastric balloon therapy (experimental device).

Full articles were then obtained for all studies accepted at level 1 and for any citations for which a determination could not be made from the abstract. For level 2 screening, inclusion required that the studies dealt with at least 1 of the following categories of information: surgical outcomes (including efficacy and/or safety), guidelines, health care economics, or disease impact (utilization [eg, hospital length of stay for bariatric surgery and readmissions] and quality of life).

Study Selection for Data Extraction

For inclusion in the subset of studies for data extraction, the screened studies had to report outcomes for one or more of the following comorbid conditions: diabetes, hyperlipidemia, hypertension, and obstructive sleep apnea, or on health care economics. Extracted studies could be of any design, published from 1990 to 2003, and had to have enrolled at least 10 patients undergoing bariatric surgery. All outcomes were preferentially extracted at the time points for which the comorbidity outcomes were available or the latest time point available for follow-up of at least 50% of the population. In studies reporting morbidity improvement, an effort was made to determine both the number of patients evaluated and the time point of evaluation. In some studies, however, the number of patients with a condition at baseline was the only denominator available. Time points for comorbidity improvement were imputed for some studies based on the time point at which other outcomes were reported (principally weight loss). *Kin relationships*, defined as multiple publications describing the same or overlapping series of patients, were identified and entered into our catalog only once to avoid the double counting of patients.

Definitions

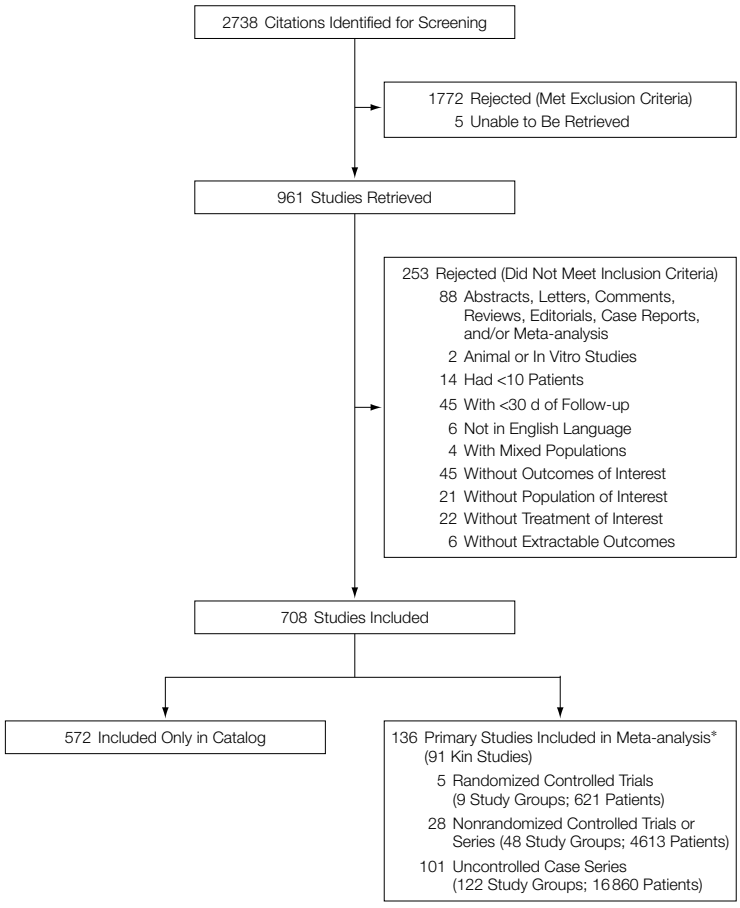
Surgical Procedures. Surgical procedures were grouped into the following categories: gastric banding (including adjustable and nonadjustable bands), gastric bypass (principally Roux-en-Y variations), gastroplasty (principally vertical banded gastroplasty), biliopancreatic diversion or duodenal switch (including a variety of modifications), and mixed and other (biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, and unspecified bariatric). Procedures that included a gastric bypass component (eg, gastroplasty with gastric bypass, biliopancreatic diversion with gastric bypass, and banding with gastric bypass) were classified as gastric bypass surgery. The history and evolution of the procedures discussed, by open and laparoscopic techniques, have been described.[20]

Results are reported individually for gastric banding, gastric bypass, gastro-

plasty, and biliopancreatic diversion or duodenal switch procedure groups, as well as for the *total population*, which included gastric banding, gastric bypass, gastroplasty, and biliopancreatic diversion or duodenal switch, plus mixed groups and other less common bariatric surgery procedures (biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, and unspecified bariatric surgery).

Resolved and Resolved or Improved. Outcomes of the selected comorbidities were grouped into categories of resolved and resolved or improved. For the calculation of the percentage resolved, we included those studies reporting the number of patients in which comorbid conditions disappeared or no longer required therapy. We preferentially extracted the number of patients evaluated as the denominator wherever possible. For the calculation of the percentage resolved or improved, we included studies reporting numbers of patients in both of these 2 categories (in which case, the 2 were summed), as well as studies that only used the term *improved*, but not the studies reporting only resolution. Consequently, the percentage resolved or improved may be lower than the percentage deemed resolved due to different study cohorts and, therefore, different denominators for the percentage calculations. *Improved* in lipid disorders was defined as normalization of laboratory values or the reduction or discontinuation of medical therapy.

Figure. Study Attrition Diagram



Asterisk indicates 2 health care economics studies without efficacy or safety data are included in the 136 primary studies.

Weight Loss. Weight loss is reported as the mean percentage of excess weight loss, which is the standard in the bariatric surgery nomenclature. This calculation is derived from the formula: percentage of excess weight loss = (weight loss/excess weight) × 100, where excess weight = total preoperative weight – ideal weight. Changes in absolute weight (kilograms), BMI, and percentage of initial weight are also reported when appropriate.

Safety Data. Operative mortality (≤30 days) is reported. Complication rates were difficult to catalog because they were variably reported, dependent on duration of follow-up, and were procedure specific, as well as a function of open compared with laparoscopic technique. They are not included in this article.

Statistical Analysis

Analyses were performed only on the data from the studies in the data extraction subset. Study, patient, and treatment-level data were summarized using basic descriptive statistics (simple counts and means). The number of patients enrolled or randomized was used in the calculation of study and patient demographics.

Efficacy outcomes of interest were synthesized via meta-analytic pooling of similar surgery group results across studies with stratification by the type of surgery. In addition, meta-analysis of within-study surgery effects on weight loss and diabetes-related outcomes were stratified by studies with extractable outcomes for a general population compared with subgroups of patients with diabetes or impaired glucose tolerance.

Meta-analyses of all efficacy outcomes were conducted using a random-effects model, estimated by using the restricted maximum likelihood method.[21,22] Efficacy outcomes included both proportions (eg, response rates) and raw mean before and after changes (eg, absolute weight changes). The random-effects model meta-analyses take into account both study sample size and the estimate of between-study variation (ie, study het-

erogeneity) when weighting study effects. Meta-analytic means and mean changes are expressed with 95% confidence intervals (CIs).

