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Weight-loss and metabolic outcomes of laparoscopic bariatric surgery: a single-center retrospective cohort study at a tertiary care center in Thailand

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Research Article

Keywords: Metabolic surgery, Sleeve gastrectomy, Diabetes remission, Weight loss, Asian population

Posted Date: November 23rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11055692/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Longitudinal bariatric-surgery data from Southeast Asian centers remain limited, and reports beyond two years are even scarcer. We evaluated weight-loss and metabolic outcomes after laparoscopic bariatric surgery, predominantly sleeve gastrectomy, in Thailand.

Methods

We retrospectively analyzed 805 adults undergoing primary laparoscopic bariatric surgery at a Thai university hospital between July 2011 and September 2025 (data freeze on 30 September 2025). We assessed weight loss at 3, 6, 12, and 24 months. Attendance continued beyond this schedule, so we also captured later visits, yielding observations up to fourteen years; when patients were measured at both horizons, we compared %TWL within individuals between 12 months and five years or later. Diabetes outcomes were derived from hospital laboratory and pharmacy records and were bounded against all eligible diabetic patients.

Results

The cohort was 67.7% female (mean BMI 43.5 kg/m²); 46.5% had type 2 diabetes, and 753 (93.5%) underwent sleeve gastrectomy. Mean %TWL was 31.4% at both 12 and 24 months (31.4 ± 8.7% and 31.4 ± 10.0%, respectively, across patient subsets). Follow-up among eligible patients was 68.1% at 12 months and 55.2% at 24 months; for the full cohort, which includes patients not yet eligible, it was 51.7% and 27.1%. Medication-confirmed diabetes remission at 12 months ranged from 51.5% to 92.6% among 136 pre-medicated patients; because only about half were tested, this range is preliminary. Beyond 24 months, 50.9% of eligible patients attended, with a mean %TWL of about 27% at 3 years (n = 84), 24–26% at 5 years (n = 31), and 18–21% at 10 years (n = 21).

Conclusions

Laparoscopic bariatric surgery, predominantly sleeve gastrectomy, produced substantial weight loss and metabolic improvement in this Asian cohort. Weight loss attenuated after the second year: among the 29 patients measured at both 12 months and five years or later, %TWL declined by 5.7 percentage points (95% CI 1.2 to 10.2). Late returners were no better than eligible non-returners or early responders, excluding one selection mechanism but not attendance driven by regain itself, so the decline is best read as an upper estimate. These observations rest on small subsets from the program's earliest years and are descriptive, not estimates of population durability.

Background

The global obesity epidemic has reached unprecedented proportions: the World Health Organization reports that worldwide obesity rates have tripled since 1975, now affecting more than 650 million adults [1]. Southeast Asia has not been spared. Thailand illustrates the trend: successive National Health Examination Surveys show mean body-mass index rising from 21.6 to 23.3 kg/m² in men and from 22.8 to 24.4 kg/m² in women between 1991 and 2009, with class II obesity (BMI ≥ 30 kg/m²) reaching 9.0% of adults by 2009 [2]. What concerns clinicians more than obesity itself is the constellation of associated medical problems it brings — type 2 diabetes, hypertension, and dyslipidemia, chief among them. Collectively, these conditions define metabolic syndrome under harmonized criteria, and this clustering markedly increases cardiovascular morbidity and mortality [3].

Obesity-attributable medical spending in the United States was estimated to reach $147 billion per year by 2008, up from $78.5 billion a decade earlier [4], underscoring the need for durable, effective interventions. Bariatric surgery has emerged as an evidence-based treatment for severe obesity and its associated metabolic disorders. The 2022 joint statement of the American Society for Metabolic and Bariatric Surgery (ASMBS) and the International Federation for the Surgery of Obesity and Metabolic Disorders (IFSO) recommends metabolic and bariatric surgery for individuals with a BMI above 35 kg/m², regardless of the presence, absence, or severity of associated medical problems, and states that surgery should be considered at a BMI of 30–34.9 kg/m² in the presence of metabolic disease [5]. The statement was explicitly framed as a major update to the 1991 National Institutes of Health criteria, which conditioned surgery below a BMI of 40 kg/m² on the presence of comorbidity. Terminology in the field has shifted accordingly, from "bariatric surgery" to "metabolic surgery," reflecting growing recognition that these procedures confer metabolic benefits extending well beyond weight loss alone [6].

Systematic review evidence indicates substantial weight loss maintained beyond two years: in a synthesis of 29 studies and 7,971 patients, the sample-size-weighted mean excess weight loss was 65.7% after gastric bypass and 45.0% after gastric banding, outcomes that exceed what lifestyle modification or pharmacotherapy typically achieve [7]. The metabolic benefits appear durable and are well documented across the literature. In the landmark Swedish Obese Subjects (SOS) study, diabetes remission two years after surgery reached 72.3% (219 of 303) versus 16.4% in matched controls, falling to 30.4% at fifteen years; over a median of roughly eighteen years, the surgical group also accrued fewer microvascular (hazard ratio 0.44) and macrovascular (hazard ratio 0.68) complications [8]. A one-stage meta-analysis of matched cohorts and controlled trials, covering 174,772 participants and 1.2 million patient-years, subsequently reported a 49.2% reduction in the hazard of death and a median life expectancy 6.1 years longer than with usual care [9]. A large-scale meta-analysis corroborates this pattern for diabetes: across 621 studies and 135,246 patients, complete resolution occurred in 78.1% of diabetic patients, and diabetes was improved or resolved in 86.6% [10]. Pooled figures for hypertension and dyslipidemia are not reported in that analysis, and contemporary reviews emphasize instead that perioperative mortality now falls between 0.03% and 0.2% [11].

Bariatric surgery is recognized as an effective treatment for type 2 diabetes in patients with obesity [6]. Minimally invasive techniques have reshaped this field, improving both the safety and accessibility of these procedures. Contemporary minimally invasive approaches are associated with low perioperative mortality, although reported rates vary by study design and era: pooled randomized trials report a 30-day mortality of 0.08% (95% CI 0.01–0.24) and a 17% complication rate [12], whereas a prospective multicenter cohort of consecutive patients reports 0.3% 30-day mortality and at least one major adverse outcome in 4.3% [13]. Enhanced Recovery After Surgery (ERAS) protocols have further improved perioperative outcomes [14]. Laparoscopic sleeve gastrectomy (LSG) is now the most commonly performed bariatric procedure worldwide and remained the most frequently performed procedure in the International Federation for the Surgery of Obesity and Metabolic Disorders (IFSO) Worldwide Survey 2020–2021, which recorded 507,806 procedures in 2020 and 598,834 in 2021 [15].

LSG offers several advantages: technical simplicity, preservation of gastrointestinal continuity, avoidance of foreign material implantation, and effective weight-loss outcomes [16, 17]. Evidence from Western populations is robust, yet comprehensive data on bariatric surgery outcomes in Asian populations remain limited. This gap matters because genetic, cultural, and metabolic differences may significantly influence surgical outcomes. Asian populations tend to develop metabolic complications at lower BMI thresholds, with diabetes and cardiovascular risks emerging at BMIs above 23 kg/m² [18]. Differences in visceral adiposity distribution, insulin sensitivity, and dietary patterns may also shape disease pathophysiology and surgical outcomes in ways that Western-derived data cannot fully capture [19, 20].

A 2023 analysis of 594,837 bariatric surgery patients found that Asian race was not associated with higher complication or mortality rates, a pattern consistent with generally safe outcomes across this population [21]. Cultural factors, including food preferences and family dynamics, may shape long-term success, underscoring the need for population-specific evaluation [22]. Bariatric surgery volume in the United States rose by approximately 60% from 2011 to 2018 [23]. Growth has been equally striking in the Asia-Pacific region, where Thailand has emerged as a regional leader. Yet comprehensive outcome data that combine weight-loss efficacy with detailed metabolic outcomes from Thai centers remain sparse — a gap that limits how confidently regional practice patterns can be benchmarked against Western cohorts.

Our aim was descriptive rather than comparative. To our knowledge, no laparoscopic bariatric surgery cohort from a Thai tertiary center has previously been reported at this scale, and the existing Asian evidence base derives largely from cohorts and meta-analyses in other East and South Asian countries [24–26]. We therefore set out to document outcomes in a single large Thai cohort so that these results can be placed alongside those of neighboring Asian populations. Two objectives anchored the analysis. The first was to evaluate weight-loss efficacy, measured by percentage total weight loss (%TWL) and percentage excess weight loss (%EWL). The second was to assess metabolic outcomes by evaluating remission of obesity-related conditions — diabetes, hypertension, and dyslipidemia — using transparent, per-timepoint denominators and analytic methods appropriate for unbalanced longitudinal data. We

make no claim of superiority over other procedures or centers; we aim to add Thai data to a regional literature in which it has so far been absent.

In Thailand, the Thai Society for Metabolic and Bariatric Surgery (TSMBS) issued the country's first consensus guideline on bariatric surgery [27]. Rather than adopting Western thresholds unchanged, the guideline tailors selection criteria to the Asian phenotype. This approach aligns closely with WHO Asian-Pacific anthropometric cut-offs [18] and is reflected in the 2022 ASMBS/IFSO statement, which recommends lowering BMI thresholds for Asian patients, defining clinical obesity at a BMI above 25 kg/m² and offering surgery at a BMI above 27.5 kg/m². Taken together, these criteria indicate that metabolic disease emerges at lower BMI in Thai and other Asian populations—a pattern the TSMBS guideline explicitly recognizes. Our center's practice follows the TSMBS guideline, and the present cohort comprises patients selected under these Asian-adapted criteria; as such, findings should be interpreted within this regionally calibrated selection framework rather than generalized to cohorts defined by Western BMI cut-offs.

Methods

This retrospective cohort study was conducted at a 1,000-bed tertiary care academic medical center in northeastern Thailand. The Khon Kaen University Ethics Committee in Human Research approved the protocol (HE671120) on February 27, 2024, and the investigators conducted the study in accordance with the Declaration of Helsinki. Clinical trial registration did not apply given the retrospective design. Because the study relied on anonymized data, the ethics committee waived informed consent. The report follows the STROBE guidelines. A completed STROBE checklist, cross-referencing each item to the relevant manuscript section, is provided as a supplementary file.

The study included all adult patients aged 18 years or older who underwent elective laparoscopic bariatric surgery between July 2011 and September 2025. Patient selection followed the Thai Society for Metabolic and Bariatric Surgery (TSMBS) consensus guideline [27], which adapts eligibility thresholds to the Asian phenotype: surgery was offered to patients with BMI ≥ 37.5 kg/m², or BMI ≥ 32.5 kg/m² with at least one significant associated medical problem (such as type 2 diabetes, hypertension, dyslipidemia, or obstructive sleep apnea). These lower thresholds align closely with recommendations for Asian populations and were later reflected in the 2022 ASMBS/IFSO statement. Inclusion required an American Society of Anesthesiologists (ASA) classification of II–III. We excluded patients with incomplete medical records, severe uncontrolled associated medical problems, emergency procedures, or previous bariatric surgery — except for planned conversion procedures, where patients undergoing conversion from a prior bariatric operation remained eligible. Accrual continued for months after data extraction, so follow-up denominators at each time point were defined by eligibility rather than by calendar cutoff: a patient contributed to a given visit only if sufficient time had elapsed since their operation to reach that visit window and they had actually been assessed. Patients operated on too recently to have reached a given visit were therefore not counted as lost to follow-up at that visit. A small number of patients were operated on outside these thresholds on individualized metabolic indications: 38 (4.7%) had a baseline

BMI below 32.5 kg/m² and 8 (1.0%) below 30 kg/m². These were clinical decisions made before the study; the individual indications for the eight patients below BMI 30 are detailed in the Results. Sleeve gastrectomy served as the default procedure for most patients. We reserved laparoscopic Roux-en-Y gastric bypass for patients with intractable gastroesophageal reflux disease (reflux persisting despite optimized medical therapy) or poorly controlled type 2 diabetes, while laparoscopic sleeve gastrectomy with proximal jejunal bypass was considered for patients with BMI above 50 kg/m² and diabetes. Procedure choice followed these indications through shared decision-making rather than randomization; this limitation is worth stating plainly. The resulting predominance of sleeve gastrectomy reflects real-world practice patterns, but it also precludes any formal procedure-specific comparison.

