Obesity

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Pediatric Obesity

Bariatric Surgery in Adolescents With Obesity: Weight and Cardiometabolic Outcomes—Real-World Data

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ABSTRACT

Objective: This study evaluated changes in weight status and cardiometabolic parameters following bariatric surgery (BS) among adolescents with obesity using population-based real-world data.

Methods: This retrospective cohort study used electronic health records from Clalit Health Services, Israel. Adolescents aged 12–20 years who underwent BS between 2010 and 2024 were included. Demographic characteristics, socioeconomic position (SEP), anthropometry, blood pressure, and laboratory parameters were extracted. Longitudinal changes in BMI and cardiometabolic outcomes were analyzed using mixed-effects models adjusted for sex, ethnicity, SEP, age at BS, and baseline BMI. Median follow-up was 5.8 years.

Results: The cohort included 1035 adolescents (69.7% female; median age at surgery ~18.6 years), with sleeve gastrectomy as the predominant procedure. BMI declined significantly over time ($p_{time} < 0.001$), with maximal reduction at 1–3 years and sustained improvement thereafter. Males experienced greater BMI reduction than females ($p_{time \times sex} < 0.001$). BMI trajectories were similar across SEP and ethnic groups, while individuals with higher baseline BMI maintained higher BMI throughout follow-up ($p_{group} < 0.001$). Blood pressure and multiple metabolic parameters improved substantially, with durable long-term benefits and some sex-specific differences.

Conclusions: Adolescent BS was associated with sustained improvements in BMI and cardiometabolic risk factors in a large real-world cohort, supporting its long-term effectiveness across population subgroups.

1 | Introduction

The global prevalence of adolescent obesity has increased markedly over recent decades, despite extensive implementation of preventive strategies aimed at curbing this trend [1]. Obesity in adolescence is associated with a broad spectrum of chronic health conditions, including impaired glucose tolerance (IGT), type 2 diabetes (T2D), hypertension, dyslipidemia, obstructive sleep apnea (OSA), metabolic dysfunction-associated steatotic liver disease (MASLD), and pseudotumor cerebri (PTC) [2]. Beyond its physical health implications, adolescent obesity is also linked to substantial psychological morbidity, low self-esteem, and social stigmatization [3].

Although lifestyle modification remains the cornerstone of treatment of adolescent obesity, its effectiveness is often limited, typically resulting in only modest weight reduction among adolescents with obesity [4]. Pharmacotherapy, considered a secondary treatment approach, is generally indicated for individuals aged 10 years and older with severe obesity who fail to achieve adequate weight loss through lifestyle interventions. This approach is particularly relevant for patients

Study Importance

- Bariatric surgery has emerged as an effective treatment for severe obesity in adolescents, yet data on medium- and long-term outcomes, particularly from real-world settings, remain limited.
- In this large, national real-world cohort, adolescent bariatric surgery was associated with substantial and durable improvements in BMI and multiple cardiometabolic risk factors extending into long-term follow-up. BMI trajectories were similar across socioeconomic position and ethnic groups.
- Comparable benefits across socioeconomic position and ethnic groups support equitable access to BS, while observed sex-specific trajectories highlight the need for tailored long-term monitoring after surgery.

presenting with obesity-related comorbidities such as IGT, insulin resistance, steatohepatitis, metabolic syndrome, or a strong family history of any of the above cardiometabolic diseases [5].

Bariatric surgery (BS) has emerged as an additional and increasingly accepted treatment option for adolescents with severe obesity [6–8]. The two procedures most commonly performed in this age group are sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB). These techniques differ in their degree of excess weight loss, impact on quality of life, and associated complication profiles.

BS in adolescents is typically offered within structured, multidisciplinary obesity programs conducted in specialized centers to optimize clinical outcomes and minimize potential adverse effects.

Adolescence represents a critical developmental stage encompassing physical growth, pubertal progression, cognitive maturation, and psychosocial identity formation. These factors collectively increase vulnerability to treatment attrition and nonadherence, potentially influencing long-term outcomes [9].

Randomized controlled trials comparing BS with non-surgical treatment in adolescents have included relatively small sample sizes. O'Brien et al. [10] reported that among adolescents with obesity, laparoscopic adjustable gastric banding ($n = 24$) compared with lifestyle intervention ($n = 18$) resulted after 2 years in a significantly greater proportion of participants achieving a ≥ 50% reduction in excess weight, adjusted for age, along with improvements in health outcomes and quality of life. Similarly, Järvholm et al. [11] reported outcomes of BS in adolescents, predominantly RYGB ($n = 24$), compared with intensive non-surgical treatment ($n = 23$), which began with an 8-week low-calorie diet. After 2 years, the mean change in body mass index (BMI) was −12.6 kg/m^2 in the surgical group versus −0.2 kg/m^2 in the non-surgical group ($p < 0.0001$).

While the short-term effects of BS in adolescents have been well documented, evidence regarding medium- and long-term outcomes remains limited. In adult populations, the need for reoperation and the emergence of metabolic complications often occur several years post surgery. However, only a few studies have examined comparable long-term results in adolescents [12–17].

The aim of this study was to evaluate the short-, medium-, and long-term outcomes of BS in adolescents with obesity using real-world data. Specifically, the study sought to examine postoperative changes in weight status and cardiometabolic parameters, thereby providing insight into the sustained efficacy of BS in this population.