Weighted means (ie, weighting results by sample size) were calculated for all studies for a given outcome to provide a non–meta-analytic comparison for each result. A drawback of the weighted means analysis is that it ignores between-study variations, providing a result similar to that found by a fixed-effects analysis. There are, however, positive aspects of the use of weighted means. In the analysis of continuous data, some outcomes had exceedingly wide fluctuations in within-study variation, allowing certain studies of the same size to be weighted quite differently.

All calculations were performed using SAS (version 8.1, SAS Institute Inc, Cary, NC) and SPSS (version 11.0, SPSS Inc, Chicago, Ill) statistical software.

RESULTS

Data Retrieval

A flow diagram outlining the systematic review process is provided (FIGURE). The initial literature review identified 2738 citations for screening. Of these, 1772 were rejected after reviewing the abstracts and 5 publications could not be retrieved prior to the retrieval cutoff date of July 18, 2003. Of the remaining 961 articles, 253 did not meet inclusion criteria for the catalog, and 572 studies met inclusion criteria only for the catalog but not for further analysis. Therefore, 136 fully extracted primary studies (for which there were 91 "kin" or linked publications) were available for meta-analysis.

Decisions about relationships among publications were made to maximize information on the comorbidities of interest without double counting patients. Several important studies had numerous kin publications. Outcomes of interest were typically presented in the more recently published articles in which longer periods of follow-up were reported for some or all of the patients. On the other hand, in some large studies only small subgroups of patients with outcomes relevant to the comorbidities of interest were reported and these articles were again dealt with to avoid counting patients more than once.

There were a total of 136 studies, within which there were 179 treatment groups and 22 094 patients either enrolled or analyzable in the data set, including those in comparator control

Table 1. Characteristics of Total Population and Gastric Banding and Gastric Bypass Studies*

	Total Population†			Gastric Banding			Gastric Bypass‡		
	No. of Studies	No. of Treatment Groups	No. of Patients	No. of Studies	No. of Treatment Groups	No. of Patients	No. of Studies	No. of Treatment Groups	No. of Patients
Publication year									
1990-1995	35	48	3653	1	1	12	12	15	1527
1996-2002	99	131	18 441	24	33	3861	32	44	5547
Study location									
Europe	58	76	9977	19	26	2769	7	10	416
North America	56	78	9786	2	2	81	33	43	6272
Other	20	25	2331	4	6	1023	4	6	386
Study design									
Randomized controlled trial	5	9	621	2	3	80	1	2	155
Nonrandomized controlled trial or series	28	48	4613	4	5	327	14	22	1163
Uncontrolled case series	101	122	16 860	19	26	3466	29	35	5756
Institutional setting									
Single	126	168	18 628	24	33	3634	43	57	7022
Multicenter	5	8	3120				1	2	52
Not reported	3	3	346	1	1	239			
Continuous outcomes time point, y§									
≤2	95	125	16 651	24	33	3855	31	40	5798
>2	32	35	3434	1	1	18	7	7	950
Not reported	10	19	2009				6	12	326
Categorical outcomes time point, y§									
≤2	64	77	14 290	16	18	3121	24	27	5306
>2	25	26	2895	1	1	18	6	6	842
Not reported	51	76	4909	9	15	734	15	26	926

*Table does not include 2 health care economics studies without efficacy or safety data.
†Includes gastric banding, gastric bypass, gastroplasty, biliopancreatic diversion or duodenal switch, as well as mixed groups and other less common procedures (biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, and unspecified bariatric surgery).
‡Includes standard and long-limb gastric bypass procedures with additional components (eg, gastroplasty, band).
§Total number of studies with categorical or continuous outcomes is greater than the total number of studies because some studies contained multiple treatment groups extracted at different time points.

groups. Health care economic outcomes were varied and not amenable to meta-analysis. We did, however, include the weight loss efficacy and operative mortality data from those studies in these respective analyses.

Study Characteristics

After excluding 2 health care economics studies with no weight loss or mortality data, 134 studies were extracted. Fifty-six of the extracted studies were based in North America, 58 in Europe, and 20 were conducted in other locations throughout the world (Australia, New Zealand, South America, Japan, Israel, Saudi Arabia, and Taiwan) (TABLE 1 and TABLE 2). Included were 5 randomized controlled trials, 28 nonrandomized controlled trials or series with comparison groups, and 101 uncontrolled case series. The majority of studies were conducted at single centers (n=126) and only a few were multicenter studies (n=5). At least 1 categorical outcome of interest (eg, proportion of patients with resolution or improvement in diabetes, hyperlipidemia, hypertension, or obstructive sleep apnea) or 1 continuous outcome of interest (change in a laboratory or physiological measure) was reported by each of the extracted studies.

Patient Characteristics

In studies reporting sex (150 treatment groups), 19.4% (n=3769) of patients were men and 72.6% (n=14082) were women (TABLE 3). Sex was not reported for 1537 patients (8%). The overall mean age was 38.97 years (range, 16.20-63.60 years) in studies for which this was reported. The BMI for 16944 patients at baseline was 46.85 (range, 32.30-68.80). Patient characteristics such as mean age and BMI at baseline were relatively similar across surgical procedure types.

Weight Loss

Given the emphasis on comorbidities, weight loss efficacy outcomes were preferentially extracted at time points for which comorbidity changes were reported. In addition, whenever possible, outcome time points representing at least 50% of the patient population undergoing surgery were used.

Substantial weight reduction was observed in this study set by both meta-analytic techniques and simple pooling across studies using weighted means (TABLE 4). The mean (95% CI) percentage of excess weight loss by meta-analysis at the outcome time point for which comorbidities were assessed was 47.5% (40.7%-54.2%) for gastric banding, 61.6% (56.7%-66.5%) for gastric bypass, 68.2% (61.5%-74.8%) for gastroplasty, and 70.1% (66.3%-73.9%) for biliopancreatic diversion or duodenal switch. The overall percentage of excess weight loss for 10172 patients for all surgery types was 61.2% (95% CI, 58.1%-64.4%). Although less common, weight loss outcomes were also reported as a decrease in BMI (mean [95% CI], 14.2 [13.3-15.1] in 8232 patients) and a decrease in absolute weight (mean [95%

Table 2. Characteristics of Gastroplasty and Biliopancreatic Diversion or Duodenal Switch Studies*

	Gastroplasty			Biliopancreatic Diversion or Duodenal Switch		
	No. of Studies	No. of Treatment Groups	No. of Patients	No. of Studies	No. of Treatment Groups	No. of Patients
Publication year						
1990-1995	17	19	534			
1996-2002	20	22	1034	17	20	4035
Study location						
Europe	14	16	582	12	14	2773
North America	13	15	439	5	6	1262
Other	10	10	547			
Study design						
Randomized controlled trial	1	1	30	1	2	46
Nonrandomized controlled trial or series	9	9	203	5	7	117
Uncontrolled case series	27	31	1335	11	11	3872
Institutional setting						
Single	35	39	1506	17	20	4035
Multicenter	1	1	34			
Not reported	1	1	28			
Continuous outcomes time point, y†						
≤2	23	27	1046	14	17	3179
>2	11	11	453	3	3	856
Not reported	3	3	69			
Categorical outcomes time point, y†						
≤2	14	17	798	9	11	3092
>2	8	8	343	2	2	842
Not reported	15	16	427	6	7	101

*Table does not include 2 health care economics studies without efficacy or safety data.
†Total number of studies with categorical or continuous outcomes is greater than the total number of studies because some studies contained multiple treatment groups extracted at different time points.