Experienced bariatric surgeons performed all procedures using standardized laparoscopic techniques. For laparoscopic sleeve gastrectomy (LSG), we used a five-port approach: we divided the stomach along the greater curvature with sequential stapler firings from the antrum to the fundus, creating a tubular stomach over a 36-French bougie. Laparoscopic Roux-en-Y gastric bypass (LRYGB) entailed construction of a small gastric pouch (15–20 mL), a 75–100 cm Roux limb, and a 150 cm biliopancreatic limb; the gastrojejunostomy was fashioned in an antecolic, retrogastric configuration, with the Roux limb brought antecolic to the transverse colon and passed behind the gastric remnant to reach the pouch. Laparoscopic sleeve gastrectomy with proximal jejunal bypass (LSGPJB) combines a sleeve gastrectomy with an additional jejunal bypass, whereas one-anastomosis gastric bypass (OAGB) relies on a single gastrojejunal anastomosis between a long gastric pouch and the jejunum. Every patient underwent preoperative esophagogastroduodenoscopy. When endoscopy identified a hiatal hernia, the surgical team reduced the hernia and performed a concurrent posterior crural repair with multifilament non-absorbable sutures, restoring the intra-abdominal esophageal segment before completing the gastric reconstruction.

Data originated from the institutional bariatric surgery registry, a structured clinical database maintained prospectively at each perioperative and follow-up encounter. The registry served as the primary source for baseline characteristics (age, sex), anthropometric measurements (weight, height, BMI), associated medical problems (type 2 diabetes, hypertension, dyslipidemia, and obstructive sleep apnea), operative details, and serial weight and metabolic outcomes at 3, 6, 12, and 24 months. Because self-contained registry fields can drift from the source record over a fourteen-year accrual, we verified every laboratory and medication value used in the analysis against the hospital information system (HIS). We reconciled glycated hemoglobin and lipid results patient by patient with the central laboratory system, and confirmed glucose-lowering, antihypertensive, and lipid-lowering medication status against pharmacy dispensing and outpatient prescription records. This cross-check mattered most for the biochemical diabetes-remission definition, which requires both a laboratory HbA1c value and documented cessation of glucose-lowering therapy; only patients with an HIS-confirmed pairing of both elements contributed to that denominator. We used the same HIS records to adjudicate every reoperation flag (see below). Even so, baseline severity data — diabetes duration, detailed pre-treatment regimens, and some historical laboratory values — were incompletely captured, a constraint inherent to any retrospective dataset that

limits full characterization of the severity of associated medical problems at baseline. Estimated blood loss, operative time, and Clavien–Dindo grading were not recorded in either system.

Ascertainment of associated medical problems. Diabetes and hypertension were ascertained from Hospital Information System laboratory and pharmacy records — measured HbA1c and dispensed glucose-lowering or antihypertensive agents — rather than from a single categorical registry field, which captures patients whose diagnosis appears only in narrative notes or who are managed on medication prescribed elsewhere. Dyslipidemia was deliberately left in the registry field because neither Hospital Information System source yields a clean case definition for it: lipid-lowering prescriptions do not map onto a dyslipidemia diagnosis (most pre-operative statin users in this cohort were also diabetic, and statins are prescribed for cardiovascular prevention independent of a lipid diagnosis), and a single lipid value has no diagnostic threshold analogous to an HbA1c of 6.5% for diabetes. Laboratory- and pharmacy-based counts are reported throughout for diabetes and hypertension, and the registry-based count for dyslipidemia. Anthropometric records were screened for record-linkage error: a small number of measurements had a height differing by more than 5 cm from the patient's modal height, together with an internally consistent weight and body-mass index, indicating that another patient's observation had been attached to the record. We excluded these (405 of 7,175 measurements with a recorded height, 5.6%); the exclusion changed long-term %TWL estimates by no more than 0.1 percentage points and the weight-regain estimates by 0.2 kg.

The primary weight-loss outcome was percentage total weight loss (%TWL), reported at 3, 6, 12, and 24 months postoperatively. We adopted %TWL as the principal metric because, unlike percentage excess weight loss, it does not depend on baseline BMI and therefore supports direct comparison across patients and cohorts — a consideration that carries particular weight in an Asian population operated on at lower BMI thresholds. Percentage excess weight loss (%EWL) was reported as a secondary outcome to permit comparison with the older literature. Metabolic outcomes — remission of diabetes, hypertension, and dyslipidemia — were tracked at the same intervals. Secondary outcomes also included postoperative complications (any adverse event requiring medical or surgical intervention), an optimal clinical response defined a priori as ≥ 50% EWL, and long-term weight maintenance. Protocol-defined outcome assessment ended at 24 months. Because patients continued to attend clinically after that point, we additionally ascertained any later visits and weights from the registry and the hospital information system, and report these post-protocol observations separately as descriptive data. An AI-assisted analysis tool (Claude, Anthropic) was used under author supervision to support statistical recomputation (per-visit denominators, linear mixed-effects modeling with categorical time, predictor and attrition analyses, and diabetes outcomes from laboratory and pharmacy records), generation of tables and figures, and language editing; all inputs were de-identified, and the authors reviewed and verified all outputs. The tool is not, and cannot be, an author. Full details are provided in the ‘Use of AI-assisted technology’ declaration.

Metabolic remission definitions: We assessed diabetes outcomes using directly measured Hospital Information System (HIS) laboratory and pharmacy records. For each timepoint, we defined a ± 3-month

window, required an HbA1c value within it, and reported two complementary measures. Glycemic control was defined as HbA1c < 6.5% at the window HbA1c nearest the timepoint. Medication-confirmed remission, aligned with the 2021 ADA/consensus framework, required HbA1c < 6.5% together with no glucose-lowering agent dispensed at any visit within the window, and was assessed only in patients with documented pre-operative diabetes pharmacotherapy, so diet-controlled patients — for whom medication discontinuation is not informative — were excluded. Each metabolic endpoint is defined by a threshold, and a threshold measures crossing: patients already on the target side of it before surgery cannot demonstrate a change. Among the 277 diabetic patients with an HbA1c recorded in the hospital extract within that same two-year pre-operative window, 167 (60.3%) were already below 6.5%, but 82 of those were taking glucose-lowering medication and still had to reach the target with treatment withdrawn, so only the 85 at target without medication (30.7% of those tested) make a threshold reading uninformative — and those patients are the ones the medication-confirmed metric excludes by the rule stated above. The corresponding figures for the other two endpoints are 83 of 341 hypertensive patients (24.3%) already below 130 mmHg and 83 of 243 dyslipidemic patients (34.2%) already below 100 mg/dL; both are reported in Table 1.

Table 1
Baseline characteristics (n = 805)

Characteristic	Value	Note
n	805	
Female, n (%)	545 (67.7%)	
Age, yr	38.7 ± 11.1	
Weight, kg	119.6 ± 29.7	
Height, cm	165.4 ± 8.8	
BMI, kg/m²	43.5 ± 8.7	
BMI < 30	8 (1.0%)	
BMI 30–34.9	86 (10.7%)	
BMI 35–39.9	229 (28.4%)	
BMI 40–49.9	336 (41.7%)	
BMI ≥ 50	146 (18.1%)	
Type 2 diabetes	374 (46.5%)	
Hypertension	367 (45.6%)	
Dyslipidemia	302 (37.5%)	
OSA	419 (52.0%)	
GERD (preop)	61/302 (20.2%)	of assessed
Baseline HbA1c, %	7.0 ± 1.83	n = 300
Baseline systolic BP, mmHg	141.3	n = 341 of 367 hypertensive; 83 (24.3%) already < 130
Baseline LDL, mg/dL	120.5	n = 243 of 302 dyslipidemic; 83 (34.2%) already < 100
LSG, n (%)	753 (93.5%)	
LSGPJB/LRYGB/OAGB	35/14/3	

Because HbA1c was not obtained at every visit, each figure is reported with its own denominator. Values at 3 months should be interpreted as early glycemic improvement rather than remission by the durational criterion. For each diabetes metric, we report the assessed percentage — remissions divided by the eligible diabetic patients who had an HbA1c in the window — together with worst-case and best-case bounds computed using all eligible diabetic patients, in which patients without a window HbA1c are

counted as non-remission and as remission, respectively (Supplementary Figure S1). Because roughly half of eligible diabetic patients lacked a window HbA1c, the assessed percentage is an upper-bound estimate for the tested subgroup, and the true population rate lies between the two bounds. We used concurrent fasting plasma glucose (< 126 mg/dL) to cross-check the HbA1c-based classification. We captured glucose-lowering therapy from Hospital Information System dispensing records across all visits; 16 agents spanning eight classes were represented (biguanide, sulfonylurea, DPP-4 inhibitor, SGLT2 inhibitor, GLP-1 receptor agonist, thiazolidinedione, alpha-glucosidase inhibitor, and insulin). Every time-based definition in this study is anchored to the date of the primary operation. A dispensing record counts as pre-operative if it falls within two years before that date, the window used to build the cohort's original medication figures; because a dispensing record carries a date rather than a statement of current use, this window is a definition rather than an observation. Counts of patients at a visit are stated as patients observed in that window, not patients eligible for it, since an eligibility count would need censoring at the freeze while attendance continues past it; the pre-medicated count is accordingly window-sensitive, ranging from 134 patients at 90 days to 198 with no window applied. Post-operative outcomes are assigned to the scheduled follow-up visit whose window contains the record; those windows are 1.5 to 4.5 months for the 3-month visit, 4.5 to 9 months for the 6-month visit, 9 to 15 months for the 12-month visit, and 18 to 30 months for the 24-month visit; where a patient has more than one qualifying record in a window, the one nearest the nominal visit date is used. Of the 374 registry-diagnosed diabetic patients, 182 (48.7%) had a glucose-lowering agent dispensed within two years before surgery and formed the denominator for medication-confirmed remission; the remaining 192 had no such dispensing record, consistent with diet-controlled diabetes or medication prescribed at outside facilities, and were therefore excluded from that metric to avoid misclassifying them as being in drug-free remission. The pre-operative medication profile is detailed in Supplementary Table S1. “Off-medication” was defined as the absence of any dispensed glucose-lowering agent throughout the ± 3-month window around the timepoint, not merely on the day of the HbA1c measurement.

For dyslipidemia, we report attainment of the LDL-cholesterol goal (< 100 mg/dL) rather than remission. This choice reflects clinical reality: many patients reached target lipid levels only while continuing lipid-lowering medication, so remission — implying resolution independent of pharmacologic support — would misrepresent their status. We use the single term “LDL goal attainment” for this measure throughout.

The calculation formulas are as follows: %TWL = [(Preoperative weight − Postoperative weight)/Preoperative weight] × 100; %EWL = [(Preoperative weight − Postoperative weight)/Excess weight] × 100, where excess weight = Preoperative weight − Ideal body weight (BMI 25 kg/m²). We derived ideal body weight from a target BMI of 25 kg/m². WHO Asian-Pacific guidelines define overweight as BMI ≥ 23 kg/m² for Asian populations, and a stricter threshold might better reflect regional risk; we nonetheless retained BMI 25 kg/m² for %EWL, since it is the near-universal standard in the bariatric literature and permits direct comparison with published series, at the cost of understating %EWL relative to an Asian-specific threshold. This BMI dependence is precisely why we designated %TWL, independent of the reference BMI, as the primary weight-loss metric. Where %EWL figures appear later for comparison with published series, they are reported because those series report %EWL, and any

apparent association between baseline BMI and %EWL should be read as the metric property described in the Results rather than as a clinical predictor.