2 | Methods

2.1 | Study Design and Population

This observational, population-based retrospective cohort study included individuals younger than 35 years at data retrieval (June 2025) who underwent BS for adolescent obesity between the ages of 10 and 20 years, from January 2010 through June 2024. Individuals with implausible BMI measurements (BMI > 100 or < 25 kg/m^2 before surgery) or missing documented BMI data before BS were excluded.

A secondary analysis included participants with available postoperative BMI data at least 1 month following BS.

2.2 | Clinical Criteria for Adolescent Bariatric Surgery (BS) in Israel

Under Israel's National Health Insurance Law, universal health coverage is provided to all citizens and includes coverage for BS. In Israel, BS in adolescents is performed within multidisciplinary obesity management programs and requires assessment by a specialized multidisciplinary team. The recommended minimum age for surgery is 13 years with confirmation of near-complete linear growth, defined by a bone age > 15 years in boys and > 13 years in girls. Both adolescent assent and parental or guardian consent are mandatory.

Prior to August 2017, eligibility required BMI > 50 kg/m^2 with mild obesity-related complications, or BMI > 40 kg/m^2 with severe complications, including T2D, severe OSA, PTC, or metabolic dysfunction-associated steatohepatitis, or in those older than 16 years BMI > 45 kg/m^2 with mild obesity-related complications. Since August 2017, criteria have been modified to BMI > 40 kg/m^2 with mild complications or BMI > 35 kg/m^2 with severe complications. Adolescents under 16 years require approval for BS by a special exceptions committee.

Prior to surgical intervention, careful assessment of treatment adherence and psychosocial readiness is essential to mitigate the risk of nutritional deficiencies and other postoperative complications. Candidates and their caregivers participated in a preoperative preparation program encompassing lifestyle modification, nutritional counseling, and physical activity education, guided by a multidisciplinary team including a dietitian and psychosocial professionals. Education focused on potential benefits, risks, side effects, behavioral changes, and the lifelong requirement for medical follow-up after surgery.

2.3 | Data Source

This study was conducted using the electronic database of Clalit Health Services (CHS), an Israeli payer-provider integrated health care system that serves about 54% of the Israeli population. The database is accumulated by continuous real-time input from physicians and health service providers, and it includes patient demographic, socioeconomic, and clinical characteristics, hospital discharge and outpatient clinic diagnoses, laboratory test results, medical treatments, and medication dispensation information. Data were extracted from CHS using the Clalit Research Data sharing platform powered by MDClone (https://www.mdclone.com).

2.4 | Data Collection

Demographic and clinical data were retrieved from electronic medical records, including sex, ethnicity, age, and socioeconomic position (SEP). Clinical parameters included anthropometric measurements (height, weight, BMI), blood pressure, laboratory measurements, and documentation of obesity-related comorbidities (dyslipidemia, T2D, IGT, hypertension, OSA, MASLD, PTC, and polycystic ovary syndrome [PCOS] in females) based on medical diagnoses according to the International Statistical Classification of Diseases and Related Health Problems (ICD)-10. Medication data included the use of antiobesity agents and drugs prescribed for obesity-related comorbidities.

SEP was determined using the Israel Central Bureau of Statistics index, which classifies statistical areas based on 14 variables reflecting demographics, education, living standards, and employment. SEP scores range from 1 (lowest) to 10 (highest) [18]. For analysis, SEP clusters were categorized as low (1–4), medium (5, 6), and high (7–10).

2.5 | Outcomes

Weight loss outcomes were expressed as changes in absolute BMI (calculated as weight [kg] divided by height [m^2]) from baseline. Baseline BMI (prior to BS) was categorized into tertiles: BMI < 40.5 kg/m^2, BMI 40.5–45.4 kg/m^2, and BMI > 45.4 kg/m^2. Blood pressure measurements obtained during follow-up included systolic (SBP) and diastolic (DBP) values (mmHg).

Laboratory measurements obtained during follow-up included fasting plasma glucose (FPG), glycated hemoglobin (HbA1c), lipid profile, uric acid, and liver enzyme levels.

The prevalence of comorbidities before BS was determined using two complementary approaches. First, documented diagnoses extracted from electronic medical records according to the ICD-10. Second, objective clinical measurements obtained within 1 year before surgery were assessed. These included blood pressure and laboratory parameters, applying predefined cardiometabolic cutoff values for hypertension, dyslipidemia, impaired fasting glucose/prediabetes, and T2D.

Cardiometabolic outcomes were evaluated both as absolute changes from baseline and as changes in the prevalence of comorbidities from baseline (pre-BS) to the most recent documented follow-up visit.

As the majority of patients (97%) were ≥ 16 years at the time of BS, IDF cutoff values were applied for the definition of cardiometabolic comorbidities [19]. Hypertension was defined as SBP ≥ 130 mmHg or DBP ≥ 85 mmHg. Dyslipidemia was defined as triglycerides ≥ 150 mg/dL or LDL cholesterol ≥ 130 mg/dL or HDL cholesterol < 40 mg/dL in males and < 50 mg/dL in females. Impaired fasting glucose was defined as FPG > 100 mg/dL, pre-diabetes as 6.5% > HbA1c > 5.7%, and diabetes as FPG ≥ 126 mg/dL or HbA1c level ≥ 6.5% [19]. Abnormal liver function was defined as GPT > 40 U/L or GGT > 40 U/L. Hyperuricemia was defined as serum uric acid levels > 6.0 mg/dL in females and > 7.2 mg/dL in males.