CI], 39.7 kg [37.2-42.2 kg] in 7588 patients). In most cases, weight loss outcomes did not differ significantly for assessments at 2 years or less compared with those at more than 2 years. All of the weight loss reductions reported in Table 4 are significant at the $P<.001$ level.

Operative Mortality

Operative mortality—mortality at 30 or less days—was 0.1% for the purely restrictive procedures (2297 patients undergoing banding and 749 patients undergoing gastroplasty), 0.5% in 5644 patients undergoing gastric bypass procedures, and 1.1% in 3030 patients undergoing biliopancreatic diversion or duodenal switch procedures.

Comorbidity Outcomes

Diabetes. When defined as the ability to discontinue all diabetes-related medications and maintain blood glucose levels within the normal range, strong evidence for improvement in type 2 diabetes and impaired glucose tolerance was found across all the surgery types. Within studies reporting resolution of diabetes, 1417 (76.8% [meta-analytic mean, 76.8%; 95% CI, 70.7%-82.9%]) of 1846 patients experienced complete resolution. Within studies reporting both resolution and improvement or only improvement of diabetes, 414 (85.4% [meta-analytic mean, 86.0%; 95% CI, 78.4%-93.7%]) of 485 patients experienced resolution or improvement of diabetes. The changes in glycosylated hemoglobin (HbA_{1c}), fasting glucose, and fasting insulin are also reported in TABLE 5 and TABLE 6.

In patients selected for diabetes or impaired glucose tolerance at baseline, the mean change in percentage of excess weight loss was 57.25% (95% CI, 46.21%-68.30%) and the reduction in the BMI was 14.03 (95% CI, 10.77-17.30), both of which are close to the values for unselected populations. Reductions in HbA_{1c} and fasting glucose levels were much greater in groups selected for baseline diabetes or impaired glucose tolerance. The reduction in fasting glucose levels was significantly different for the total diabetic population (mean change, 71.53 mg/dL; 95% CI, 49.37-93.69 mg/dL [3.97 mmol/L; 95% CI, 2.74-5.20 mmol/L]; n=296 by meta-analysis) compared with unselected populations (mean change, 13.33 mg/dL; 95% CI, 10.81-15.86 mg/dL [0.74 mmol/L; 95% CI, 0.60-0.88 mmol/L]; n=2092 by meta-analysis).

There was a difference in diabetes outcomes analyzed according to the 4 categories of operative procedures. With respect to diabetes resolution, there was a gradation of effect from 98.9% (95% CI, 96.8%-100%) for biliopancreatic diversion or duodenal switch to 83.7% (95% CI, 77.3%-90.1%) for gastric bypass to 71.6% (95% CI, 55.1%-88.2%) for gastroplasty, and to 47.9% (95% CI, 29.1%-66.7%) for gastric banding. The percentage of patients with diabetes resolved or improved showed different results (Table 5); this variation from the trend solely for diabetes resolved may be due to the far greater number of patients assessed for this variable (n=1846) compared with the number assessed for the combined variable (n=485) in the total population.

Hyperlipidemia. By both meta-analysis and by weighted means, the outcome categories of hyperlipidemia, hypercholesterolemia, and hypertriglyceridemia were significantly improved across all surgical procedures (including the mixed and other bariatric surgery groups; TABLE 7). The percentage of patients improved was typically 70% or higher, with some variation as a function of the measure used and the procedure performed. The maximum improvements in hyperlipidemia by meta-analysis occurred with the biliopancreatic diversion or duodenal switch procedure (99.1%; 95% CI, 97.6%-100%) and with gastric bypass (96.9%; 95% CI, 93.6%-100%).

In the total population, meta-analysis of the continuous measures demonstrated a significant decrease in total cholesterol level (mean change, 33.20 mg/dL; 95% CI, 23.17-43.63 mg/dL [0.86 mmol/L; 95% CI, 0.60-1.13 mmol/L]; n=2573), low-density lipoprotein cholesterol level (mean change, 29.34 mg/dL; 95% CI, 17.76-40.93 mg/dL [0.76 mmol/L; 95% CI, 0.46-1.06 mmol/L]; n=879), and level of triglycerides (mean change, 79.65 mg/dL; 95% CI, 64.60-95.58 mg/dL [0.90 mmol/L; 95% CI, 0.73-1.08 mmol/L]; n=2149). While there was not a significant increase in high-density lipoprotein cholesterol level in the total population, significant improvements were seen with gastric banding (mean change, 4.63 mg/dL; 95% CI, 1.54-7.72 mg/dL [0.12 mmol/L; 95% CI 0.04-0.20 mmol/L]; n=623) and with gastroplasty (mean change, 5.02 mg/dL; 95% CI, 0.77-9.27 mg/dL [0.13 mmol/L; 95% CI, 0.02-0.24 mmol/L]; n=253).

Hypertension. By both meta-analysis and by weighted proportions, hypertension significantly improved in the total patient population and across all surgical procedures (TABLE 8). The percentage of patients in the total population whose hypertension resolved was 61.7% (95% CI, 55.6%-67.8%). The percentage of patients in the total population whose hypertension resolved or

Table 3. Patient Characteristics*

	No./Total (%) of Patients
Sex†	
Male	3769/19 388 (19.4)
Female	14 082/19 388 (72.6)
Current or former smoker	455/1881 (24.2)
Nonsmoker	397/571 (69.5)
Prior bariatric surgery	255/5799 (4.4)
Comorbidities	
Type 2 diabetes	2507/16 342 (15.3)
Glucose tolerance impairment‡	1118/4331 (25.8)
Sleep disordered breathing	2399/12 266 (19.6)
Hypertension	5808/16 421 (35.4)
Dyslipidemia	1021/2868 (35.6)
Hypercholesterolemia	2568/6391 (40.2)
Hypertriglyceridemia	1092/4488 (24.3)
Asthma	279/2601 (10.7)
Coronary artery disease	132/1887 (7.0)
Congestive heart failure	8/348 (2.3)
Degenerative joint disease	4160/8277 (50.3)
Depression	402/2306 (17.4)
Gastroesophageal reflux	1983/4583 (43.3)

*The range of patient ages is 16 to 64 years and is based on ages reported in 87% of the trials. The body mass index range is 32.3 to 68.8 and is based on body mass indices reported in 77% of the trials. Body mass index is calculated as weight in kilograms divided by the square of height in meters.
†Not reported for 1537 patients (8%).
‡Includes hyperglycemia, hyperinsulinemia, metabolic syndrome, and impaired glucose tolerance.

improved was 78.5% (95% CI, 70.8%-86.1%). The rank order of efficacy among the surgical groups was variable for both resolution and resolution or improvement.

Obstructive Sleep Apnea. Diagnoses of sleep apnea, sleep-disordered breathing, and pickwickian syndrome were combined as representative of obstructive sleep apnea. By both meta-analysis and by weighted means, the combined outcome category of obstructive sleep apnea was significantly improved in the total patient population group and in each surgical procedure group (Table 8). The percentage of patients in the total population whose obstructive sleep apnea resolved was 85.7% (95% CI, 79.2%-92.2%). The percentage of patients in the total population whose obstructive sleep apnea resolved or improved was 83.6% (95% CI, 71.8%-95.4%).