Statistical Analysis: No a priori power calculation was performed. This descriptive retrospective cohort comprises all consecutive eligible patients operated on during a fixed 14- year window (July 2011–September 2025), rather than a hypothesis- driven comparison based on a pre- specified effect size. The achieved sample (n = 805, with outcome- specific denominators reported throughout) reflects institutional volume rather than a calculated target. We presented descriptive statistics as mean ± standard deviation for continuous variables and as frequencies with percentages for categorical variables. We computed all outcome proportions using timepoint- specific denominators—patients eligible for and assessed at each visit—rather than the baseline cohort, so each reported rate reflects the population from which it was measured. For diabetes remission, denominators followed the Hospital Information System data for each metric: glycemic control was assessed among diabetic patients with an HbA 1 c value within a ± 3- month window at each timepoint, whereas medication- confirmed remission was restricted to those with documented pre- operative pharmacotherapy and both a window HbA 1 c and dispensing records. To identify independent predictors of optimal clinical response (at least 50% EWL at 12 months), we constructed multivariate logistic regression models, entering variables that met $p < 0.10$ on univariate analysis, and reported odds ratios (OR) with 95% confidence intervals (CI). For longitudinal weight- loss outcomes, which are unbalanced because patients contributed differing numbers of visits, we used a linear mixed- effects model with a random intercept per patient and time entered as a categorical factor (to accommodate the non- linear plateau after 12 months); this uses all available observations under a missing- at- random assumption rather than requiring complete cases. Diabetes, hypertension, and dyslipidemia outcomes are reported descriptively at each time point with worst- and best- case bounds rather than modeled over time, because incomplete laboratory ascertainment rather than a smooth temporal process governs the observed denominators. We set statistical significance at $p < 0.05$ and conducted analyses in Python (statsmodels) and SPSS version 28.0. 0. 0 (IBM Corp., Armonk, NY).

Missing-data and attrition strategy: Follow-up in this retrospective cohort was incomplete and declined over time, so we addressed missing data at three levels. First, the mixed-effects and generalized estimating equation models above use all available visit records rather than complete cases and remain valid under a missing-at-random (MAR) assumption. Second, to assess whether that assumption was tenable, we tested baseline predictors of attending each follow-up visit and compared baseline characteristics of completers versus non-completers using chi-square and independent t-tests; attendance was associated with baseline BMI, age, and diabetes, but not with sex (Limitations). Because the variables predicting attendance are also associated with the outcome, this pattern constrains rather than supports the missing-at-random assumption, and the sensitivity bounds described next carry correspondingly more of the inferential weight. Third, because MAR cannot be verified and outcomes-dependent dropout cannot be excluded, we bounded the potential impact of attrition on the primary 12-month response with best-case and worst-case sensitivity limits (assuming all non-assessed eligible patients had, respectively, achieved or failed the outcome).

Results

Baseline characteristics (Table 1): During the study period, 805 patients underwent primary laparoscopic bariatric surgery. Procedure types and follow-up at each timepoint are shown in Fig. 1. Women predominated in the cohort (67.7%, 545 patients), with a mean age of 38.7 ± 11.1 years and a mean BMI of 43.5 ± 8.7 kg/m². Obesity class distribution followed an expected skew toward higher categories: BMI below 30, 8 patients (1.0%); 30–34.9, 86 (10.7%); 35–39.9, 229 (28.4%); 40–49.9, 336 (41.7%); and ≥ 50, 146 (18.1%). Thirty-eight patients (4.7%) had a baseline BMI below the TSMBS threshold of 32.5 kg/m², and eight (1.0%) had a recorded BMI below 30. These patients underwent surgery for individualized metabolic indications (see Methods). Hepatic status was not collected cohort-wide and was reviewed ad hoc for these eight only: on chart review, four had non-alcoholic fatty liver disease or steatohepatitis documented on imaging or pathology, one had isolated aminotransferase elevation without imaging confirmation, and three had no hepatic markers; four carried at least one of type 2 diabetes, hypertension, or dyslipidemia, and none had obstructive sleep apnea. Taken together, six of the eight had at least one documented indication (a hepatic marker, a metabolically associated medical problem, or both); for the remaining two, no qualifying indication was retrievable from the available records. The burden of associated medical problems at baseline was substantial. Type 2 diabetes affected 374 patients (46.5%), hypertension 367 (45.6%), and dyslipidemia 302 (37.5%), while obstructive sleep apnea was the most prevalent condition, present in 419 patients (52.0%). HbA1c values were available for only 300 of 805 patients (37%), a limitation that constrains the generalizability of the glycemic findings; among these, the mean was 7.00 ± 1.83%, closely matching the value observed in the diabetes subgroup (299 of these 300 patients had diabetes). This baseline-table count differs from the 277 diabetic patients with a pre-operative HbA1c used for the threshold analysis in the Methods; that figure is drawn from the hospital extract within the declared two-year pre-operative window, whereas this one counts any recorded baseline value.

Table 5

Metabolic outcomes by timepoint: glycemic control, diabetes remission, hypertension, and dyslipidemia.

Timepoint	DM follow-up: visited/eligible; HbA1c-tested	DM glycemic control (HbA1c < 6.5%): assessed% (worst–best); events/tested, eligible	DM med-confirmed remission: assessed% (worst–best); events/tested, eligible	HTN remission (BP < 130/80 off-med): assessed% (worst–best); n	DLP at LDL goal (< 100 mg/dL): assessed% (worst–best); n
3m	352/359 (98.1%); 308	88.0% (75.5–89.7); 271/308 tested, 359 eligible	73.5% (65.7–76.3); 111/151 tested, 169 eligible	9.6% (8.9–16.6); n = 323/350	35.3% (30.9–43.4); n = 252/288
6m	275/329 (83.6%); 239	95.0% (69.0–96.4); 227/239 tested, 329 eligible	83.9% (64.7–87.6); 99/118 tested, 153 eligible	29.0% (23.7–42.0); n = 272/333	28.8% (22.0–45.5); n = 212/277
12m	173/243 (71.2%); 133	95.5% (52.3–97.5); 127/133 tested, 243 eligible	87.5% (51.5–92.6); 70/80 tested, 136 observed	37.8% (26.5–56.4); n = 201/287	38.4% (22.9–63.2); n = 138/231
24m	72/149 (48.3%); 46	89.1% (27.5–96.6); 41/46 tested, 149 eligible	87.1% (31.8–95.3); 27/31 tested, 85 observed	29.9% (13.5–68.2); n = 87/192	54.5% (18.5–84.6); n = 44/130

Diabetes glycemic control and medication-confirmed remission are ascertained from Hospital Information System laboratory and pharmacy records; hypertension remission and dyslipidemia LDL-goal attainment use the same denominator conventions as Table 2.

Operative characteristics (Table 1): Laparoscopic sleeve gastrectomy (LSG) accounted for most cases (753 patients, 93.5%). Surgeons reserved LSG with proximal jejunal bypass (LSGPJB, 35 patients), laparoscopic Roux-en-Y gastric bypass (LRYGB, 14 patients), and one-anastomosis gastric bypass (OAGB, 3 patients) for a smaller subset; after chart verification, every patient in the final cohort had a documented procedure type. Selection followed clear clinical logic: LRYGB was reserved for patients with intractable gastroesophageal reflux disease (GERD) or poorly controlled diabetes, whereas LSGPJB was considered for those with a BMI above 50 kg/m² and diabetes. This distribution reflects institutional practice patterns during the study period rather than a formal randomized allocation, a point worth bearing in mind when interpreting procedure-specific outcomes.

Weight-loss efficacy: Mean %TWL rose from 17.1% at 3 months (n = 541) to 26.0% at 6 months (n = 457), 31.4 ± 8.7% at 12 months (n = 416), and 31.4% at 24 months (n = 218). By 12 months, mean %EWL reached 79.7%, and 86.3% of assessed patients achieved at least 50% EWL (Table 2, Fig. 2a). Because the trajectory is not linear — weight loss accrues steeply through 12 months and then plateaus — we modeled time as a categorical factor in a linear mixed-effects model (random intercept per patient; 1,632 observations, 636 patients). Relative to 3 months, adjusted mean %TWL increased by 8.9 points at 6

months, 14.3 at 12 months, and 14.4 at 24 months (all $p < 0.001$). The near-identical 12- and 24-month coefficients captured the plateau that a linear time term (which estimated + 0.71% per month) could not represent. The declining denominators at later time points warrant caution in interpreting the 24-month figures. To analyze the binary clinical response over time, we additionally fitted a generalized estimating equation model (logit link, exchangeable working correlation, patient as cluster) for the odds of achieving ≥ 50% excess weight loss across visits (1,632 observations, 636 patients; within-patient correlation $\alpha = 0.40$). Relative to 3 months, the odds of ≥ 50% EWL rose sharply at 6 months (odds ratio 7.511), 12 months (odds ratio 15.127), and 24 months (odds ratio 15.64; all $p < 0.001$), then plateaued between 12 and 24 months, consistent with the mixed-effects trajectory.

Table 2
Weight-loss outcomes by time point (per-visit assessed n)

Timepoint	n assessed	%TWL (mean ± SD)	%EWL (mean ± SD)	Optimal response ≥ 50%EWL
3 months	541	17.1 ± 5.4	44.1 ± 17.8	30.1%
6 months	457	26.0 ± 6.9	66.6 ± 23.4	76.6%
12 months	416	31.4 ± 8.7	79.7 ± 27.8	86.3%
24 months	218	31.4 ± 10.0	76.4 ± 26.0	84.9%

Follow-up and weight loss beyond 24 months: Although the protocol-defined outcome schedule ended at 24 months, patients continued to attend clinically and were captured in both the registry and the hospital information system. Among patients whose operation was long enough before the data freeze to make later attendance possible, 201 of 395 (50.9%) had at least one bariatric follow-up visit recorded beyond 24 months; 78 of the 185 eligible for a 60-month window (42.2%) attended beyond 60 months, and 32 of 89 (36.0%) attended beyond 120 months; the longest observed interval was 168 months (14 years). Because 63.7% of the cohort was operated from 2023 onward and only 20.3% before 2020, the patients contributing 60-month and longer outcomes were necessarily operated in the program's earlier, lower-volume years; the long-term rows therefore describe an earlier era of practice rather than a random sample of the cohort, and this is a further reason not to read them as the cohort's expected long-term course. Weight data at these later visits were available for a smaller subset and were derived separately from the registry and the hospital information system, which agreed closely. Because both records document the same clinic encounters, this concordance verifies transcription fidelity rather than providing independent ascertainment: a patient who did not attend is absent from both for the same reason. Mean %TWL was 26.9% (registry, n = 84) and 27.0% (hospital records, n = 106) at 36 months, 25.7% (n = 31) and 23.6% (n = 50) at 60 months, 19.6% (n = 22) and 23.1% (n = 35) at 84 months, and 17.9% (n = 21) and 21.0% (n = 31) at 120 months (Table 3, Fig. 3). These figures indicate partial attenuation from the 31.4% observed at both 12 and 24 months (the identical means at these two timepoints are a genuine feature of the data, not a transcription error, and arise in different patient

subsets of 416 and 218), consistent with the recognized pattern of gradual recurrent weight gain. Still, they rest on subsets whose composition we were able to characterize. Comparing the 201 patients seen after 24 months with the 194 who were not, attenders were older (44.1 vs 38.9 years, p < 0.001) and more often hypertensive (55.7% vs 41.2%, p = 0.005), while baseline BMI, weight, sex, diabetes, and dyslipidemia did not differ. Attenders had also achieved slightly less weight loss at 12 months (30.0% vs 33.0% %TWL, p = 0.023). Continued attendance therefore tracked older age and a heavier burden of associated medical problems rather than better results, so if these later figures are biased, the likely direction is an underestimate of what the full cohort achieved rather than an overestimate. They remain descriptive. Post-protocol visits also allowed several outcomes to be characterized beyond the trial window (Table 4). Among 175 patients with both a nadir weight within 24 months and a later measurement, weights for this analysis being taken from the bariatric registry follow-up form, which the operating surgeon completes at the visit where recurrent weight gain is clinically assessed (median last contact 38 months, maximum 154), mean regain from nadir was 2.3 kg and the mean within-patient regain against each patient's own nadir was 4.6% (the mean of per-patient ratios; the ratio of the two means is 2.7%, a different quantity that need not agree because lighter patients contribute larger ratios). Because the registry captures roughly a third as many observations as the hospital system, we repeated the analysis on hospital weights (height-consistency screened): 179 patients, mean regain 6.7 kg, within-patient ratio 12.5%, versus 2.3 kg and 4.6% in the sparser registry series. The two bracket the true value rather than compete for it: a denser sampling series finds a lower nadir and so a larger apparent regain, so 2.3 kg is a lower bound and 6.7 kg an upper bound, a property of measurement frequency rather than data quality. Same-day concordance was high (3,048 pairs across 714 patients; 68.6% within 0.05 kg, 80.1% within 0.5 kg), while sampling density differed substantially (20.7 hospital observations per patient versus 5.1 registry entries; the hospital-derived minimum was lower in 46% of patients, the registry-derived minimum lower in 22%, and the two identical in 32%). This measurement-frequency effect likely applies to published series generally, since few report it. In all, 57 of 175 registry-series patients (32.6%) had regained nothing or continued to lose, and the median proportion of lost weight regained, 17.2% (IQR 0.7–39.8), is a hospital-series figure reported in Table 4: since the registry follow-up form does not record a pre-operative weight, this proportion cannot be computed for the registry series and is reported only for the hospital series. Mean BMI at the latest long-term visit was 34.0 kg/m² against a baseline of 43.5, with 33.3% below 30 and 17.4% still at or above 40. Metabolic control was largely preserved: 47 of 53 diabetic patients with a late HbA1c were below 6.5% (mean 5.64%), whereas 49 of the 102 hypertensive patients with a late blood-pressure reading had a systolic pressure below 130 mmHg, and only 30 of the 107 patients with a late lipid panel had an LDL below 100 mg/dL. Micronutrient testing beyond 24 months showed anaemia in 17 of 82 (20.7%), microcytosis in 42 of 120 (35.0%), and low ferritin in 12 of 73 (16.4%); anaemia was, however, already present pre-operatively in 36 of 217 tested patients (16.6%), so the late figure represents a modest rise on an already-high baseline rather than a purely post-surgical effect, while vitamin B12 and albumin were normal in every patient tested (0/65 and 0/84), a pattern consistent with the predominantly restrictive procedures performed. Because glucagon-like peptide-1 receptor agonists are dispensed through the same pharmacy system as the other glucose-lowering agents, later use could be established directly: only 7 of the 182 patients