2.6 | Ethics

The study was approved by the Institutional Ethics Committee of Rabin Medical Center (approval no. RMC-0360-25) and conducted in accordance with the Declaration of Helsinki. The requirement for written informed consent was waived due to the retrospective and anonymized nature of the data.

2.7 | Statistical Analysis

Statistical analyses were performed using SPSS software, version 29 (SPSS Inc., Chicago, Illinois). Data are presented as *n* (%) or median (interquartile range [IQR] for skewed distributions).

Comparisons between sexes were conducted using Pearson's chi-square tests for categorical variables or Mann–Whitney *U* tests for numerical variables.

Mixed-model repeated-measures analysis was conducted to evaluate the changes in BMI and in blood pressure measurements and laboratory results. Mixed-effects models were estimated using maximum likelihood, which incorporates all available repeated measurements without requiring complete follow-up. This approach provides valid inference under the missing at random (MAR) assumption, whereby the probability of missingness may depend on observed covariates included in the model but not on unobserved outcome values. The data are expressed as estimated marginal means and standard errors. All models were adjusted for the following possible confounders, excluding the group effect variable of each specific model: sex; SEP category; ethnicity; age at BS; and baseline BMI.

The related-samples McNemar test was used to explore the change between pre-BS and post-BS rates of obesity-related comorbidities and use of medications for obesity and obesity-related comorbidities.

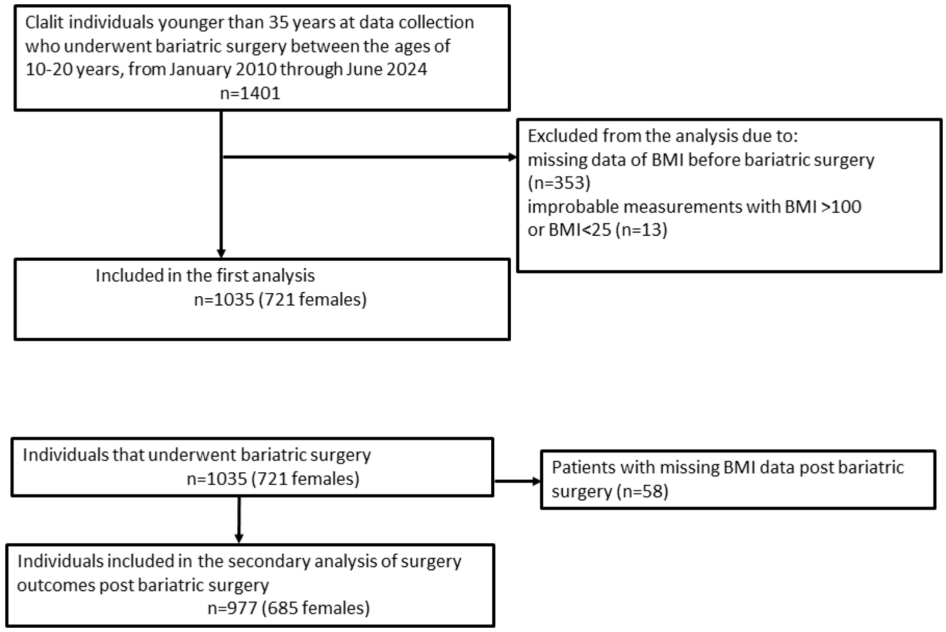

FIGURE 1 | Flowchart of patients who underwent BS for adolescent obesity included in the initial analysis of the study cohort. Participants with available postoperative BMI data at least 1 month following BS included in the secondary analysis.

3 | Results

3.1 | Sample Characteristics

During the study period, 1401 adolescents with obesity aged 12–20 years underwent BS. Following the exclusion of individuals with missing preoperative BMI data ($n = 353$) and those with implausible BMI values ($n = 13$), the final analytical cohort consisted of 1035 patients (Figure 1). Baseline characteristics of this study cohort are presented in Table 1.

The annual number of bariatric procedures increased steadily over the study period, from 16 operations in 2010 to 121 in 2023 ($p < 0.001$) (Figure 2), except for a temporary decline in BS volume in 2020.

The majority of patients were female (69.7%) and of Jewish origin (66.5%). The majority belonged to the medium (62%) or low (30.4%) SEP categories. The median age at surgery was 18.5 years for males and 18.7 years for females. Twenty-eight patients were younger than 16 years at the time of BS; of them, 3 patients were younger than 13 years, with the youngest being 12 years old. Among those with available data on type of bariatric procedure ($n = 454$), SG was the predominant procedure (84.8%), and 17 patients underwent a second bariatric reoperation. Median preoperative BMI was 44.2 kg/m^2 in males and 42.2 kg/m^2 in females. The prevalence of most obesity-related comorbidities was significantly higher in males compared with females.

Preoperative use of obesity medications (one or more) was recorded in 16 (5.1%) males and 39 (5.4%) females ($p = 0.836$), while pharmacotherapy for obesity-related comorbidities of one medication or more was documented in 49 (15.6%) males and 69 (9.6%) females ($p = 0.005$).

Of the total cohort, preoperative BMI data (< 1 year before surgery) and at least one postoperative BMI measurement ≥ 1 month after BS were available for 94.4% of participants ($n = 977$, 70.1% females) (Figure 1). The median duration of follow-up was 5.8 years (IQR 3.25–8.51 years). These individuals were included in the secondary analysis, which examined longitudinal changes in BMI, blood pressure, and laboratory parameters, including FPG, HbA1c, lipid profiles, uric acid, and liver enzymes, throughout postoperative follow-up.