Evidence for changes in obstructive sleep apnea was primarily available for gastric bypass patients. This was particularly so for the continuous objective variable of apneas or hypopneas per hour (4 available studies), which decreased by 33.85 per hour (95% CI, 17.47-50.23 per hour) in the total population, including 2 gastric bypass groups.

Randomized Controlled Trials

Data from the 5 randomized controlled trials were examined separately for weight loss and, when feasible, for the impact on mortality for 30 or fewer days and the 4 comorbidities (TABLE 9). These outcomes were within the range of values and the trends found for the overall meta-analysis.

COMMENT

Bariatric surgery in morbidly obese individuals reverses, eliminates, or significantly ameliorates diabetes, hyperlipidemia, hypertension, and obstructive sleep apnea. These benefits occur in the majority of patients who undergo surgery.

With respect to type 2 diabetes, more than three quarters of the patients experienced complete resolution of their diabetes following bariatric surgery. Of those patients not experiencing complete resolution, more than half showed demonstrable improvement. Thus, about 85% of patients with diabetes experienced improvement in their diabetes course after bariatric surgery.

A landmark article on bariatric surgery was published in 1995.[28] Provocatively titled, "Who would have thought it? An operation proves to be the most effective therapy for adult-onset diabetes mellitus," this article inspired more than 30 studies demonstrating resolution or marked improvement in type 2

Table 4. Efficacy Outcomes for Weight Reduction*

Outcome Measure	No. of Patients Evaluated	No. of Treatment Groups	Mean Change (95% Confidence Interval)†	Weighted Mean Change (Range of Mean Change)
Total population‡				
Absolute weight loss, kg	7588	83	–39.71 (–42.23 to –37.19)	–40.53 (–70.0 to –9.0)
BMI decrease	8232	96	–14.20 (–15.13 to –13.27)	–14.01 (–27.0 to –4.10)
Initial weight loss	1386	9	–32.64% (–36.39% to –28.89%)	–35.58% (–39.0% to –20.90%)
Excess weight loss	10 172	67	–61.23% (–64.40% to –58.06%)	–64.67% (–93.0% to –32.0%)
Gastric banding				
Absolute weight loss, kg	482	13	–28.64 (–32.77 to –24.51)	–32.36 (–45.40 to –13.10)
BMI decrease	1959	25	–10.43 (–11.52 to –9.33)	–10.83 (–16.40 to –4.70)
Excess weight loss	1848	12	–47.45% (–54.23% to –40.68%)	–49.59% (–70.0% to –32.0%)
Gastric bypass§				
Absolute weight loss, kg	2742	20	–43.48 (–48.14 to –38.82)	–47.06 (–62.70 to –21.0)
BMI decrease	2705	22	–16.70 (–18.43 to –14.98)	–17.10 (–25.0 to –8.0)
Initial weight loss	969	4	–34.93% (–35.61% to –34.26%)	–34.97% (–36.20% to –31.40%)
Excess weight loss	4204	22	–61.56% (–66.45% to –56.68%)	–68.11% (–77.0% to –33.0%)
Gastroplasty				
Absolute weight loss, kg	936	28	–39.82 (–44.74 to –34.90)	–39.45 (–70.0 to –9.0)
BMI decrease	942	27	–14.20 (–16.14 to –12.27)	–14.50 (–22.60 to –4.10)
Initial weight loss	27	2	–24.35% (–31.31% to –17.40%)	–25.90% (–28.0% to –20.90%)
Excess weight loss	506	15	–68.17% (–74.81% to –61.53%)	–69.15% (–93.0% to –48.0%)
Biliopancreatic diversion or duodenal switch				
Absolute weight loss, kg	1282	10	–46.39 (–51.58 to –41.20)	–45.96 (–54.20 to –33.0)
BMI decrease	984	12	–17.99 (–19.40 to –16.59)	–16.75 (–27.0 to –13.10)
Initial weight loss	311	2	–38.98% (–40.01% to –37.94%)	–38.97% (–39.0% to –38.20%)
Excess weight loss	2480	7	–70.12% (–73.91% to –66.34%)	–72.09% (–75.0% to –62.0%)

Abbreviation: BMI, body mass index.
*Body mass index is calculated as weight in kilograms divided by the square of height in meters.
†Comparison across studies significant ($P<.01$) for heterogeneity except for initial weight loss for gastric bypass and biliopancreatic diversion or duodenal switch.
‡Includes gastric banding, gastric bypass, gastroplasty, biliopancreatic diversion or duodenal switch, as well as mixed groups and other less common procedures (biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, and unspecified bariatric surgery).
§Includes standard and long-limb procedures with additional components (eg, gastroplasty, band).

Table 5. Efficacy for Improvement in Diabetes-Related Outcomes for All Patients

	Diabetes Course			Chemistry Level		
	Resolved	Resolved or Improved	New or Worse	HbA_{1c}	Fasting Glucose, mmol/L	Fasting Insulin, pmol/L
Total Population*						
Patients evaluated	1846	485	1835	270	2092	1460
No. (%) with improvement in characteristic	1417 (76.8)	414 (85.4)	12 (0.7)			
No. of treatment groups	63	30	10	5	46	36
Mean (95% CI)	76.8% (70.7% to 82.9%)	86.0% (78.4% to 93.7%)		–0.40% (–0.55% to –0.24%)	–0.74 (–0.88 to –0.60)	–117.50 (–136.10 to –98.89)
P Value for heterogeneity	<.01	<.01		<.10	<.01	<.01
Weighted mean change (range)				–0.31% (–0.60% to 0)	–0.86 (–4.77 to 0.49)	–114.57 (–269.10 to –42.0)
Gastric Banding						
Patients evaluated	205	217	521	237	289	166
No. (%) with improvement in characteristic	98 (47.8)	174 (80.2)	1 (0.2)			
No. of treatment groups	9	9	2	2	14	10
Mean (95% CI)	47.9% (29.1% to 66.7%)	80.8% (72.2% to 89.4%)		–0.27% (–0.36% to –0.19%)	–0.78 (–1.05 to –0.51)	–79.72 (–99.57 to –59.87)
P Value for heterogeneity	<.01	<.10		NS†	<.01	<.01
Weighted mean change (range)				–0.29% (–0.40% to –0.26%)	–0.71 (–1.80 to –0.20)	–77.07 (–171.50 to –46.40)
Gastric Bypass‡						
Patients evaluated	989	127	1142	20	196	93
No. (%) with improvement in characteristic	829 (83.8)	115 (90.6)	6 (0.5)			
No. of treatment groups	26	6	3	2	9	6
Mean (95% CI)	83.7% (77.3% to 90.1%)	93.2% (79.3% to 100.0%)		–0.59% (–0.82% to –0.37%)	–1.25 (–1.52 to –0.97)	–121.26 (–137.31 to –105.20)
P Value for heterogeneity	<.01	<.01		NS†	<.01	
Weighted mean change (range)				–0.42% (–0.60% to 0)	–1.43 (–1.80 to –0.70)	–118.32 (–173.60 to –107.60)
Gastroplasty						
Patients evaluated	66	38	15		326	334
No. (%) with improvement in characteristic	45 (68.2)	34 (89.5)	1 (6.7)			
No. of treatment groups	11	8	1		12	12
Mean (95% CI)	71.6% (55.1% to 88.2%)	90.8% (76.2% to 100.0%)			–0.44 (–0.58 to –0.30)	–109.57 (–138.15 to –80.98)
P Value for heterogeneity	<.10	<.10			<.10	<.01
Weighted mean change (range)					–0.56 (–4.77 to 0)	–122.92 (–190.10 to –42.0)
Biliopancreatic Diversion or Duodenal Switch						
Patients evaluated	288	101			89	87
No. (%) with improvement in characteristic	282 (97.9)	89 (88.1)				
No. of treatment groups	9	6			6	6
Mean (95% CI)	98.9% (96.8% to 100.0%)	76.7% (42.2% to 100.0%)§			–0.59 (–1.06 to –0.11)	–148.53 (–213.69 to –83.36)
P Value for heterogeneity	NS†	<.01			<.01	<.01
Weighted mean change (range)					–0.67 (–1.41 to 0.49)	–132.51 (–269.10 to –73.40)