(a different set from the 182 pre-medicated diabetic patients above) with any hospital information system encounter beyond 24 months, whether or not that encounter was a bariatric follow-up visit, had a GLP-1 prescription (3.8%; 5 of 78 diabetic patients, 6.4%), so the late weight-loss figures are not materially attributable to incretin pharmacotherapy dispensed within this hospital. Agents purchased privately would not be captured, although this would be unusual in our public-sector patient population. Proton-pump inhibitor use, by contrast, is documented only in free-text clinical notes rather than a structured field: among the 22 patients with a narrative note beyond 24 months, 2 were recorded as taking a proton-pump inhibitor. Because narrative notes accompany only a minority of registry visits (326 of 3,751 visits with a recorded procedure type, 8.7%), the absence of a documented prescription cannot be read as the absence of reflux, and these data cannot be used to estimate late GERD prevalence.

Table 3
Follow-up and weight loss beyond the 24-month protocol window.

Months after surgery	Eligible	Seen (either source)	% of eligible	Registry %TWL (n)	HIS %TWL (n)
36m	264	138	52.3%	26.9 ± 10.1 (84)	27.0 ± 10.3 (106)
60m	185	78	42.2%	25.7 ± 11.7 (31)	23.6 ± 10.4 (50)
84m	123	48	39.0%	19.6 ± 12.6 (22)	23.1 ± 12.2 (35)
120m	89	32	36.0%	17.9 ± 11.5 (21)	21.0 ± 11.5 (31)

Ascertained independently from the clinical registry and the hospital information system. Eligibility denotes patients whose operation preceded the data freeze by at least the stated interval.

Table 4
Outcomes beyond the 24-month protocol window: weight, metabolic, and micronutrient status.

Outcome	Value	Note
Recurrent weight gain from nadir		
Patients with nadir (≤ 24 mo) and later weight	175	median last follow-up 38 mo (max 154); weights from the registry follow-up form, surgeon-recorded
Mean regain from nadir	2.3 kg	mean of per-patient ratios (regain ÷ own nadir) 4.6%; ratio of the two means 2.7%
Median % of lost weight regained (hospital-information-system series)	17.2%	IQR 0.7–39.8
Regained ≥ 20% of lost weight	not computable from registry weights	
No regain or continued loss	57/175 (32.6%)	
BMI at latest long-term visit (hospital-information-system series; heights are not recorded on the registry follow-up form)		
Mean BMI	34.0 kg/m²	baseline 43.5
BMI < 30 / <35 / ≥40	46 (33.3%) / 87 (63.0%) / 24 (17.4%)	n = 138
Metabolic status beyond 24 months (latest value)		
Diabetic patients with HbA1c < 6.5%	47/53 (88.7%)	mean HbA1c 5.64%
Hypertensive patients with SBP < 130 mmHg	49/102 (48.0%)	mean SBP 130
LDL < 100 mg/dL	30/107 (28.0%)	mean LDL 119
Nutritional status beyond 24 months (latest value)		
Anaemia (Hb < 12 g/dL women, < 13 men)	17/82 (20.7%)	
Microcytosis (MCV < 80 fL)	42/120 (35.0%)	
Low ferritin (< 30 ng/mL)	12/73 (16.4%)	
Low vitamin B12 (< 200 pg/mL)	0/65 (0%)	

Includes recurrent weight gain from nadir and BMI category. Denominators differ by outcome and reflect the subset of patients with the relevant measurement recorded after 24 months.

Outcome	Value	Note
Hypoalbuminaemia (< 3.5 g/dL)	0/84 (0%)	
Not captured		GERD symptom score and GLP-1 use were not recorded at post-protocol visits

Includes recurrent weight gain from nadir and BMI category. Denominators differ by outcome and reflect the subset of patients with the relevant measurement recorded after 24 months.

Metabolic outcomes: Diabetes outcomes were assessed from Hospital Information System laboratory and pharmacy records (Fig. 2b). Each figure is reported as the assessed percentage with worst-case and best-case bounds, acknowledging that only about half had a window HbA1c. The two rows use different eligible populations, and the bounds follow that distinction: glycemic-control bounds are computed against all eligible diabetic patients (243 at 12 months, 149 at 24 months), whereas medication-confirmed remission bounds are computed against the pre-medicated patients observed in each window (136 at 12 months and 85 at 24 months), since remission off medication is undefined for a patient never on it. Medication-confirmed remission (HbA1c < 6.5% off all glucose-lowering agents, among patients with documented pre-operative pharmacotherapy) was 73.5% (bounds 65.7–76.3) at 3 months, 83.9% (64.7–87.6) at 6 months, 87.5% (51.5–92.6) at 12 months, and 87.1% (31.8–95.3) at 24 months. Glycemic control (HbA1c < 6.5%) followed a similar course: 88.0% (75.5–89.7) at 3 months, 95.0% (69.0–96.4) at 6 months, 95.5% (52.3–97.5) at 12 months, and 89.1% (27.5–96.6) at 24 months. Concurrent fasting plasma glucose confirmed the HbA1c classification in 98–100% of patients tested with both, so these estimates are not laboratory artifacts; their height reflects a mild baseline diabetic profile (mean HbA1c 7.0%) and incomplete laboratory ascertainment, as the widening lower bounds at later timepoints make explicit. The width of these intervals is itself the finding: at 12 months the medication-confirmed bound spans 51.5–92.6%, and an interval of that width cannot support inference about the underlying remission rate. We report it not as an estimate but to bound what the tested-subgroup figure of 87.5% could mean once the untested remainder of the 136 pre-medicated patients observed in that window is taken into account; only protocolized HbA1c measurement at each scheduled visit would narrow it. Table 5 summarizes hypertension remission and dyslipidemia LDL-goal attainment. LDL-goal attainment did not follow a monotonic time course (35.3%, 28.8%, 38.4%, 54.5% at 3, 6, 12, and 24 months); this pattern most likely reflects differential ascertainment — which patients had lipids drawn at each visit — rather than a biological dip, and should be read with the same denominator caution as the other metabolic outcomes. Among the 182 patients with documented pre-operative glucose-lowering therapy, the proportion off all diabetes medication among those observed at each visit was 84.5% at 3 months, 89.7% at 12 months and 89.4% at 24 months, and the mean number of agents per patient fell from 1.49 before surgery to 0.15 at 12 months (paired n = 138); of 18 patients on pre-operative insulin, 11 had discontinued it by 12 months (Supplementary Table S2). The three diabetes denominators are nested subsets of the same diabetic cohort, not independent samples: glycemic control is assessed among all eligible diabetic patients with a window HbA1c; medication-confirmed remission is restricted to those with documented pre-operative pharmacotherapy; and off-medication status is read from any

attended visit. Restricting medication-confirmed remission to pre-medicated patients excludes diet-controlled diabetics, who may be less likely to reach a drug-free remission endpoint; this restriction therefore tends to raise the medication-confirmed rate, and the figure should be read as an estimate within the pre-treated subgroup rather than the whole diabetic cohort.

Predictors of clinical response: In a multivariable logistic regression for achieving at least 50% EWL at 12 months (n = 416; variables entered at $p < 0.10$ on univariate screening), younger age (OR 0.950 per year, 95% CI 0.926–0.974, $p < 0.001$) and lower baseline BMI (OR 0.906 per unit, 95% CI 0.877–0.936, $p < 0.001$) were independent predictors, whereas female sex (OR 0.903, 95% CI 0.467–1.747, $p = 0.762$) and baseline diabetes (OR 0.831, 95% CI 0.440–1.569, $p = 0.568$) were not (full model in Table 6). The inverse association with baseline BMI is at least partly a mathematical property of the %EWL metric: %EWL is referenced to excess weight above a BMI of 25 kg/m², so a lower starting BMI yields a smaller excess-weight denominator and requires less absolute loss to cross the 50% threshold. To test this directly, we refit the model with a %TWL-based response (≥ 20% TWL), which is independent of baseline BMI: age remained a predictor (OR 0.958, 95% CI 0.932–0.984, $p = 0.001$) but baseline BMI was no longer significant (OR 1.04, 95% CI 0.993–1.091, $p = 0.099$), confirming that the apparent BMI effect on the %EWL endpoint is largely an artefact of the metric. We therefore adopt %TWL as the primary weight-loss measure and caution against interpreting baseline BMI as a biological predictor of response.

Table 6
Multivariable logistic regression for optimal clinical response at 12 months.

Variable	Unadjusted OR (95% CI), p	Adjusted OR (95% CI), p	≥ 20% TWL sensitivity OR (95% CI), p
Age (per year)	0.96 (0.938–0.982), p < 0.001	0.95 (0.926–0.974), p < 0.001	0.958 (0.932–0.984), p = 0.001
Baseline BMI (per unit)	0.913 (0.886–0.941), p < 0.001	0.906 (0.877–0.936), p < 0.001	1.04 (0.993–1.091), p = 0.099
Female sex	1.572 (0.884–2.795), p = 0.123	0.903 (0.467–1.747), p = 0.762	0.998 (0.476–2.094), p = 0.996
Baseline diabetes	0.709 (0.398–1.263), p = 0.243	0.831 (0.44–1.569), p = 0.568	0.629 (0.313–1.264), p = 0.193

Optimal clinical response is defined a priori as ≥ 50% excess weight loss (EWL). A %TWL-based sensitivity model is reported alongside the primary EWL-based model.

Follow-up completeness varied by time point. Among patients who had reached each visit window by the data-freeze date (the eligible denominator), follow-up was 71.0% at 3 months, 63.7% at 6 months, 68.1% at 12 months, and 55.2% at 24 months; expressed against the full cohort, these correspond to 67.2%, 56.8%, 51.7%, and 27.1%, respectively. Computing eligibility against the data freeze rather than the analysis date avoids misclassifying recently operated patients — whose visit windows fall after the freeze — as lost to follow-up (Table 7, Fig. 1). Follow-up among eligible patients is not strictly monotonic — it is higher at 12 months (68.1%) than at 6 months (63.7%) — reflecting that the 12-month visit is the

one most consistently prioritized by patients and the program, not a data error. The diabetic share of the eligible pool declines at later time points (47.1% at 3 months to 37.7% at 24 months) because diabetes was more prevalent among patients operated in the most recent, higher-volume years (54.9% of the 410 patients operated within the final two years versus 37.7% of the 395 operated earlier), consistent with a maturing metabolic-surgery referral pattern rather than with any change in the eligibility rule. The median follow-up was 12 months (interquartile range 6–24) among the 636 patients with at least one postoperative visit. We do not report attended person-time for this group, because the interval from operation to last recorded visit is available only at the level of the source registry rather than for the analytic cohort as defined here; the person-time denominators used for revisional events in the following section are operation-to-ascertainment calendar time, which accrues whether or not a patient attended and is therefore a different quantity.