3.2 | Weight and Cardiometabolic Outcomes

3.2.1 | BMI Changes Post BS

Table 2 presents the longitudinal trajectories of BMI following BS, stratified by sex, SEP, ethnicity, age at BS, baseline BMI tertile, and type of bariatric procedure. Across all subgroups, BMI decreased significantly over the follow-up period, with the most pronounced reductions occurring between 1 and 3 years postoperatively ($p_{time} < 0.001$ for all subgroup analyses).

As shown in Figure 3, males had higher baseline BMI values and experienced greater postoperative BMI reductions compared with females ($p_{time \times group} < 0.001$).

When examining SEP categories, adolescents in the low-SEP category exhibited significantly higher BMI at baseline and throughout follow-up compared with those in the high-SEP category ($p_{group} = 0.002$). Nevertheless, the pattern of BMI decline after BS was similar across SEP groups ($p_{time \times group} = 0.487$).

TABLE 1 | Baseline characteristics of the male and female adolescents before bariatric surgery.

	Males, $n=314$ (30.3%)	Females, $n=721$ (69.7%)	p
Ethnicity, n (%)			
Jews	230 (73.2%)	458 (63.5%)	0.002
Arabs	84 (26.8%)	263 (36.5%)	
SEP level, n (%)			
Low	93 (32.2%)	196 (29.7%)	0.145
Medium	168 (58.1%)	421 (63.7%)	
High	28 (9.7%)	44 (6.7%)	
Age at data collection (years)			
Median (IQR)	24.5 (22.0, 27.1)	24.0 (21.7, 27.0)	0.232
Age at bariatric surgery (years)			
Median (IQR)	18.5 (17.8, 19.2)	18.7 (18.2, 19.3)	0.003
Duration of follow-up since bariatric surgery (years)			
Median (IQR)	6.1 (3.4, 8.9)	5.6 (3.2, 8.2)	0.082
Type of bariatric procedure, n (%)[a]			
Sleeve gastrectomy	121 (85.8%)	264 (84.3%)	0.804
Mini gastric bypass	6 (4.3%)	18 (5.8%)	
Roux-en-Y gastric bypass	14 (9.9%)	31 (9.9%)	
BMI before surgery			
Median (IQR)	44.2 (40.4, 49.1)	42.2 (39.2, 46.2)	<0.001
Obesity-related comorbidities before bariatric surgery, n (%)			
Hypertension			
Documented diagnosis[b]	51 (16.2%)	49 (6.8%)	<0.001
According to measurements[c]	90 (28.7%)	98 (13.6%)	<0.001
IFG			
Documented diagnosis[b]	25 (8.0%)	35 (4.9%)	0.049
According to measurements[c]	67 (21.3%)	142 (19.7%)	0.545
Type 2 diabetes			
Documented diagnosis[b]	14 (4.5%)	20 (2.8%)	0.162
According to measurements[c]	24 (7.6%)	31 (4.3%)	0.027
Dyslipidemia			
Documented diagnosis[b]	63 (20.1%)	77 (10.7%)	<0.001
According to measurements[c]	201 (64.0%)	546 (75.7%)	<0.001
OSA[b]	60 (19.1%)	73 (10.1%)	<0.001
NAFLD[b]	71 (22.6%)	117 (16.2%)	0.014
PTC[b]	3 (1.0%)	14 (1.9%)	0.251
PCO[b]		65 (9%)	
Obesity medications			
Orlistat	1 (0.3%)	9 (1.2%)	0.298

(Continues)

TABLE 1 | (Continued)

	Males, $n = 314$ (30.3%)	Females, $n = 721$ (69.7%)	p
GLP-1 receptor agonist	15 (4.8%)	31 (4.3%)	0.732
Medications for glycemic control[d]			
Metformin	36 (11.5%)	53 (7.4%)	0.030
Insulin	6 (1.9%)	6 (0.8%)	0.202
Antihypertensive medications[d]			
ACE inhibitors	16 (5.1%)	11 (1.5%)	< 0.001
ARB	2 (0.6%)	2 (0.3%)	0.589
Diuretics	7 (2.2%)	4 (0.6%)	0.022
Lipid-lowering medications			
Statins	7 (2.2%)	6 (0.8%)	0.074

Note: The data are presented as n (%) or median (IQR, skewed distribution). p represents comparison between sexes using Pearson's chi-square tests for categorial variables or Mann–Whitney U tests for numerical variables.
Abbreviations: ACE, angiotensin-converting enzyme; ARB, angiotensin receptor blocker; IFG, impaired fasting glucose; NAFLD, nonalcoholic fatty liver disease; OSA, obstructive sleep apnea; PCO, polycystic ovary; PTC, pseudotumor cerebri; SEP, socioeconomic position.
[a]Data about the type of bariatric procedure were documented only in 454 (43.9%) of the patients.
[b]Obesity-related comorbidities before surgery based on recorded diagnosis in the medical electronic file according to the International Statistical Classification of Diseases and Related Health Problems (ICD)-10.
[c]Obesity-related comorbidities before surgery based on the most recent measurement (< 1 year) before bariatric surgery. Hypertension was defined as systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg. Dyslipidemia was defined as triglycerides ≥ 150 mg/dL or LDL cholesterol ≥ 130 mg/dL or HDL cholesterol < 40 mg/dL in males and < 50 mg/dL in females. Impaired fasting glucose was defined as FPG > 100 mg/dL, prediabetes as 5.7% < HbA1c < 6.5%, and diabetes as FPG ≥ 126 mg/dL or HbA1c level ≥ 6.5%.
[d]Few patients were treated with a combination of medications for glycemic control or a combination of antihypertensive medications.