Abbreviations: CI, confidence interval; HbA_{1c}, glycosylated hemoglobin.
SI conversion factors: To convert glucose to mg/dL, divide by 0.0555; insulin to μIU/mL, divide by 6.945.
*Includes gastric banding, gastric bypass, gastroplasty, biliopancreatic diversion or duodenal switch, as well as mixed groups and other less common procedures (biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, and unspecified bariatric surgery).
†Comparison across studies not significant for heterogeneity.
‡Includes standard and long-limb gastric bypass and gastric bypass procedures with additional components (eg, gastroplasty, band).
§Lower percentage (compared with resolved category) reflects several large studies reporting only number of patients with diabetes resolution, which are not included in this category.

diabetes after bariatric surgery. Two recently published series (after our cutoff date for inclusion) by Schauer et al[29] and Sugerman et al[30] report almost identical rates of resolution as our meta-analysis, 83% and 86%, respectively. In addition, at 2-year follow-up, a 60% decrease in plasma insulin and a 20% decrease in the plasma glucose were seen in the surgical weight loss group in the Swedish Obesity Subjects study.[31] The control group at 2 years had a 3.7-fold higher risk of diabetes onset.

Resolution of diabetes often occurred days following bariatric surgery, even before marked weight loss was achieved.[28] Resolution of diabetes was more prevalent following the predominantly malabsorptive procedures (biliopancreatic diversion or duodenal switch) and the mixed malabsorptive/restrictive gastric bypass in contrast to the purely restrictive gastroplasty and gastric banding procedures. In addition, there appeared to be a gradation of diabetes resolution as a function of the operative procedure itself: 98.9% for biliopancreatic diversion or duodenal switch, 83.7% for gastric bypass, 71.6% for gastroplasty, and 47.9% for gastric banding.

The putative extent and time relationships of the different operative pro-

Table 6. Efficacy for Improvement in Diabetes-Related Outcomes for Diabetic and Glucose-Intolerant Patients*

	Weight			Chemistry Level		
	Absolute Weight Loss, kg	BMI Decrease	Excess Loss	HbA_{1c}	Fasting Glucose, mmol/L	Fasting Insulin, pmol/L
Total Population†						
Patients evaluated	266	306	267	171	296	160
No. of treatment groups	8	11	6	6	14	8
Mean (95% CI)	−41.93 (−52.63 to −31.24)	−14.03 (−17.30 to −10.77)	−57.25% (−68.30% to −46.21%)	−2.40% (−3.80% to −1.0%)	−3.97 (−5.20 to −2.74)	−123.91 (−182.94 to −64.88)
P Value for heterogeneity	<.01	<.01	<.01	<.01	<.01	<.01
Weighted mean change (range)	−41.25 (−65.50 to −19.70)	−13.94 (−24.0 to −7.0)	−58.94% (−72.20% to −38.0%)	−2.70% (−5.0% to −0.70%)	−4.10 (−8.10 to −0.50)	−142.02 (−250.0 to 6.70)
Gastric Banding						
Patients evaluated	56	56	83	83	56	56
No. of treatment groups	3	3	2	2	3	3
Mean (95% CI)	−26.02 (−32.86 to −19.17)	−9.09 (−10.88 to −7.30)	−40.99% (−47.16% to −34.82%)	−1.16% (−1.76% to −0.55%)	−3.15 (−3.99 to −2.32)	−49.53 (−77.46 to −21.61)
P Value for heterogeneity	NS‡	NS‡	<.10	<.10	NS‡	NS‡
Weighted mean change (range)	−26.63 (−27.0 to −19.70)	−9.33 (−9.50 to −7.20)	−40.50% (−44.30% to −38.0%)	−1.34% (−1.60% to −0.94%)	−3.12 (−3.40 to −0.50)	−57.66 (−210.60 to 6.70)
Gastric Bypass§						
Patients evaluated	129	166	184	88	164	90
No. of treatment groups	3	6	4	4	7	4
Mean (95% CI)	−50.54 (−60.49 to −40.59)	−18.02 (−21.04 to −15.01)	−65.66% (−72.25% to −59.07%)	−3.03% (−4.97% to −1.09%)	−3.43 (−5.20 to −1.65)	−153.68 (−243.93 to −63.43)
P Value for heterogeneity	<.10	<.01	<.01	<.01	<.01	<.01
Weighted mean change (range)	−47.72 (−65.50 to −46.0)	−16.55 (−24.0 to −13.0)	−67.25% (−72.20% to −58.0%)	−3.99% (−5.0% to −0.70%)	−3.46 (−5.99 to −0.80)	−198.66 (−250.0 to −44.50)
Gastroplasty						
Patients evaluated					9	
No. of treatment groups					1	
Mean (95% CI)					−4.77 (−6.87 to −2.67)	
Weighted mean change (range)					−4.77	
Biliopancreatic Diversion or Duodenal Switch						
Patients evaluated	14	17			67	14
No. of treatment groups	1	1			3	1
Mean (95% CI)	−60.40 (−69.37 to −51.43)	−7.00 (−11.36 to −2.64)			−5.79 (−8.20 to −3.38)	−115.30 (−132.93 to −97.67)
Weighted mean change (range)	−60.40	−7.00			−6.42 (−8.10 to −4.05)	−115.30

Abbreviations: BMI, body mass index; CI, confidence interval; HbA_{1c}, glycosylated hemoglobin.
SI conversion factors: To convert glucose to mg/dL, divide by 0.0555; insulin to μIU/mL, divide by 6.945.
*Body mass index is calculated as weight in kilograms divided by the square of height in meters.
†Includes gastric banding, gastric bypass, gastroplasty, biliopancreatic diversion or duodenal switch, as well as mixed groups and other less common procedures (biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, and unspecified bariatric surgery).
‡Comparison across studies not significant for heterogeneity.
§Includes standard and long-limb gastric bypass and gastric bypass procedures with additional components (eg, gastroplasty, band).