Table 7
Follow-up completeness and attrition

Time point	Assessed (n)	Eligible (reached visit window)	Follow-up of eligible (%)	Follow-up of full cohort (%)
3-month	541	762	71.0	67.2
6-month	457	717	63.7	56.8
12-month	416	611	68.1	51.7
24-month	218	395	55.2	27.1

Postoperative complications (Table 8): Registry-flagged reoperations and ambiguous procedure records were verified individually against the medical record. Five patients (0.66% of 753 sleeve gastrectomies) had an early complication requiring reoperation: two sleeve leaks, one stenosis, and two functional sleeve obstructions. All five recovered fully, and no perioperative deaths occurred. Nine patients in the cohort later returned for chart-verified revisional or conversion surgery—a long-term outcome captured because these patients had their primary operation in our series and re-presented over subsequent years. Two were converted to a bypass for intractable GERD documented in the clinical record (at 5 and 24 months): one had persistent pre-existing reflux, the other de novo reflux despite excellent weight loss (31% total weight loss, BMI 25.2 at conversion) and a normal pre-operative endoscopy. Reflux resolved after conversion in both, though symptom status was recorded narratively rather than with a validated score or objective testing (endoscopy or pH monitoring). The remaining seven underwent late revision a median of 7.7 years (range 4.1–11.1) after the primary operation. Because revisional events were ascertained by chart review through March 2026, the observation window for detecting them extends beyond the outcome freeze. The appropriate denominator is patient-time to that ascertainment date: against 3,127 patient-years accrued between operation and 31 March 2026, the seven late revisions correspond to 2.2 per 1,000 patient-years and all nine later operations to 2.9 per 1,000 patient-years. Among the 209 patients with at least five years of observation — the subgroup in which a revision at this

interval could be detected at all — seven underwent late revision (3.3%, 3.7 per 1,000 patient-years). Pairing the seven events against patient-time to the earlier outcome freeze would understate the denominator, since two of the revisions occurred after that date. These denominators are the appropriate ones for a count of events whose median interval exceeds seven years, since the full cohort includes patients operated too recently for such an event to have occurred. The registry recorded no explicit indication for these. Still, every one of the seven had documented recurrent weight gain from the post-operative nadir before revision — a median of 33.0 kg regained (range 5.0–62.6), equivalent to 62.8% of the weight originally lost, these seven patients' weights having been abstracted individually by chart review across each patient's whole record rather than by the 24-month nadir rule used for the cohort series, and the patients themselves having been identified because their recurrent weight gain was severe enough to warrant reoperation; the figures therefore characterise the indication for revision and are not comparable with the cohort-level distribution reported above (range 27.5–87.1%) — so recurrent weight gain is supported by the measured trajectory rather than inferred from procedure type alone. Because these events are counted against cohort members who first appear as primary cases, they do not alter the primary denominator of 805. Revisional events were ascertained by chart review conducted after the analytical freeze, and three of the nine took place between January and March 2026; they are therefore reported outside the frozen outcome window. Post-revision weight was available for five of the seven late revisions — one of the two without it was revised eight days before the freeze and one in March 2026, so neither had accrued a post-revision visit — over a follow-up ranging from 3.2 to 77.9 months: all five lost further weight after revision, reaching a body-mass index of 32.5 to 51.1 (median 37.6) at the most recent recorded visit, and no post-revision complication or death was recorded. The two longest-followed patients illustrate the range — one fell from a body-mass index of 47.3 immediately before conversion to 32.5, sustained over 6.5 years of subsequent follow-up (this patient's body-mass index before the original sleeve gastrectomy had been 73.5), while another remained at 37.6 three years after revision. During chart verification, three registry entries that lacked an operative record were confirmed as patients who had not undergone surgery and were excluded, and two entries flagged as revisional/redo procedures in the updated registry were likewise excluded from the primary cohort. De novo reflux after sleeve gastrectomy requires reflux to be documented as absent before surgery, and the pre-operative field records a value for 300 of the 800 patients the registry rules reconstruct (302 of the 805 published cohort, the two additional patients being chart-resolved). Among the 241 recorded as free of reflux before surgery, 11 (4.6%) had reflux coded at a later visit. Reading an unfilled pre-operative field as absence, which follows the institution's convention that the registry became the primary record only recently, gives 36 of 741 (4.9%); the two estimates agree closely, so the figure does not rest on that convention. A further 4 patients had reflux both before and after surgery and are not de novo cases. These are early-window figures that depend on how systematically reflux was queried at follow-up and do not capture late-onset disease.

Table 8
Safety, reoperations, and reflux outcomes

Safety parameter	Value
Total primary operations	805
LSG / LSGPJB / LRYGB / OAGB	753 / 35 / 14 / 3
Perioperative mortality	0
Reoperations after chart verification	5 early complications + 9 revisional/conversion (7 late revision + 2 GERD conversion)
Early complications requiring reoperation	5 (0.66% of 753 LSG)
Sleeve leak	2
Stenosis	1
Functional obstruction	2
Outcome	100% complete recovery
Mean hospital stay, reoperated cases	11.25 days (range 7–16), the mean of four recorded stays; the stay was not recorded for the fifth reoperated patient, and cohort-wide length of stay was not captured
Revisional / conversion (cohort members, late)	9
Timing after primary	7 late revisions (indication not stated; recurrent weight gain from nadir documented in all 7), median 7.7 year (range 4.1–11.1)
Conversion to bypass for intractable GERD	2 (sleeve gastrectomy converted to Roux-en-Y gastric bypass; documented, at 0.4 and 2.0 years)
Late revision (recurrent weight gain documented from nadir)	7 (median 7.7 year, range 4.1–11.1)
Preoperative GERD (of assessed)	61/302 (20.2%)
Management	mostly medical; intractable → RYGB/OAGB
De novo reflux after LSG	11/241 (4.6%) of patients documented reflux-free pre-operatively; 36/741 (4.9%) reading an unfilled pre-operative field as absence
Not captured	EBL, operative time, Clavien-Dindo

Nutritional and longer-term outcomes. Because supplement dispensing was not reliably coded, we assessed micronutrient status using post-operative laboratory values rather than prescriptions. Among patients with at least one post-operative measurement, anemia (hemoglobin < 12 g/dL) was present in

123/417 (29.5%), microcytosis (MCV < 80 fL) in 303/660 (45.9%), and low ferritin (< 30 ng/mL) in 58/480 (12.1%), a pattern consistent with iron-deficiency anemia commonly seen after sleeve gastrectomy. Vitamin B12 deficiency (< 200 pg/mL, 1/358) and hypoalbuminemia (< 3.5 g/dL, 6/633) were rare. These laboratory-based figures likely underestimate true deficiency, since testing was not protocolized and supplement adherence could not be verified. The registry and the hospital information system did not systematically capture 30-day readmissions, late leaks or strictures beyond the early post-operative period, or formal Clavien–Dindo grading during the study period, and we acknowledge these gaps. The reoperations we could verify are those documented in the operative record, which may undercount minor readmissions managed conservatively.

Surgical volume rose sharply over the study period, from 4 procedures in 2011 to 223 in 2024 (annual volumes are given in Supplementary Table S3). This expansion did not come at the expense of safety: the five early complications requiring reoperation fell in different years of the program rather than clustering in any single interval. Five events across fourteen years cannot establish stability, and complications managed without reoperation are not captured by this registry field; this observation reflects the absence of an evident cluster, not evidence of a constant complication rate. Where an interval was recorded, reoperation occurred within the first two postoperative weeks; for two cases, the registry could not establish the precise interval.

Diabetes ascertainment followed the same Hospital Information System window rules described in Methods; Table 5 reports assessed percentages with worst- and best-case bounds alongside tested/eligible denominators. Concurrent fasting plasma glucose confirmed the HbA1c classification in 186 of 188 paired observations (98.9%), pooled across all post-operative windows — a count of observations rather than of patients, since only 133 diabetic patients had a 12-month window HbA1c — indicating that the glycemic estimates are not a laboratory artifact. HbA1c coverage fell from 85.8% of eligible diabetic patients at 3 months to 30.9% at 24 months, which is why the worst-case bounds widen at later timepoints; this DM-subgroup follow-up, based on HIS visit and laboratory records, is not directly comparable to the weight-based follow-up in Table 7.

Discussion

The principal contribution of this single-center retrospective analysis is representational, not a claim of novel efficacy. To our knowledge, it presents the first laparoscopic bariatric surgery cohort of this size from a Thai tertiary center, complementing the Korean, Malaysian, Singaporean, and Indian series that currently define Asian outcomes and enabling cross-country comparison within the region. We frame this deliberately as an incremental contribution: the outcomes themselves fall broadly within published Asian ranges. For 12-month diabetes remission, our assessed-subset estimate sits at the upper end of regional reports, while the worst-case bound (counting every untested eligible patient as a non-remission) falls below them; we report both precisely because that range, rather than a single favorable figure, is what makes the cohort useful as a comparison point. A secondary methodological contribution is the explicit handling of unbalanced follow-up and the reporting of diabetes remission under clearly

defined terms, offered not as a superior method but as a way to make our estimates directly comparable with future series. Several features of this handling are worth stating together, since they are what make the cohort useful as a comparison point beyond the headline figures. Diabetes outcomes are ascertained from objective HbA1c values and pharmacy dispensing records rather than chart-documented impressions, with concurrent fasting plasma glucose confirming the HbA1c-based classification in 98–100% of dual-tested patients; every outcome proportion is reported against an explicit, time-point-specific denominator, with worst-case and best-case bounds where laboratory ascertainment was incomplete, so that the width of an estimate is visible alongside its point value rather than concealed by it; and we identified and corrected a metric artifact in our own analysis — an apparent inverse association between baseline BMI and %EWL-based response that, by refitting with a %TWL-based endpoint, was shown to be substantially a property of the %EWL denominator rather than a biological effect — leading us to adopt %TWL as the primary outcome accordingly. Opportunistic follow-up to fourteen years, unusual for a Southeast Asian bariatric cohort, further allowed exploratory within-patient analysis of durability and testing of one specific selection mechanism, even though these later observations remain descriptive rather than confirmatory.

Interpretation of Procedure-Specific Outcomes

This study focuses primarily on LSG outcomes, as sleeve gastrectomies accounted for 93.5% of procedures (753/805). One-anastomosis gastric bypass (OAGB, n = 3), laparoscopic Roux-en-Y gastric bypass (LRYGB, n = 14), and LSG with proximal jejunal bypass (LSGPJB, n = 35) round out the series. However, these small sample sizes preclude meaningful analysis of procedure-specific outcomes, direct comparisons between techniques, or conclusions about relative efficacy. We cannot and do not make any claims regarding the comparative effectiveness of alternative procedures versus LSG based on our data. The high proportion of LSG in our series reflects institutional practice patterns as much as global trends, given that LSG has become the most commonly performed bariatric procedure worldwide. Patients receiving Roux-en-Y gastric bypass, consistent with our selection criteria, showed a higher prevalence of baseline diabetes and reflux; those receiving sleeve gastrectomy with proximal jejunal bypass had a higher mean baseline BMI and more frequent diabetes. These patterns are consistent with non-sleeve procedures being directed toward patients with more severe metabolic disease or reflux, rather than assigned at random.

Comparison with Asian Literature and Regional Context

Our outcomes can be considered alongside the existing Asian bariatric surgery literature, with the caveat that cross-study comparisons without individual patient data and standardized definitions remain descriptive. This caveat is especially important because the procedure mix differs across series: our cohort is overwhelmingly sleeve-based, so comparisons are most informative when set against other predominantly sleeve Asian experiences. Yeo et al. published a 2019 meta-analysis comparing gastric bypass and sleeve gastrectomy in Asian cohorts [24]. Our cohort achieved a mean %EWL of 79.7% at 12

months. HIS-based, medication-confirmed diabetes remission at 12 months ranged from 51.5% (worst-case, among all 136 pre-treated patients observed in the 12-month window) to 87.5% (among tested patients only); we lead with the bound rather than the tested-subset figure because only about half of eligible patients had a window HbA1c. These figures broadly fall within the range reported in Asian series. We stop short, however, of claiming statistical superiority — differences in case mix, remission criteria, and follow-up duration across studies make such a claim premature, and comparisons with bypass-predominant series (for example, cohorts in which one-anastomosis gastric bypass predominates) are best avoided because the operations differ mechanistically from sleeve gastrectomy.