Both Jewish and Arab adolescents demonstrated significant reductions in BMI after surgery, with no meaningful differences detected between the ethnic groups (both $p_{group} > 0.05$ and $p_{time\times group} > 0.05$).

Across all baseline BMI tertiles, BMI declined significantly following BS ($p < 0.001$). The smallest absolute reduction occurred among adolescents in the lowest tertile ($p_{time\times group} < 0.001$). However, individuals in the highest baseline BMI tertile consistently maintained the highest BMI values throughout follow-up ($p_{group} < 0.001$) (Figure 4).

Across all BS procedures, BMI decreased significantly following surgery ($p < 0.001$). The greatest absolute reduction was observed among participants who underwent RYGB ($p_{time\times group} < 0.001$). Moreover, individuals in the RYGB group consistently maintained lower BMI values throughout the follow-up period ($p_{group} < 0.001$).

3.2.2 | Blood Pressure Changes Post BS

Longitudinal changes in systolic (SBP) and diastolic blood pressure (DBP) analyses by sex were evaluated using models adjusted for age at BS, ethnicity, SEP, and preoperative BMI (Table 3).

For SBP, significant sex differences were observed: males had significantly higher mean SBP at every time point compared with females ($p_{sex} < 0.001$). Although both sexes exhibited a similar trajectory, an initial decline followed by a modest increase, SBP levels at long-term follow-up remained below preoperative baseline values in both groups ($p_{time\times sex} = 0.545$). In contrast, DBP demonstrated a distinct sex-specific trajectory. Mean DBP across all assessments was significantly higher in males than in females ($p_{sex} < 0.001$). Among males, DBP initially decreased but exceeded baseline levels during long-term follow-up. In contrast, females showed an initial decline, with DBP remaining below baseline levels at later follow-up ($p_{time\times sex} = 0.036$).

3.2.3 | Laboratory Parameters Changes Post BS

Longitudinal trajectories of laboratory parameters following BS analyses by sex are presented in Table 3. All models were adjusted for age at BS, ethnic origin, SEP, and preoperative BMI.

Mean FPG levels were significantly higher in males beginning 2 years after BS ($p_{sex} < 0.001$). Glucose levels changed significantly over time in both sexes ($p_{time} < 0.001$). Although an initial decline was observed in both groups reaching a nadir at 0.5–1 year postoperatively, subsequent patterns diverged: in females, glucose levels remained below preoperative baseline values at long-term follow-up, whereas in males, values gradually returned toward baseline ($p_{time\times sex} < 0.001$).

HbA1c levels decreased in both sexes, reaching their lowest point within 1–2 years after BS, followed by a gradual rise toward baseline during extended follow-up ($p_{time} < 0.001$). No significant sex-related differences were observed.