cedures to diabetes resolution or improvement after bariatric surgery may be related to some of the changes in the gut-related hormones. The hormonal milieu, or the relative balance of foregut mediators, is differently affected when the distal stomach is bypassed, or a partial gastrectomy is performed, and the enteric contents are separated from the biliopancreatic stream in the upper small intestinal tract. The study of the impact of the various bariatric procedures on leptin, ghrelin, resistin, acylation-stimulating protein, adiponectin, entroglucagon, cholecystokinin, and other gastrointestinal satiety mediators is receiving increasing attention.[32-36]

Current metabolic studies of patients with diabetes undergoing bariatric surgery have shown a recovery of acute insulin response[37]; significant de-

Table 7. Efficacy for Improvement in Hyperlipidemia by Surgical Procedure

	Patients Improved*			Cholesterol Level, mmol/L			
	Hyperlipidemia	Hypercholesterolemia	Hypertriglyceridemia	Total	High-Density Lipoprotein	Low-Density Lipoprotein	Triglycerides Level, mmol/L
Total Population†							
Patients evaluated	1019	2051	983	2573	2003	879	2149
No. (%) with improvement in characteristic	846 (83.0)	1777 (86.6)	912 (92.8)				
No. of treatment groups	23	14	11	36	30	21	34
Mean (95% CI)	79.3% (68.2% to 90.5%)	71.3% (55.5% to 87.0%)	82.4% (71.1% to 93.7%)	–0.86 (–1.13 to –0.60)	0.07 (0 to 0.15)	–0.76 (–1.06 to –0.46)	–0.90 (–1.08 to –0.73)
P Value for heterogeneity	<.01	<.01	<.01	<.01	<.10	<.01	<.01
Weighted mean change (range)				–0.49 (–3.14 to 0.30)	–0.01 (–0.36 to 0.68)	–0.48 (–2.46 to 0.22)	–0.79 (–2.90 to –0.22)
Gastric Banding							
Patients evaluated	426	23	13	633	623	478	633
No. (%) with improvement in characteristic	303 (71.1)	18 (78.3)	10 (76.9)				
No. of treatment groups	6	1	1	10	9	5	10
Mean (95% CI)	58.9% (28.2% to 89.6%)	78.0% (61.1% to 94.9%)	77.0% (54.1% to 99.9%)	–0.30 (–0.55 to –0.05)	0.12 (0.04 to 0.20)	–0.11 (–0.40 to 0.17)	–0.78 (–1.07 to –0.48)
P Value for heterogeneity	<.01	NS‡	NS‡	<.01	<.01	<.01	<.01
Weighted mean change (range)				–0.22 (–0.90 to 0.30)	0.12 (–0.19 to 0.24)	–0.09 (–0.49 to 0.22)	–0.65 (–1.80 to –0.22)
Gastric Bypass§							
Patients evaluated	125	439	271	307	163	81	304
No. (%) with improvement in characteristic	117 (93.6)	417 (95.0)	255 (94.1)				
No. of treatment groups	6	5	4	7	6	5	7
Mean (95% CI)	96.9% (93.6% to 100.0%)	94.9% (90.7% to 99.1%)	91.2% (83.6% to 98.8%)	–0.96 (–1.16 to –0.76)	0.05 (–0.10 to 0.20)	–0.89 (–1.15 to –0.63)	–1.07 (–1.49 to –0.65)
P Value for heterogeneity	NS‡	<.10	<.01	<.01	<.10	NS‡	<.01
Weighted mean change (range of mean change)				–0.95 (–1.24 to –0.71)	0.01 (–0.22 to 0.23)	–0.93 (–1.24 to –0.59)	–1.10 (–2.0 to –0.42)
Gastroplasty							
Patients evaluated	215	102	21	261	253	123	235
No. (%) with improvement in characteristic	174 (80.9)	40 (39.2)	15 (71.4)				
No. of treatment groups	7	4	2	8	7	4	8
Mean (95% CI)	73.6% (60.8% to 86.3%)	38.4% (25.4% to 51.4%)	72.4% (53.4% to 91.4%)	–0.46 (–0.88 to –0.04)	0.13 (0.02 to 0.24)	–0.29 (–0.62 to 0.03)	–0.89 (–1.20 to –0.57)
P Value for heterogeneity	<.01	NS‡	NS‡	<.01	<.01	<.01	<.01
Weighted mean change (range)				–0.38 (–1.91 to 0.18)	0.18 (–0.10 to –0.36)	–0.28 (–0.65 to 0.10)	–0.86 (–1.97 to –0.39)
Biliopancreatic Diversion or Duodenal Switch							
Patients evaluated	200	1238	588	186	185	185	186
No. (%) with improvement in characteristic	199 (99.5)	1234 (99.7)	588 (100)				
No. of treatment groups	3	3	2	6	6	6	6
Mean (95% CI)	99.1% (97.6% to 100.0%)	87.2% (59.2% to 100.0%)	100.0% (98.1% to 100.0%)	–1.97 (–2.56 to –1.38)	0.07 (–0.22 to 0.36)	–1.36 (–1.93 to –0.79)	–0.80 (–1.11 to –0.50)
P Value for heterogeneity	NS‡	<.10	NS‡	<.01	<.10	<.01	<.01
Weighted mean change (range)				–1.81 (–3.14 to –0.88)	0.01 (–0.36 to 0.68)	–1.33 (–2.46 to –0.49)	–0.88 (–1.33 to –0.38)

Abbreviation: CI, confidence interval.
SI conversion factors: To convert high-density lipoprotein, low-density lipoprotein, and total cholesterol to mg/dL, divide by 0.0259; triglycerides to mg/dL, divide by 0.0113.
*Includes patients described by study authors as having improved by virtue of elimination or reduction in therapy, patients reported to have improved lipid parameters, and all patients evaluated for improvement.
†Includes gastric banding, gastric bypas, gastroplasty, biliopancreatic diversion or duodenal switch, as well as mixed groups and other less common procedures (biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, and unspecified bariatric surgery).
‡Comparison across studies not significant for heterogeneity.
§Includes standard and long-limb gastric bypass and gastric bypass procedures with additional components (eg, gastroplasty, band).

Table 8. Efficacy for Improvement in Hypertension and Obstructive Sleep Apnea by Surgical Procedure