When comparing with specific Asian population studies:

Comparison with the Korean experience: Park et al., in a multicenter Korean retrospective cohort, found that bariatric surgery produced substantially greater and more durable weight loss than non-surgical therapy [25]; our findings are consistent with that surgical arm at a comparable baseline BMI (43.5 ± 8.7 kg/m²), though the comparator differs (non-surgical vs. our single-arm design), so this is contextual rather than head-to-head.

East Asian consensus statements and regional reviews report substantial two-year diabetes remission after metabolic surgery in Asian populations operated on at lower BMI thresholds than Western criteria [28, 29]. In our cohort, HIS-based medication-confirmed remission at 24 months was 87.1% among those tested but only 31.8% under the worst-case assumption across all 85 pre-treated patients observed in the 24-month window; the wide interval reflects that only 31 of those 85 had a 24-month HbA1c. Any longer-term durability claim is correspondingly weak, and this interval should be read as the honest expression of that uncertainty rather than as a point estimate.

Yeo et al.'s meta-analysis of 13 Asian metabolic-surgery studies (1,052 patients) found greater excess weight loss after Roux-en-Y bypass than after sleeve gastrectomy (SMD 0.53, 95% CI 0.12–0.94). Diabetes resolution was numerically higher with bypass but not significantly so (OR 1.39, 95% CI 0.53–3.67), and there was no significant difference in hypertension resolution (OR 0.96, 95% CI 0.44–2.11) [24]. That analysis reported comparative effect sizes, not pooled absolute rates, so our single-arm, sleeve-predominant estimates cannot be placed on the same scale; we note only that our direction of effect is consistent with substantial metabolic improvement after sleeve gastrectomy in an Asian population.

Jammu and Sharma's audit of Indian patients found that type 2 diabetes resolution was highest with one-anastomosis gastric bypass [26], included here for completeness rather than as a direct comparator: that series is predominantly bypass-based, whereas ours is overwhelmingly sleeve, and the two operations differ mechanistically enough that a cross-procedure remission comparison would not be appropriate.

Our results broadly align with published Asian series across these comparisons. Still, differences in patient selection, baseline disease severity, follow-up protocols, remission criteria, and denominators preclude any conclusion about relative efficacy. We frame our outcomes as consistent with the broader observation that Asian populations can achieve meaningful metabolic benefit from bariatric surgery at lower baseline BMI than Western populations [30, 31], rather than as evidence of superior performance.

Whether these observations support ethnicity-stratified BMI thresholds for bariatric intervention, rather than uniform criteria, is a hypothesis that can be tested only by prospective, appropriately controlled studies; our retrospective, single-center data neither establish nor justify such a change in practice.

Weight Loss Outcomes

Our weight-loss outcomes are consistent with international standards. Mean %TWL reached 31.4 ± 8.7% at 12 months and was maintained at 31.4% at 24 months, indicating durable weight loss over two years among those retained in follow-up. The corresponding mean %EWL — 79.7% at 12 months and 76.4% at 24 months — exceeds the commonly cited 50% threshold for optimal clinical response and falls within the range of successful series in the literature. For context, a systematic review of studies with at least two years of follow-up reported a sample-size-weighted mean %EWL of 65.7% after gastric bypass and 45.0% after gastric banding [7]; that synthesis reported no twelve-month figure and included no sleeve gastrectomy cohorts, so it bounds the comparison rather than matching it. These results were achieved at a lower baseline BMI (43.5 kg/m²) than in many Western studies, where mean BMI often exceeds 45 to 50 kg/m² — a difference that may partly account for the more favorable trajectory. However, direct cross-study comparison remains limited by heterogeneity in patient selection and surgical technique. Our multivariate analysis identified younger age and lower baseline BMI as independent predictors of optimal clinical response at 12 months, a pattern consistent with the international literature and suggesting that patient selection and timing of intervention may influence surgical success.

Metabolic Outcomes

Our metabolic outcomes align with the upper end of the range reported in the literature, a position that must be interpreted in light of a mild baseline diabetic profile (mean HbA1c 7.0%) and incomplete laboratory ascertainment. By 3 months, glycemic parameters had already improved substantially: 88.0% of tested diabetic patients had HbA1c below 6.5% (worst-case 75.5% among all eligible), alongside a mean %TWL of 17.1%. We emphasize that this 3-month figure reflects early glycemic improvement, not remission by the 2021 ADA/consensus criterion, which requires HbA1c below 6.5% measured at least three months after cessation of glucose-lowering therapy—a durability condition that a patient assessed at exactly three months postoperatively cannot satisfy. The early response also warrants caution because we did not systematically document diabetes duration or treatment regimen; insulin-dependent diabetes carries substantially lower remission rates than non-insulin-dependent diabetes [32], so the insulin composition of our cohort may have shaped the figures observed here.

Without this stratification, we cannot determine whether our remission rate represents outcomes in predominantly mild disease or includes more severe cases.

At 12 months, 95.5% of tested diabetic patients reached HIS-based glycemic control (HbA1c below 6.5%), and 87.5% achieved medication-confirmed remission. Both are subset percentages: only 133 of 243 eligible diabetic patients had a 12-month HbA1c, so the worst-case bounds are 52.3% among the 243 and 51.5% among the 136 pre-medicated patients observed in that window — a different and smaller denominator, as set out in the Methods. The true rates lie between these bounds. Three factors temper interpretation: the cohort's mild baseline diabetes, incomplete laboratory ascertainment (residual selection toward tested patients), and incomplete medication capture. Reports of diabetes recurrence describe relapse rates of roughly 15% to 35% at five years, with some Asian cohorts potentially higher [31, 33]; our 24-month data therefore warrant cautious interpretation of longer-term durability, which future work with more complete follow-up will need to address.

Medication-confirmed remission is restricted to patients with documented pre-operative pharmacotherapy: a substantial share of diabetic patients had no glucose-lowering agent recorded in the hospital pharmacy system, reflecting diet control or prescriptions filled elsewhere, and discontinuation can only be verified where dispensing records are complete.

This distinction also bears on comparisons with Asian literature in two ways. First, baseline severity: our medication-confirmed remission was high (87.5% at 12 months) against a mild diabetic cohort (mean baseline HbA1c 7.0%). The multiethnic Singapore cohort of Lee et al., with a higher baseline HbA1c (8.4%), longer diabetes duration (9.3 years), and comparable BMI (40.0 kg/m²), reported a one-year remission of 55.9% [34] using a stricter threshold (HbA1c ≤ 6.0% vs. our 6.5%), so part of the gap is definitional; that study also identified baseline HbA1c, BMI, and diabetes duration as independent predictors, underscoring why the duration data we lack would matter. Second, ascertainment: none of the Asian sleeve and metabolic-surgery cohorts we examined [34–37] reported how many eligible diabetic patients were actually tested, so their remission rates rest on an unstated denominator — precisely what our worst- and best-case bounds make explicit, which we regard as this cohort's more durable contribution than the point estimates themselves.

At 12 months, hypertension remission — defined as normal blood pressure (< 130/80 mmHg) off all antihypertensive agents, as measured by HIS blood-pressure and pharmacy records — occurred in 37.8% of tested hypertensive patients (worst-case 26.5% among all eligible). This figure is difficult to contextualize: without baseline treatment intensity, specifically the number and classes of antihypertensive agents each patient required beforehand, we cannot judge whether it represents a favorable or modest response. It should be read as descriptive only, bounded by the same ascertainment limits as the diabetes outcomes.

Timing of the Early Metabolic Response

Glycemic improvement appeared early: 88.0% of tested diabetic patients were below 6.5% at three months. This is not evidence of a weight-independent metabolic effect: a three-month %TWL of 17.1% represents substantial exposure (20.5 kg at the cohort's mean baseline weight, 54.5% of the total weight this cohort would go on to lose by 24 months), and we measured no mediator — no gut hormone, bile acid, or insulin-sensitivity index — that could distinguish a weight-independent mechanism from a fast-acting weight-dependent one. These data show the timing of the response, not its cause. Proposed mechanisms in the experimental literature include altered gut hormone secretion, bile acid changes, gastric restriction, reduced ghrelin, and the foregut hypothesis [32, 38], with metabolic improvement reported to outpace weight loss in studies specifically designed to measure that dissociation [32] — a design ours was not.

Safety Outcomes

Five early complications required reoperation — two sleeve leaks, one stenosis, and two functional obstructions of the sleeve — representing 0.66% of sleeve gastrectomies. All five resolved successfully, with complete recovery and no mortality. Nine patients from the cohort later underwent chart-verified revisional or conversion surgery — two conversions to bypass for intractable GERD documented in the record and seven late revisions, in which recurrent weight gain from the postoperative nadir was documented in every case (median 62.8% of the weight lost, range 27.5–87.1%). However, the registry did not state the indication explicitly. The seven late revisions occurred a median of 7.7 years (range 4.1–11.1) after the primary operation. These late reoperations, occurring in patients who entered the series as primary cases and re-presented years later, provide a limited but genuine window onto long-term outcomes beyond the 24-month protocol window, and their timing is consistent with the recognized pattern of recurrent weight gain several years after sleeve gastrectomy. The registry reoperation flag could not be taken at face value: several flagged entries proved on review to be duplicate records, single-operation records, or patients who had not in fact undergone surgery. This finding points to a broader methodological caveat — when reoperation status is inferred from registry fields alone, manual case-by-case adjudication remains essential to avoid overcounting. For context, a comparably sized Indian sleeve-gastrectomy series reported an overall complication rate of 5.8%, with staple-line leak and bleeding at 1.2% each, deep vein thrombosis 0.4%, stricture 0.21%, de novo GERD 2.8%, and 30-day mortality 0.21% [36]; our early-reoperation rate (0.66%) and de novo reflux rate (4.6% of patients documented as reflux-free before surgery) are of the same order, although differences in how complications were ascertained and graded preclude a direct comparison.

Preoperative GERD was present in 20.2% of patients with a documented assessment (61 of 302 in the published cohort; 59 of 300 under the registry-reconstruction rules used for the de novo denominators below). De novo reflux after laparoscopic sleeve gastrectomy was recorded in 4.6% of patients free of reflux before surgery (11 of 241), or 4.9% (36 of 741) if an unfilled preoperative field is read as absence; both are lower bounds, since absence is assumed for unrecorded patients while a case requires a symptom actually coded, and the symptom field is sparse (582 of 741 patients with no entry at all). This is an early-window figure — reflux was not systematically queried post-protocol and PPI dispensing is not

structured, so it likely understates lifetime incidence relative to longer-observation series. Our mitigation approach includes routine preoperative endoscopy with posterior crural repair for identified hiatal hernia; even so, de novo reflux persists as a recognized limitation, and a small number of patients ultimately required conversion for intractable reflux, since most preoperative GERD responded to medical therapy and conversion was reserved for refractory disease.

Limitations

This study has several limitations that warrant careful consideration when interpreting our findings.

Retrospective Design

This study's retrospective design limits several aspects of the metabolic data. Baseline HbA1c was available for only a subset, and diabetes duration was not systematically documented — a concrete limitation, since diabetes duration independently predicts remission in a comparable multiethnic Asian cohort [34], limiting our ability to attribute the high observed rates to a mild baseline profile versus short disease duration. Diabetes treatment was characterized from HIS dispensing records, including drug class and insulin use before and after surgery (Supplementary Tables S1 and S2), but these capture only institutional dispensing and may underrepresent prescriptions from outside sources; preoperative dispensing was documented for 182 of 374 diabetic patients within a two-year window (window-dependent, ranging from 134 at 90 days to 198 with no window). Treatment details for hypertension and dyslipidemia were not extracted for severity-stratified analysis. These gaps constrain the granularity of our conclusions without undermining the core findings reported here.

Single-Center Experience

While a single-center design ensures consistency in surgical technique and perioperative management, institutional expertise, patient selection, and center-specific protocols limit how broadly the findings can be applied. The population studied was young (mean age 38.7 years) and predominantly female (67.7%), reflecting the referral pattern of a single tertiary center and may not represent the broader Thai or Southeast Asian population; outcomes may differ in older or more male-predominant groups. Confirming these findings will require multi-center studies across diverse practice settings and populations.