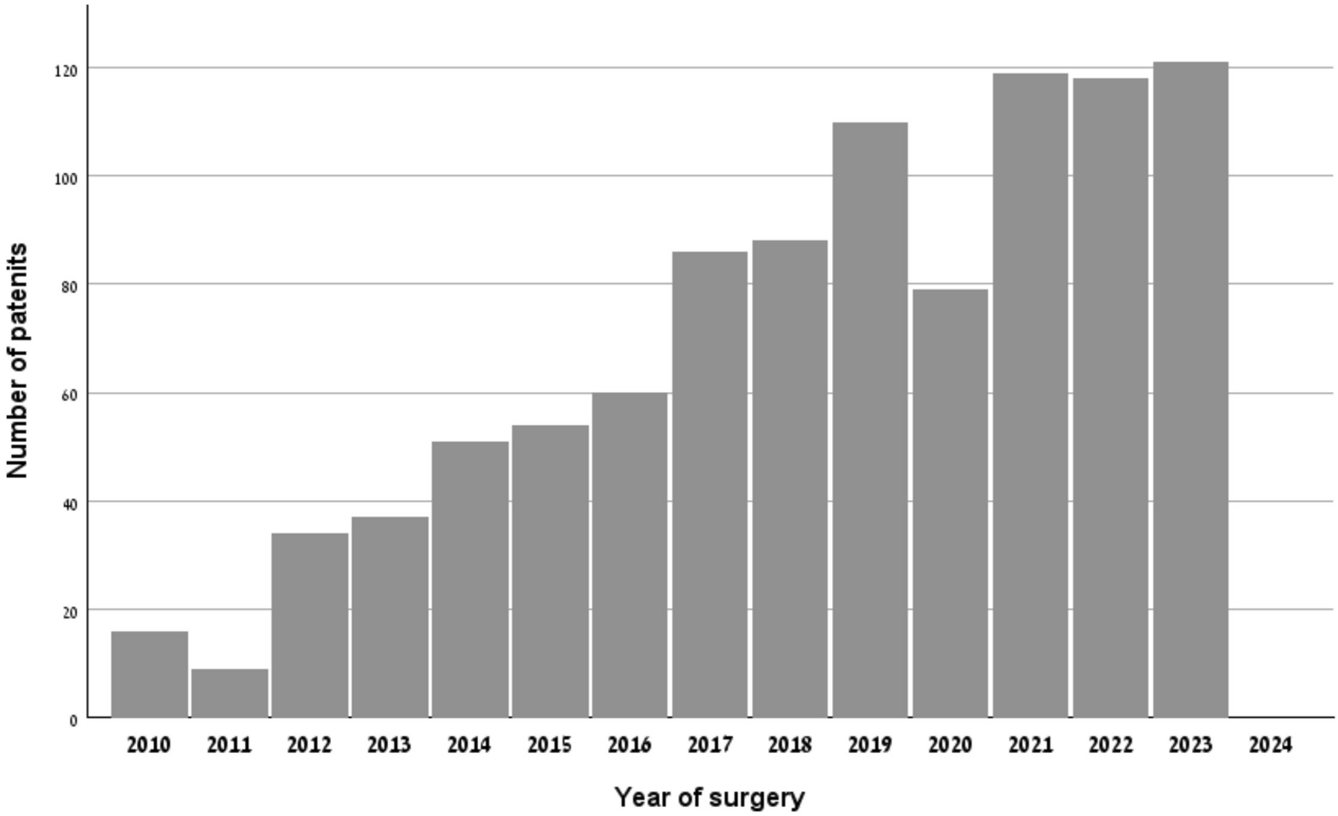

FIGURE 2 | The annual number of bariatric procedures.

Triglyceride levels also demonstrated significant temporal changes in both sexes ($p_{time} < 0.001$), remaining below preoperative baseline values across the entire follow-up period. However, trajectories differed significantly by sex, with males showing a more pronounced long-term reduction than females ($p_{time \times sex} < 0.001$).

HDL cholesterol levels were consistently higher in females across all time points, and LDL cholesterol levels were higher in females at most assessments ($p_{sex} < 0.001$). LDL cholesterol exhibited an initial decline followed by a modest increase in both sexes; however, long-term levels remained below baseline only among males, while in females levels returned to preoperative values ($p_{time \times sex} = 0.077$). HDL cholesterol trajectories were similar in both sexes, characterized by a slight early increase followed by a modest decline, with long-term levels remaining above baseline for both males and females ($p_{time \times sex} = 0.102$).

GPT and GGT levels were consistently lower in females at all time points ($p_{sex} < 0.001$). GPT and GGT levels changed significantly over time in both sexes ($p_{time} < 0.001$). Both males and females exhibited an initial decline postoperatively, and long-term GPT and GGT levels remained below preoperative baseline values. However, in females, the decline continued for a longer period until reaching the nadir ($p_{time \times sex} < 0.001$ for GPT and $p_{time \times sex} = 0.014$ for GGT).

Uric acid levels were consistently lower in females at all time points ($p_{sex} < 0.001$). Both males and females exhibited similar significant changes over time ($p_{time} < 0.001$), characterized by initial postoperative decline and long-term uric acid levels remaining below preoperative baseline values ($p_{time \times sex} = 0.103$).

3.2.4 | Changes in Obesity-Related Cardiometabolic Outcomes and the Use of Medications for Obesity and Obesity-Related Conditions Following BS

Table 4 summarizes changes in obesity-related cardiometabolic outcomes, as assessed by blood pressure and laboratory parameters, as well as medication use following BS. The prevalence of most obesity-related comorbidities was significantly higher in males than in females in both the preoperative (with the exception of dyslipidemia) and postoperative periods (with the exception of dyslipidemia and T2D). Nevertheless, a significant reduction in the prevalence of obesity-related comorbidities was observed after BS in both sexes.

In addition, BS was associated with a marked decrease in the use of medications for glycemic control in both males and females. The use of antihypertensive medications was lower in females pre BS and also declined postoperatively, reaching statistical significance only in males ($p = 0.049$). No change in the rates of statin use was demonstrated following surgery in both sexes. In contrast, the use of medications specifically indicated for obesity management, predominantly glucagon-like peptide-1 (GLP-1) receptor agonists, increased significantly among females ($p < 0.001$).

TABLE 2 | Changes in BMI measurements after bariatric surgery analyzed by sex, SEP category, ethnicity, and baseline BMI tertile.