	Hypertension		Obstructive Sleep Apnea		
	Resolved	Resolved or Improved	Resolved	Resolved or Improved	Decrease in Apneas or Hypopneas per Hour
Total Population*					
Patients evaluated	4805	2141	1195	726	92
No. (%) with improvement in characteristic	3151 (65.6)	1752 (81.8)	1051 (87.9)	585 (80.6)	
No. of treatment groups	67	43	38	24	4
Mean (95% CI)	61.7% (55.6% to 67.8%)	78.5% (70.8% to 86.1%)	85.7% (79.2% to 92.2%)	83.6% (71.8% to 95.4%)	–33.85 (–50.23 to –17.47)
P Value for heterogeneity	<.01	<.01	<.01	<.01	<.01
Weighted mean change (range)					–40.09 (–52.80 to –16.0)
Gastric Banding					
Patients evaluated	604	685	56	18	
No. (%) with improvement in characteristic	232 (38.4)	490 (71.5)	53 (94.6)	10 (55.6)	
No. of treatment groups	12	10	5	3	
Mean (95% CI)	43.2% (30.4% to 55.9%)	70.8% (61.9% to 79.6%)	95.0% (88.8% to 100.0%)	68.0% (26.2% to 100.0%)	
P Value for heterogeneity	<.01	<.01	NS†	<.10	
Gastric Bypass‡					
Patients evaluated	2115	435	896	176	31
No. (%) with improvement in characteristic	1594 (75.4)	379 (87.1)	776 (86.6)	167 (94.9)	
No. of treatment groups	20	11	13	6	2
Mean (95% CI)	67.5% (58.4% to 76.5%)	87.2% (78.4% to 95.9%)	80.4% (68.4% to 92.3%)	94.8% (91.5% to 98.1%)	–31.64 (–44.15 to –19.13)
P Value for heterogeneity	<.01	<.01	<.01	NS†	NS†
Weighted mean change (range)					–31.71 (–33.0 to –31.0)
Gastroplasty					
Patients evaluated	382	103	43	28	
No. (%) with improvement in characteristic	277 (72.5)	83 (80.6)	33 (76.7)	25 (89.3)	
No. of treatment groups	20	12	10	6	
Mean (95% CI)	69.0% (59.1% to 79.0%)	85.4% (74.1% to 96.7%)	78.2% (53.6% to 100.0%)	90.7% (78.5% to 100.0%)	
P Value for heterogeneity	<.01	<.01	<.01	NS†	
Biliopancreatic Diversion or Duodenal Switch					
Patients evaluated	774	782	165	166	
No. (%) with improvement in characteristic	629 (81.3)	718 (91.8)	157 (95.2)	144 (86.7)	
No. of treatment groups	7	7	6	6	
Mean (95% CI)	83.4% (73.2% to 93.6%)	75.1% (44.7% to 100.0%)	91.9% (81.9% to 100.0%)	71.2% (34.5% to 100.0%)	
P Value for heterogeneity	<.10	<.01	<.01	<.01	

Abbreviation: CI, confidence interval.
*Includes gastric banding, gastric bypass, gastroplasty, biliopancreatic diversion or duodenal switch, as well as mixed groups and other less common procedures (biliary intestinal bypass, ileogastrostomy, jejunoileal bypass, and unspecified bariatric surgery).
†Comparison across studies not significant for heterogeneity.
‡Includes standard and long-limb gastric bypass and gastric bypass procedures with additional components (eg, gastroplasty, band).

creases of inflammatory indicators (C-reactive protein and interleukin 6)[38]; improvement in insulin sensitivity correlated with increases in plasma adiponectin[32,39]; significant changes in the enteroglucagon response to glucose[40]; significant reduction in ghrelin levels following gastric bypass[41] but not gastric banding[42]; and significant improvement in beta cell function following gastric banding.[43]

Considerable attention recently has focused on the Swedish Obesity Subjects study, in which 2010 patients after gastric bypass, gastroplasty, or gastric banding were compared with 2037 matched-pair controls who underwent conventional nonoperative obesity management. After 2 years, the incidence of hyperlipidemia was lower by 10-fold in the surgical weight loss group compared with the control group.[31] Similar findings have been reported by others.[44-47] In 1990, the Program on the Surgical Control of the Hyperlipidemias reported marked reductions in the levels of total (23%) and low-density lipoprotein cholesterol (38%), in association with increases in high-density lipoprotein cholesterol (4%) after a surgical distal ileal malabsorptive procedure.[48] In the current meta-analysis, the improvement in hyperlipidemia also was more prevalent with the malabsorptive procedures.

Resolution or improvement of hypertension by weight reduction is well-known. Even a modest weight loss (eg, 10%) can lower blood pressure significantly. As a generalization, a decrease of 1% in body weight will decrease systolic blood pressure by 1 mm Hg and diastolic blood pressure by 2 mm Hg.[49-51] The bariatric surgery literature extracted for this analysis is replete with reports of the resolution or improvement in hypertension postoperatively. This reduction in blood pressure, in distinction to the effect of weight loss on type 2 diabetes and hyperlipidemia, seems to be independent of the operative procedure performed.

In the current analysis, improvement in obstructive sleep apnea was dramatic—in the 80% or higher range. The extracted bariatric surgery literature is quite prolific on this subject. In association with the clinical findings, improvements in oxygen saturation, de-

Table 9. Surgical Outcomes for the 5 Randomized Controlled Trials*

Source	Type of Surgery	Duration of Follow-up, mo	Outcome
Ashy and Merdad,[23] 1998			
	Vertical banded gastroplasty (n = 30)	6	Patients experienced 87% excess weight loss
	Laparoscopic adjustable gastric banding (n = 30)	6	Patients experienced 50% excess weight loss
Hall et al,[24] 1990			
	Gastrogastrostomy, vertical gastroplasty, Roux-en-Y gastric bypass (n = 310)	36	Patients experienced 53% excess weight loss; 6 of 8 diabetes cases improved (medication reduced and/or laboratory values improved); 22 of 29 cases of hypertension were resolved (medication discontinued and/or blood pressure was normalized)
Mingrone et al,[25] 2002			
	Biliopancreatic diversion in women (n = 31)	12	Mean (SD) decreases: BMI, 48.3 (6.3) to 35.2 (7.6); fasting blood glucose, 5.26 (0.26) mmol/L to 4.57 (0.30) mmol/L; insulin, 163.8 (17.4) pmol/L to 84.0 (25.2) pmol/L; total cholesterol level, 4.55 (1.09) mmol/L to 3.67 (0.57) mmol/L; HDL cholesterol level, 0.77 (0.16) mmol/L to 1.03 (0.34) mmol/L; and LDL cholesterol level, 4.00 (1.19) mmol/L to 1.96 (0.49) mmol/L
	Biliopancreatic diversion in men (n = 15)	12	Mean (SD) decreases: BMI, 48.0 (5.4) to 30.4 (3.5); fasting blood glucose, 5.27 (0.43) mmol/L to 3.86 (0.35) mmol/L; insulin, 184.2 (40.8) pmol/L to 51.0 (27.0) pmol/L; total cholesterol level, 5.39 (1.05) mmol/L to 3.61 (0.45) mmol/L; HDL cholesterol level, 0.66 (0.16) mmol/L to 1.34 (0.29) mmol/L; and LDL cholesterol level, 2.79 (1.17) mmol/L to 2.03 (0.69) mmol/L
Nguyen et al,[26] 2001			
	Laparoscopic gastric bypass (n = 79)	6	Mean (SD) excess weight loss: 54% (14%)
	Open gastric bypass (n = 76)	6	Mean (SD) excess weight loss: 45% (12%)
Thorne et al,[27] 2002			
	Swedish adjustable gastric band (n = 25)	24	Mean (SD) decreases: BMI, 9.0 (6.0); fasting blood glucose, 0.70 (0.70) mmol/L; insulin, 68.1 (47.2) pmol/L; and total cholesterol level, 0.9 (0.8) mmol/L
	Swedish adjustable gastric band with omentectomy (n = 25)	24	Mean (SD) decreases: BMI, 13.0 (5.0); fasting blood glucose, 1.80 (0.8) mmol/L; and insulin, 120.1 (64.6) pmol/L