High Attrition Rate

The decline in follow-up, from 71.0% at 3 months to 55.2% of eligible patients (27.1% of the full cohort) at 24 months, is the study's principal limitation: reported 24-month outcomes reflect only patients who remained in follow-up. Sensitivity analysis found that 24-month completers had a modestly higher baseline BMI (45.3 vs. 43.1 kg/m², $p = 0.005$) and were slightly older (41.2 vs. 39.2 years, $p = 0.046$) than non-completers. Thus, attrition is patterned on the same clinical factors that predict outcome — constraining rather than supporting a missing-at-random interpretation. To bound the effect on the primary endpoint, we recomputed the 12-month optimal-response rate under extreme assumptions: 58.8% (all non-assessed failed) to 90.7% (all non-assessed succeeded) among all eligible patients, versus 86.3% among those assessed. The same caution applies to diabetes outcomes: HbA1c coverage

declines over time, so the high glycemic-control and medication-confirmed remission rates are best read as estimates from the tested subset rather than definitive population results, since patients tested in routine care may differ systematically from those not tested.

Our 24-month follow-up — 55.2% of eligible patients (27.1% of the full cohort) — is broadly comparable to other retrospective bariatric surgery studies, which commonly report 40–60% at 2 years. This shortfall is not unique to our cohort; it reflects a persistent methodological challenge across the field. That context helps explain the limitation but does not resolve it. Readers should weigh the sensitivity analysis presented under Follow-up completeness.

Interpretation of Diabetes Outcomes

Our diabetes rates are high but rest on incomplete laboratory ascertainment; the resulting worst-and best-case bounds are summarised by outcome domain in Table 9 rather than restated here. Two points from this ascertainment are not stated elsewhere and are isolated here for that reason.

Table 9
Evidence certainty by outcome domain.

Outcome domain	Ascertainment basis	Approx. coverage of eligible denominator	Certainty
Weight loss (%TWL, %EWL) to 24 months	Direct anthropometric measurement at scheduled visits	51.7%–71.0% of eligible patients per timepoint	Moderate – point estimates reasonably stable; declining n limits 24-month precision
Diabetes glycemic control / medication-confirmed remission	HbA1c + pharmacy dispensing, ± 3-month window	Falls from ~ 86% at 3 months to ~ 31% at 24 months (HbA1c-tested)	Low at later timepoints – worst-/best-case bounds span 40 + points by 12–24 months
Hypertension remission / LDL goal attainment	BP and lipid records, ± 3-month window	Highly variable; denominators smaller than diabetes metrics	Low – wide bounds, non-monotonic LDL trend reflects ascertainment, not biology
Outcomes beyond 24 months (weight, revision, micronutrients)	Opportunistic registry/HIS attendance, not protocolised	36–51% of eligible patients, shrinking with horizon	Low – small, self-selected, early-era subsets; descriptive only

Added in response to peer review, to let readers calibrate confidence per outcome at a glance; does not replace the denominator-specific reporting in Tables 2–4 and 7–8.

Untested diabetic patients did not have more favorable baseline glycemic profiles than tested patients (mean baseline HbA1c 7.4% untested vs 7.1% tested, p = 0.21), arguing against the concern that testing selectively captured patients most likely to be in remission. Tested patients, however, had marginally higher baseline BMI (46.4 vs 44.5 kg/m²), consistent with the assessed percentages being upper-leaning. Because glucagon-like peptide-1 receptor agonists are increasingly prescribed for weight management as well as glycemia, a patient continuing such an agent post-operatively is not counted as

off medication under our definition. This definition is therefore conservative with respect to drug-free remission rather than biased toward it.

Procedure-Specific Limitations

Given the predominance of LSG (93.5%), meaningful comparison across bariatric procedures is not possible in this cohort. Our outcomes should therefore be interpreted explicitly as LSG outcomes in an Asian population rather than as generalizable findings across bariatric procedures broadly.

Duration of Follow-up

The 24-month protocol-defined follow-up is adequate for assessing early outcomes but was not designed to capture the long-term durability of weight loss, and recurrent weight gain commonly occurs after 2–5 years [39]. Opportunistic later contacts partly mitigate this: about half the eligible cohort was seen beyond 24 months and %TWL at 3 to 10 years remained in the 18–27% range in both the registry and the hospital information system (Table 3, Fig. 3), records that verify each other against transcription error but share the same attendance-based selection, but these later observations come from small, self-selected subsets and cannot substitute for scheduled long-term assessment. Because these later observations come from different patients at each horizon, we also compared the same individuals over time. Among the 29 patients with both a 12-month and a five-year-or-later measurement, mean %TWL fell from 28.8% to 23.1%, a within-patient decline of 5.7 percentage points (95% CI 1.2 to 10.2; paired t-test p = 0.016, Wilcoxon signed-rank p = 0.013). The standard deviation of the individual changes was 11.9 percentage points and 22 of the 29 declined, so the mean summarises a heterogeneous set rather than a uniform trajectory, and the interval locates the size of the decline only between clinically negligible and clinically substantial. The late measurement was taken as each patient's mean %TWL across all visits at or beyond 60 months, at a median of 88 months after surgery (range 55 to 168). The estimate is not an artefact of that choice: using the first qualifying visit gives 5.4 percentage points, the last gives 5.7, and the lowest gives 7.9. Three of the 29 had a late weight recorded after a revisional or conversion procedure; excluding them gives a decline of 6.8 percentage points (95% CI 2.4 to 11.2), so the finding does not depend on post-revision weights. To test whether patients contributing late measurements were selected on early response (which would manufacture the decline), we compared the 50 eligible-but-non-attending patients against attenders: the two groups were indistinguishable at 12 months (28.8% vs. 28.7%; difference 0.1 points, 95% CI -4.2 to + 4.0), excluding an early-response advantage large enough to account for the 5.7-point decline. This rules out one selection mechanism but not others — a patient may attend years later precisely because weight has returned, against which a 12-month-anchored comparison has no power. Across the whole cohort, the seven late revisions reported above occurred at a median of 7.7 years and are consistent with regain-driven late attendance; six of these 29 patients underwent a second operation at a median of 7.9 years. The within-patient decline should therefore be read as an upper estimate of what the typical patient experiences rather than as an unbiased one. These 29 patients were also necessarily operated in the program's earliest years. Within that constraint they are informative: recurrent weight gain from nadir averaged 2.3 kg across the 175 patients with paired registry measurements, and 57 of them (32.6%) had regained nothing or continued

to lose, and micronutrient testing showed iron-related abnormalities (anaemia 20.7%, microcytosis 35.0%, low ferritin 16.4%) without any B12 or albumin deficiency — a pattern that warrants iron surveillance rather than reassurance. It should not, however, be read as iron deficiency alone: microcytosis was far more common than low ferritin, and in a northeastern Thai population thalassemia trait is a frequent competing cause that we did not screen for. The nutritional figures here and in the Results also rest on different denominators—120 patients with a late hematology panel versus 660 with any post-operative panel—and are not interchangeable (Table 4, Fig. 3). Diabetes recurrence presents a similar blind spot: relapse is documented in 15–35% of patients at 5 + years [31, 32]. The one long-term signal our data do provide is indirect: seven cohort members returned for late revisional surgery a median of 7.7 years after their primary operation (Supplementary Table S4). The registry did not record a specific indication for these reoperations, but their timing and procedure type are consistent with late recurrent weight gain; we therefore read them as a presumptive rather than confirmed signal that late regain occurs in this population. Prospective long-term follow-up, diabetes-recurrence surveillance, and sustained quality-of-life assessment nonetheless remain outside this study's observation window.

One pattern in these late data warrants comment for service delivery: glycaemic control was durable (47 of 53 diabetic patients with a late HbA1c were below 6.5%), whereas only 48.0% of hypertensive patients reached systolic < 130 mmHg and only 28.0% an LDL < 100 mg/dL. Ascertainment differs across these three — late HbA1c is ordered selectively, and blood pressure is recorded at nearly every visit — so bounding each against all condition-group patients seen beyond 24 months is more informative: glycaemic control falls to a worst case of 46.1% (from 88.7%, a 42.6-point range), and systolic control to 38.3% (from 48.0%), at which point the two are indistinguishable. The LDL row admits no comparable bound, since its 107 tested patients exceed the 99 dyslipidaemic patients seen beyond 24 months. We therefore claim only that lipid targets were least well attained of the three in the assessed figures, and that glycaemia and blood pressure cannot be separated once ascertainment is bounded; all three continue to require medical management this follow-up structure was not designed to deliver. External anchors are scarce but informative: the PCORnet cohort of 29,693 sleeve patients had mean %TWL of 25.2% at one year and 18.8% at five years [40], and a Polish multicentre series reported median %TWL of 30.1% at five years among patients whose diabetes remitted versus 23.0% among those whose diabetes did not [41]. Neither matches our timepoints (ours 3- and 10-year, theirs 1- and 5-year, the Polish medians stratified by remission), but our 27% at 3 years and 18–21% at 10 years are of the same order and show a downward trajectory — as much as mismatched timepoints permit, not evidence that our attenuation is typical.

Future Research Directions

Three priorities follow directly from the gaps identified above. First, prospective multi-center follow-up extending 5–10 years, with structured retention strategies, is needed to establish durability, diabetes-recurrence rates, and long-term complications, with less attrition bias than retrospective series. Second, systematic collection of baseline diabetes duration, treatment intensity, and lipid profiles would enable severity-stratified and predictive analyses that this dataset cannot support. Third, a dedicated cost-

effectiveness evaluation within the Thai healthcare system remains a natural extension but requires prospective economic data that this study does not have; no inference about cost-effectiveness or coverage policy can be drawn from the present results.

Conclusions

This single-center experience, drawn from one Asian institution and comprising 805 patients who underwent predominantly laparoscopic sleeve gastrectomy, indicates that laparoscopic sleeve gastrectomy yields weight-loss outcomes broadly comparable with international benchmarks. Glycemic and metabolic parameters also improved early, within the first months after surgery. Five patients developed early complications requiring reoperation — two sleeve leaks, one stenosis, and two functional obstructions — and all recovered fully, with no perioperative deaths. Nine cohort patients underwent chart-verified revisional surgery, with late revision occurring a median of 7.7 years after the primary operation, so the reoperative burden in this cohort accrued late rather than perioperatively. The seven late revisions each had documented recurrent weight gain from nadir (median 33.0 kg, 62.8% of the weight lost). However, those patients were identified because their recurrent weight gain was severe enough to warrant reoperation, and their weights were abstracted individually by chart review under a different nadir definition from the cohort analysis; their figures therefore describe the indication for surgery and cannot be read as evidence about how recurrent weight gain is distributed in the cohort, where the mean was 2.3 kg and a third of patients had regained nothing. Together, these observations support that reoperation in this population is a late event affecting a small minority, at 2.2 late revisions per 1,000 patient-years, rather than a general trajectory of the cohort. As a single-center series, these findings should be interpreted with caution regarding generalizability to other practice settings.

These findings support metabolic and bariatric surgery, including sleeve gastrectomy, as an approach that can yield an optimal clinical response and meaningful improvement in associated medical problems such as type 2 diabetes, hypertension, and dyslipidemia. Diabetes outcomes, drawn from directly measured laboratory and pharmacy records, were high among tested patients but rest on incomplete ascertainment, so we report them as assessed percentages bracketed by worst- and best-case bounds rather than as single figures. The width of those bounds, together with the decline in follow-up by 24 months, is the honest measure of how much remains uncertain about longer-term durability — a distinction that matters for how outcomes are compared across studies and that prospective follow-up will need to resolve.

Baseline BMI showed an inverse association with the likelihood of an optimal clinical response at 12 months in this cohort. Patients who completed 24-month follow-up also had significantly higher baseline BMI and were older than those lost to follow-up — a pattern that points to non-random attrition (survivor) effect and limits how far the longer-term results can be interpreted. Against this backdrop, the finding that Asian patients in this cohort achieved meaningful metabolic and weight-loss benefits at lower baseline BMI than typically reported in Western populations warrants cautious interpretation. It is best regarded as a hypothesis for future prospective, multicenter studies to test, not as evidence sufficient to

justify lowering BMI thresholds or otherwise revising bariatric surgery eligibility criteria or healthcare coverage policy at this time.

Abbreviations

LSG
laparoscopic sleeve gastrectomy
LSGPJB
laparoscopic sleeve gastrectomy with proximal jejunal bypass
LRYGB
laparoscopic Roux-en-Y gastric bypass
OAGB
one-anastomosis gastric bypass
%TWL
percentage total weight loss
%EWL
percentage excess weight loss
T2DM
type 2 diabetes mellitus
HbA1c
glycated hemoglobin
HTN
hypertension
DLP
dyslipidemia
OSA
obstructive sleep apnea
GERD
gastroesophageal reflux disease
BMI
body mass index
ADA
American Diabetes Association
TSMBS
Thai Society for Metabolic and Bariatric Surgery
GEE
generalized estimating equations
OR
odds ratio.