Group effect variable	<1 year before surgery	0–0.5 year	0.5–1 year	1–2 years	2–3 years	3–4 years	4–5 years	5–6 years	6–7 years	7–8 years	8–9 years	9–10 years	10–15 years	p_{time}	p_{group}	$p_{time \times group}$
Sex																
Males	44.7^{a} (0.43)	36.7^{b} (0.58)	30.9^{cde} (0.69)	29.7^{de} (0.60)	29.1^{e} (0.71)	29.7^{de} (0.77)	29.1^{e} (0.71)	31.7^{cd} (0.93)	33.0^{bc} (1.01)	33.2^{bc} (1.12)	30.2^{cde} (1.39)	34.9^{b} (1.66)	31.4^{cde} (1.26)	< 0.001	< 0.001	< 0.001
Females	42.7^{a} (0.25)	35.8^{b} (0.34)	31.5^{d} (0.38)	30.0^{e} (0.33)	30.3^{e} (0.37)	30.9^{de} (0.38)	31.3^{cd} (0.41)	32.3^{c} (0.48)	33.3^{c} (0.54)	34.8^{bc} (0.65)	33.3^{bc} (0.73)	34.9^{b} (0.87)	35.0^{b} (0.72)	< 0.001		
SEP level																
Low	43.9^{a} (0.36)	36.1^{b} (0.53)	32.0^{c} (0.62)	30.1^{d} (0.47)	29.8^{d} (0.56)	32.1^{c} (0.65)	31.5^{c} (0.66)	33.3^{bc} (0.91)	34.2^{b} (0.99)	34.9^{b} (1.10)	34.2^{b} (1.45)	36.6^{b} (1.56)	34.0^{bc} (1.27)	< 0.001	0.002	0.487
Medium	43.0^{a} (0.27)	35.8^{b} (0.36)	31.0^{e} (0.41)	29.6^{f} (0.36)	29.9^{ef} (0.43)	29.8^{f} (0.42)	30.1^{e} (0.44)	31.6^{d} (0.51)	32.8^{bcd} (0.58)	34.1^{bc} (0.67)	32.2^{bcd} (0.77)	34.3^{b} (0.97)	34.2^{b} (0.77)	< 0.001		
High	41.1^{a} (1.05)	35.5^{b} (1.25)	28.5^{c} (1.33)	29.3^{c} (1.30)	29.8^{c} (1.35)	30.2^{c} (1.48)	29.6^{c} (1.41)	30.0^{c} (1.68)	30.1^{c} (1.82)	31.2^{bc} (2.62)	27.6^{c} (2.25)	31.5^{bc} (2.42)	28.6^{c} (2.08)	< 0.001		
Ethnicity																
Jews	43.3^{a} (0.27)	36.1^{b} (0.36)	30.8^{d} (0.41)	29.5^{d} (0.37)	29.8^{d} (0.41)	30.0^{d} (0.42)	30.4^{d} (0.42)	32.1^{cd} (0.50)	33.2^{bc} (0.58)	34.4^{b} (0.67)	32.5^{bc} (0.75)	35.6^{b} (0.95)	34.4^{b} (0.70)	< 0.001	0.481	0.098
Arabs	42.6^{a} (0.63)	35.3^{b} (0.72)	31.7^{c} (0.76)	30.0^{d} (0.68)	29.7^{d} (0.75)	31.3^{cd} (0.78)	30.6^{cd} (0.82)	31.2^{cd} (0.98)	32.2^{c} (1.01)	33.0^{c} (1.14)	31.7^{c} (1.41)	32.7^{c} (1.44)	31.0^{c} (1.46)	< 0.001		
Baseline BMI tertile																
1st (BMI < 40.5)	36.5^{a} (0.34)	31.4^{b} (0.47)	28.2^{c} (0.56)	28.3^{c} (0.47)	28.4^{c} (0.52)	28.6^{c} (0.56)	28.8^{c} (0.59)	30.2^{bc} (0.64)	29.8^{bc} (0.71)	32.4^{b} (0.89)	29.0^{c} (0.94)	31.0^{bc} (1.08)	30.7^{bc} (0.94)	< 0.001	< 0.001	< 0.001
2nd (BMI 40.5–45.4)	42.5^{a} (0.33)	35.1^{b} (0.44)	30.0^{cd} (0.50)	28.9^{de} (0.44)	28.6^{e} (0.51)	29.6^{de} (0.54)	28.8^{de} (0.54)	29.3^{d} (0.65)	31.5^{c} (0.71)	31.5^{c} (0.85)	29.7^{cd} (0.95)	33.8^{b} (1.21)	31.5^{c} (0.88)	< 0.001		
3rd (BMI > 45.4)	50.6^{a} (0.48)	41.4^{b} (0.63)	35.6^{cd} (0.69)	32.4^{e} (0.61)	32.8^{e} (0.72)	33.1^{de} (0.72)	33.8^{de} (0.72)	35.7^{cd} (0.97)	37.5^{cd} (1.16)	38.4^{c} (1.22)	38.8^{bc} (1.68)	38.0^{c} (1.97)	38.3^{c} (1.54)	< 0.001		
Type of surgery*																
Sleeve gastrectomy	43.9^{a} (0.32)	36.1^{b} (0.44)	31.5^{c} (0.49)	30.6^{d} (0.43)	30.8^{d} (0.48)	32.3^{c} (0.49)	31.9^{c} (0.52)	33.6^{bc} (0.61)	33.8^{bc} (0.66)	34.7^{bc} (0.78)	33.2 (0.89)	35.0^{bc} (1.08)	34.8^{bc} (0.92)	< 0.001	< 0.001	< 0.001
Mini gastric bypass	46.3^{a} (1.4)	40.6^{b} (1.9)	38.0^{bc} (2.4)	33.0^{c} (1.7)	32.8^{c} (2.6)	36.3^{bc} (3.9)	36.7^{bc} (6.8)	28.3^{c} (4.9)	29.2^{c} (4.9)	29.2^{c} (6.8)	28.2^{c} (6.8)	40.9^{abc} (6.6)	28.6^{c} (4.0)	< 0.001		
Roux-en-Y gastric bypass	45.0^{a} (0.64)	37.7^{b} (0.98)	31.8^{c} (1.2)	28.2^{cd} (0.78)	27.8^{cd} (1.01)	27.1^{cd} (1.58)	29.2^{cd} (1.40)	26.4^{cd} (2.90)	25.3^{d} (2.94)	31.7^{c} (2.93)	31.0^{c} (4.2)	30.3^{cd} (4.1)	28.5^{cd} (2.4)	< 0.001		

Note: Mixed-model repeated-measures analysis. All models were adjusted for the following possible confounders, excluding the group effect variable of each specific model: sex; SEP category; ethnicity; age at bariatric surgery; and baseline BMI. Values are presented as estimated means and standard errors (SE). Variables with different superscripts (a, b, c, d) significantly differ from each other at $p < 0.05$ at post hoc least significant difference pairwise comparisons.