Abbreviations: BMI, body mass index; HDL, high-density lipoprotein; LDL, low-density lipoprotein.
SI conversion factors: To convert glucose to mg/dL, divide by 0.0555; insulin to μIU/mL, divide by 6.945; HDL, LDL, and total cholesterol to mg/dL, divide by 0.0259.
*Body mass index is calculated as weight in kilograms divided by the square of height in meters.

creases in arterial carbon dioxide, and increases in arterial oxygen content have been demonstrated.[52,53] These favorable physiological changes in the blood contents, which in turn affect the neurological pathways and cerebral centers responsible for respiration, are primarily the result of an increase in diaphragmatic excursion. This increase is brought about by a reduction in intra-abdominal pressure after successful bariatric surgery.[54,55]

Reversal of or marked improvement in diabetes, hyperlipidemia, hypertension, obstructive sleep apnea, and obesity itself, should markedly increase life expectancy. A large, prospective, observational study, which controlled for unintentional weight loss and for smoking, of 43 457 women had a 12-year follow-up and showed that a weight loss of at least 9 kg was associated with a 53% reduction in all obesity-related deaths.[56] A growing amount of evidence relates increased longevity with successful bariatric surgery. The Swedish Obesity Subjects study in diabetic patients has shown an 80% decrease in the annual mortality in the surgical weight loss group.[31] Specifically, the obese diabetic patients in the surgical group had a 9% mortality at 9 years, whereas, the control group had a 28% mortality, with most deaths related to cardiovascular disease. In a comparable study, MacDonald et al[57] reported that diabetic patients treated with an oral hypoglycemic had a 4.5% mortality rate for every 9 years of follow-up compared with a 1% mortality rate in diabetic patients who underwent gastric bypass. Christou et al[58] demonstrated that weight-loss surgery in 1035 patients compared with 5746 controls with a 5-year follow-up reduced the relative risk of death by 89% (95% CI, 73%-96%), with an absolute mortality reduction of 5.49% ($P<.001$).

All therapeutic interventions need to have efficacy balanced against risk. In such an assessment, bariatric surgery does well. The operative 30-day mortality rates of 0.1% for the restrictive procedures, 0.5% for gastric bypass, and 1.1% for biliopancreatic diversion or duodenal switch compare favorably with the accepted operative mortality rates for other major surgical procedures.

The heterogeneity of the immediate postoperative and long-term morbidity data did not allow for meta-analysis. However, although these data are diverse, operation-specific reports of adverse outcomes are available for gastric banding,[59-61] gastric bypass,[28,30,62] gastroplasty,[23,63,64] and biliopancreatic diversion or duodenal switch.[65-67]

Even after accounting for the pain and anxiety of surgery, the inconveniences of dietary restrictions, and possible complications including reoperation, quality of life should improve for the majority of bariatric surgery patients. A weight loss often in excess of 45 kg, relief from fatal comorbid diseases, improved appearance, and improved social and economic opportunities should markedly enhance quality of life and several studies support this contention.[68-73] The perception of well-being, social function, body self-image, self-confidence, ability to interact with others, and time spent in recreational and physical activities increases after successful bariatric surgery. Productivity and economic opportunities are enhanced, including new employment and more lucrative employment.

In summary, in addition to the effective weight loss achieved by patients undergoing bariatric surgical procedures, a substantial majority of patients with diabetes, hyperlipidemia, hypertension, and obstructive sleep apnea experienced complete resolution or improvement of their comorbid condition.

Author Contributions: Dr Buchwald had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Buchwald, Avidor, Pories, Fahrbach, Schoelles.
Acquisition of data: Buchwald, Avidor, Pories, Schoelles.
Analysis and interpretation of data: Buchwald, Avidor, Braunwald, Jensen, Pories, Fahrbach, Schoelles.
Drafting of the manuscript: Buchwald, Avidor, Pories, Fahrbach.
Critical revision of the manuscript for important intellectual content: Buchwald, Avidor, Braunwald, Jensen, Pories, Schoelles.
Statistical expertise: Buchwald, Fahrbach.
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of serving bowl size on consumption was statistically significant for men ($P=.02$) but not women ($P=.17$).

In the sensitivity analysis to estimate the potential impact of the 5 nonparticipants, the effect of bowl size remained significant ($P=.02$).

Comment. Small environmental factors can have a large influence on food consumption.[4] At this party, large serving bowls led to a 56% greater intake (a mean of 142 more calories/person). The size of a serving bowl (or of a portion) may provide a consumption cue that implicitly suggests an appropriate amount to eat.[5] Larger bowls, like larger packages or portions, may suggest that a proportionately larger amount is appropriate to consume. Although this study was not conducted in a medical setting, it is possible that if a physician giving diet-related advice recommends using smaller serving bowls, patients may serve themselves smaller portions.

Portion distortion has generally focused on how consumption cues lead people to overeat less healthy, energy-dense foods. An appropriate area for further research is whether these same cues, ie, larger serving bowls, can be used to encourage people to eat greater amounts of healthier foods such as fruits and vegetables.

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CORRECTIONS

Incorrect Data: In the Clinical Review entitled "A Simplified Approach to the Management of Non–ST-Segment Elevation Acute Coronary Syndromes" published in the January 19, 2005, issue of *JAMA* (2005;293:349-357), incorrect data were reported. In the "Anticoagulation" rows of the Table on Page 352, "creatinine clearance <60 mL/min" should have been reported as "<30 mL/min." Also, in the center column on page 353, "creatinine clearance <60 mL/min [1.0 mL/s]" should have been reported as "<30 mL/min [0.5 mL/s]."

Incorrect Information: In the Medical News & Perspectives article "Michael E. DeBakey, MD: Father of Modern Cardiovascular Surgery" published in the February 23, 2005, issue of *JAMA* (2005;293:913-918), President John F. Kennedy was erroneously described as one of the world leaders who were treated by DeBakey. DeBakey worked with Kennedy on medical legislation for Medicare.

Reference Error: In the Review entitled "Bariatric Surgery: A Systematic Review and Meta-analysis" published in the October 13, 2004, issue of *JAMA* (2004;292:1724-1737), there was a reference error. The Swedish Obese Subjects Intervention Study has not published any of its mortality data. On page 1736, column 1, first full paragraph, sentences 4 and 5 should be deleted. Sentence 6 should be "MacDonald et al[57] reported that diabetic patients treated with an oral hypoglycemic had a 4.5% annual mortality rate for 9 years of follow-up compared with a 1% mortality rate in diabetic patients who underwent gastric bypass."

Error in Table: In the Preliminary Contribution entitled "Detection of Paternally Inherited Fetal Point Mutations for β-Thalassemia Using Size-Fractionated Cell-Free DNA in Maternal Plasma" published in the February 16, 2005, issue of *JAMA* (2005;293:843-849), there was an error in Table 2. On pages 847 and 848, Table 2 should have read as follows. For each case (2 rows), the genotype and results (circulating fetal DNA and chorionic villus sampling) information (3 columns) was switched for mother and father. For example, in case 1 for paternal *IVSI*-1 mutation, "Codon 39/N" and "*IVSI*-1" and "*IVSI*-1/N" should be in the row with "Mother," and "*IVSI*-1/N" should be in the row with "Father" in that order. The subsequent rows of genotype and results information should be switched for each case for the rest of the Table. Also, on page 848, the column heading "Patient Sex" should read "Parent."