Declarations

Ethics approval and consent to participate. The Khon Kaen University Ethics Committee in Human Research (HE671120) approved the study on 27 February 2024, and it was conducted in accordance with the Declaration of Helsinki. Because this retrospective design involved anonymized data, the ethics committee waived the requirement for informed consent.

Consent for publication. Not applicable.

Availability of data and materials. The de-identified analytic dataset and the analysis code, including the self-contained diabetes-remission script with embedded reproducibility checks, are available from the corresponding author on reasonable request. Patient-level records cannot be shared publicly because they contain potentially identifying clinical information.

Competing interests. The authors declare no competing interests.

Funding. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Authors' contributions. Conceptualization: S.T., T.S., J.W., P.W., S.P., K.J. Data collection: J.W., T.K., V.P. Statistical analysis: S.T., T.S., J.W. Writing — original draft: S.T., T.S. Writing — review and editing: S.T., T.S., J.W. All authors read and approved the final manuscript.

Acknowledgements. The authors thank the staff of the bariatric surgery unit and the medical records department for assistance with data retrieval.

Use of AI-assisted technology. The authors used an AI-assisted analysis and drafting tool (Claude, Anthropic) to support statistical reanalysis (recomputation of per-visit denominators, linear mixed-effects modeling with categorical time, predictor and attrition analyses, and diabetes outcomes from laboratory and pharmacy records), table and figure generation, and language editing. No patient identifiers were shared with the tool; all inputs were de-identified. The analysis code and cleaned analytic dataset, including the self-contained diabetes-remission script with embedded reproducibility checks, are available as described in the Availability of data and materials statement, enabling reproduction of the reported values from the source data. The authors have reviewed all outputs and are responsible for verifying their accuracy and integrity; the AI tool is not, and cannot be, an author. We used Grammarly for English language editing.

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Figures

Participant flow diagram

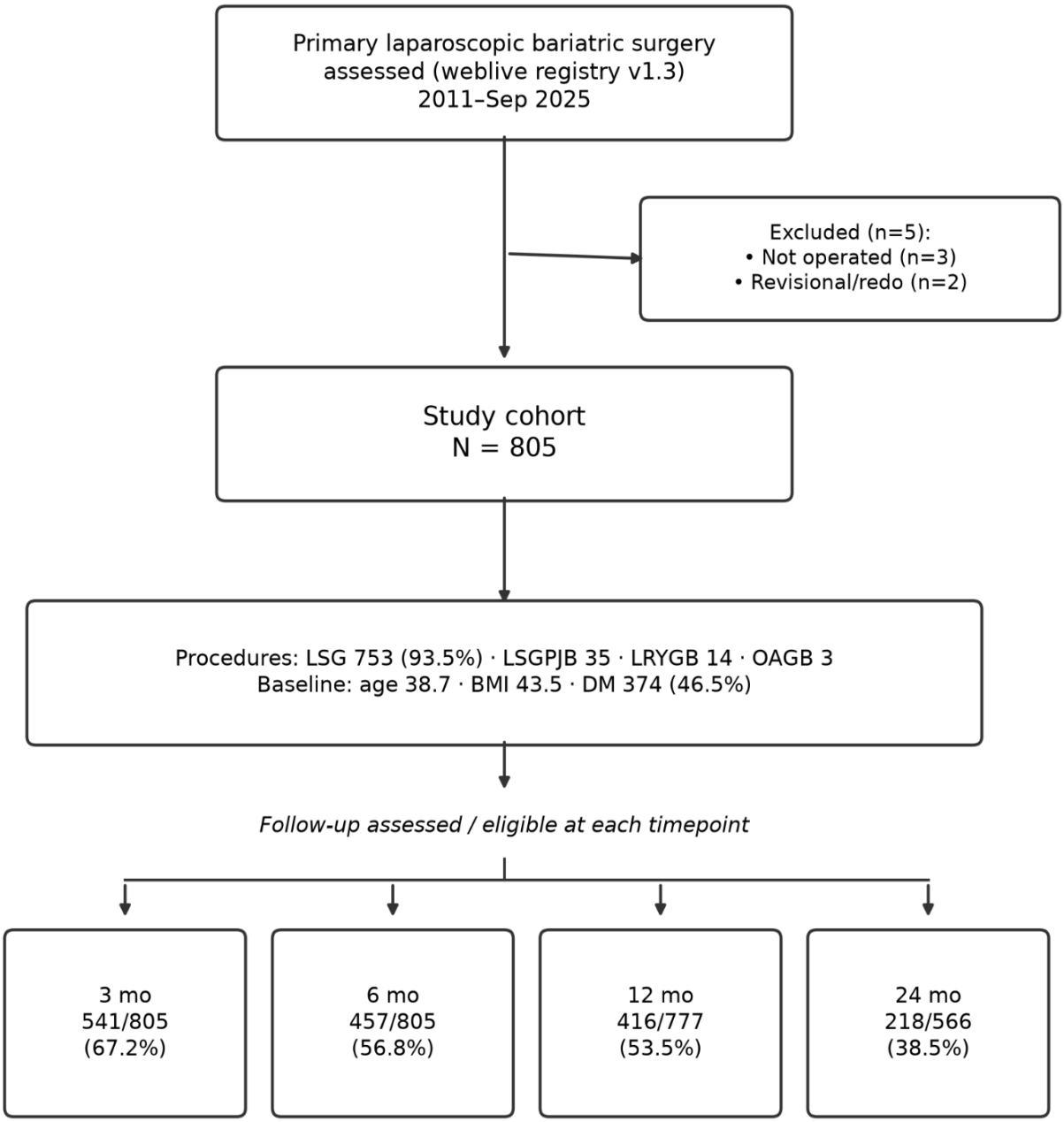

Figure 1

Participant flow and attrition. Numbers assessed at each postoperative timepoint (weight-loss denominators); associated-medical-problem outcomes use patients with the relevant baseline condition who were also assessed at each visit (see Table 5).

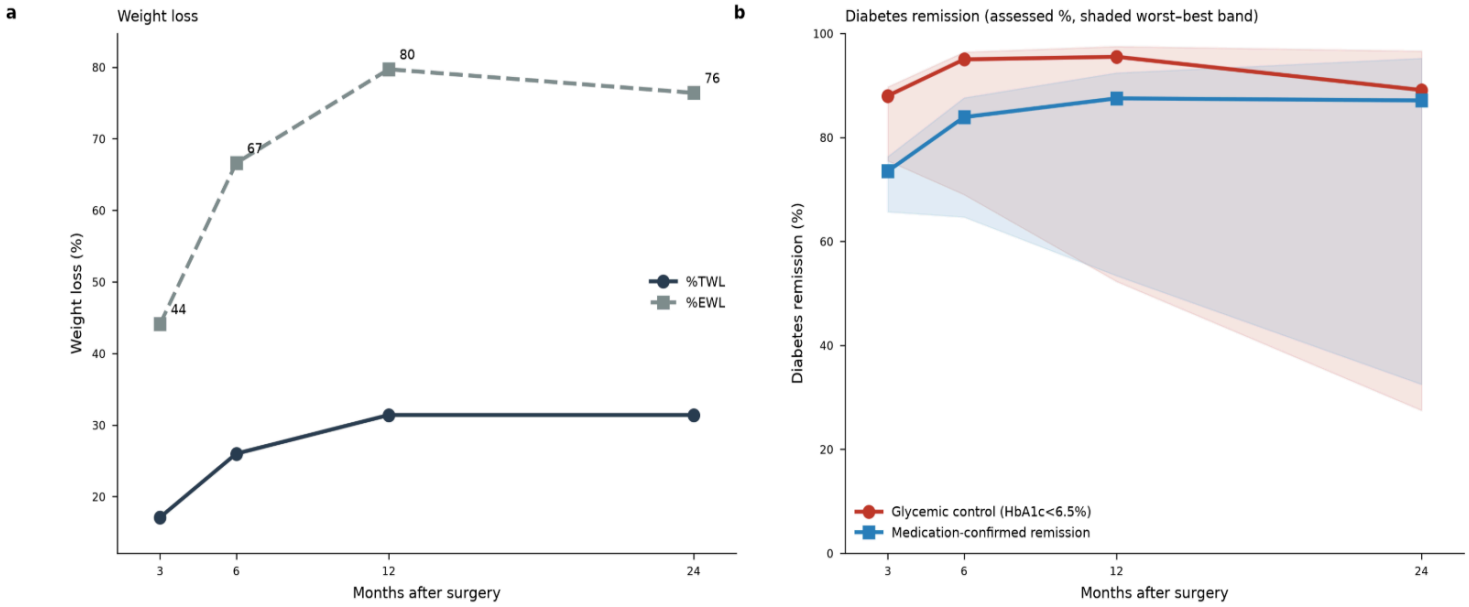

Figure 2

Longitudinal outcomes. (a) Mean %TWL and %EWL by timepoint. (b) Diabetes outcomes from Hospital Information System laboratory and pharmacy records: glycemic control (HbA1c <6.5%) and medication-confirmed remission (HbA1c <6.5% off all glucose-lowering agents, among patients with documented pre-operative pharmacotherapy). Solid lines are assessed percentages (remissions ÷ eligible diabetic patients with a window HbA1c); shaded bands span the worst-case (untested counted as non-remission) to best-case (untested counted as remission) bounds against all eligible diabetic patients. Concurrent fasting plasma glucose confirmed the HbA1c classification in 98–100% of dual-tested patients.

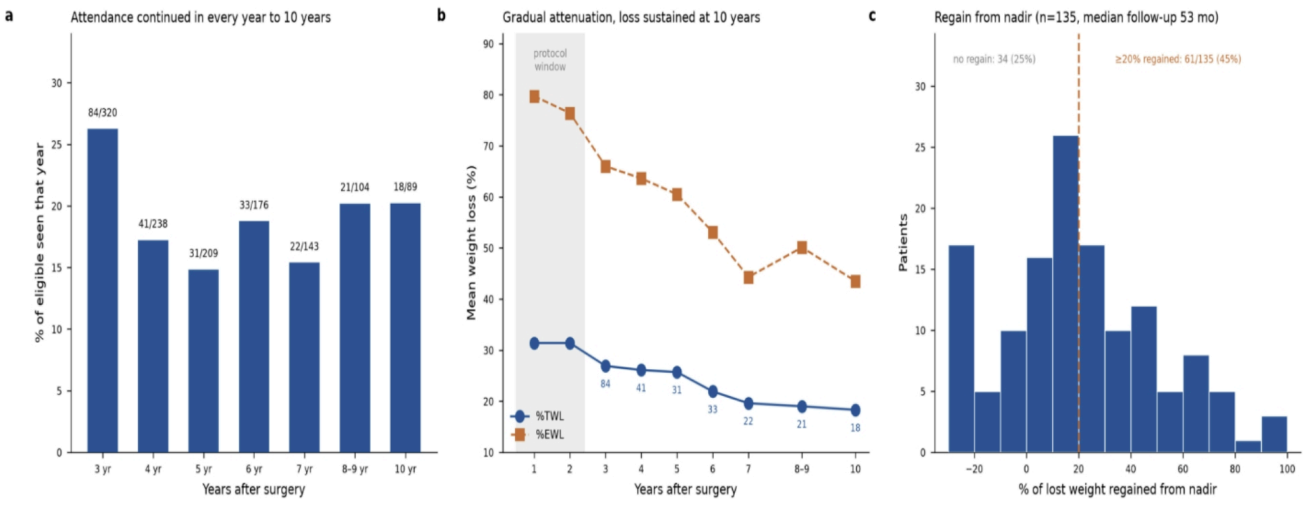

Figure 3

Outcomes beyond the 24-month protocol window. (a) Proportion of eligible patients with a recorded visit in each year after surgery, showing continued attendance to 10 years. (b) Mean %TWL and %EWL by year; the shaded band marks the protocol-defined window, and n per point is annotated. (c) Distribution of recurrent weight gain from nadir, expressed as the percentage of lost weight regained, among patients with both a nadir within 24 months and a later measurement. Later timepoints rest on small, self-selected subsets and are descriptive.