Abbreviation: SEP, socioeconomic position.

*Data about the type of bariatric surgery were documented only in 439/977 of the patients (sleeve gastrectomy, $n = 373$; mini gastric bypass, $n = 22$; Roux-en-Y gastric bypass, $n = 44$).

4 | Discussion

This population-based study demonstrates a marked increase in the utilization of BS among adolescents with obesity in Israel over the past decade. SG has emerged as the predominant surgical procedure in this population, while RYGB is reserved for selected cases, consistent with data from other national registries [20–23]. Owing to its relative technical simplicity and lower risk of micronutrient deficiencies compared with RYGB, SG is generally regarded as the preferred bariatric procedure for adolescents in Israel. In cases of substantial long-term weight regain, conversion from SG to RYGB may be considered as a revisional strategy.

A temporary decline in BS volume was observed in 2020, coincided with the COVID-19 pandemic. The overall rise in BS utilization likely reflects evolving eligibility criteria, including the gradual lowering of BMI thresholds for surgery.

Although BS is approved in Israel from the age of 13 years for adolescents with severe obesity, the median age at surgery in our cohort was approximately 18.6 years in both sexes, slightly older than reported in other national datasets [12, 20, 23]. As in prior studies, most procedures were performed in late adolescence [23]. Given growing evidence that young patients may derive greater benefit when BS is undertaken before the development of obesity-related comorbidities [24], the relatively advanced age at surgery observed in our cohort likely reflects restrictive national regulatory barriers, including the requirement for special approval in patients younger than 16 years. Accordingly, only a small proportion of patients ($n = 28$) in our cohort underwent surgery before this age.

BS utilization was higher among adolescents of Jewish ethnicity, consistent with our previous findings on obesity medication use [25]. This disparity may be influenced by sociocultural norms related to body image and differing attitudes toward obesity across ethnic groups. However, the relative contributions of patient preference and clinician referral patterns remain uncertain.

Adolescents from low- and medium-SEP backgrounds made up the majority of BS recipients in our cohort. This aligns with national data showing a higher prevalence of severe obesity among lower SEP adolescents in Israel [26], likely reflecting environmental and behavioral determinants.

Females constituted a greater proportion of adolescents undergoing BS, in line with international data [23, 27–30] and our previous study of pharmacotherapy for obesity in adolescents [25]. Female patients presented with lower preoperative BMI and lower prevalence of most obesity-related comorbidities compared with males, consistent with prior reports [23]. These sex differences may reflect earlier referral driven by heightened weight-related stigma, social pressures, and potential clinician bias toward intervention at lower BMI thresholds in females [30].

Because documentation of obesity-related comorbidities may be incomplete in medical records, prevalence estimates in this study were derived from both recorded diagnoses and objective cardiometabolic parameter cutoffs prior to BS. The cohort exhibited a high burden of cardiometabolic comorbidities before BS, underscoring the severity of metabolic risk in this population. Nevertheless, baseline comorbidity prevalence was lower than that reported in adolescents with severe obesity in the Teen-Longitudinal Assessment of Bariatric Surgery (Teen-LABS) study [31]. The higher baseline BMI in Teen-LABS and potential differences in genetic susceptibility to metabolic dysregulation across populations may partly explain the observed variation in comorbidity burden despite comparable degrees of severe obesity.

Only a minority of patients received obesity pharmacotherapy before surgery. This likely reflects the recent approval and limited accessibility of once-weekly GLP-1 receptor agonists for pediatric use in Israel, with semaglutide becoming available only in 2024 and currently accessible through private purchase. As access expands, future treatment paradigms may increasingly incorporate a therapeutic trial of GLP-1 receptor agonists before consideration of BS. During the study period, other agents, including phentermine, bupropion, and topiramate, were not approved for pediatric obesity treatment in Israel, which likely accounts for the absence of these medications in the medical records.

4.1 | Weight Outcomes and Durability of BMI Reduction

Across all subgroups, BS resulted in a marked and sustained reduction in BMI. The greatest weight loss occurred within the first 1–3 years postoperatively, followed by partial regain or stabilization, consistent with previous adolescent registry studies [32, 33]. Despite this attenuation, long-term BMI remained well below baseline across all groups, confirming the durability of surgical weight loss.

Sex-specific differences were evident, with males presenting with higher baseline BMI and experiencing greater absolute BMI reductions than females, a pattern reported previously [34]. This likely reflects higher preoperative BMI in males, resulting in larger absolute reductions, and may also relate to sex differences in body composition, hormonal milieu, and postoperative behaviors (as better adherence to physical activity).

Consistent with prior adolescent cohorts and registry analyses of BS in adolescents [35], baseline BMI strongly influenced postoperative weight outcomes. Adolescents with the highest baseline BMI achieved the largest absolute reductions but continued to have the highest BMI during follow-up, whereas those with lower baseline BMI experienced smaller absolute changes. These findings support consideration of earlier surgical referral to optimize long-term weight outcomes.

Although prior studies have reported comparable weight loss following SG and RYGB in adolescents [31, 36], our cohort demonstrated greater absolute BMI reduction and more sustained lower BMI values among participants undergoing RYGB. However, because the majority of patients underwent SG, definitive procedure-specific conclusions cannot be drawn.

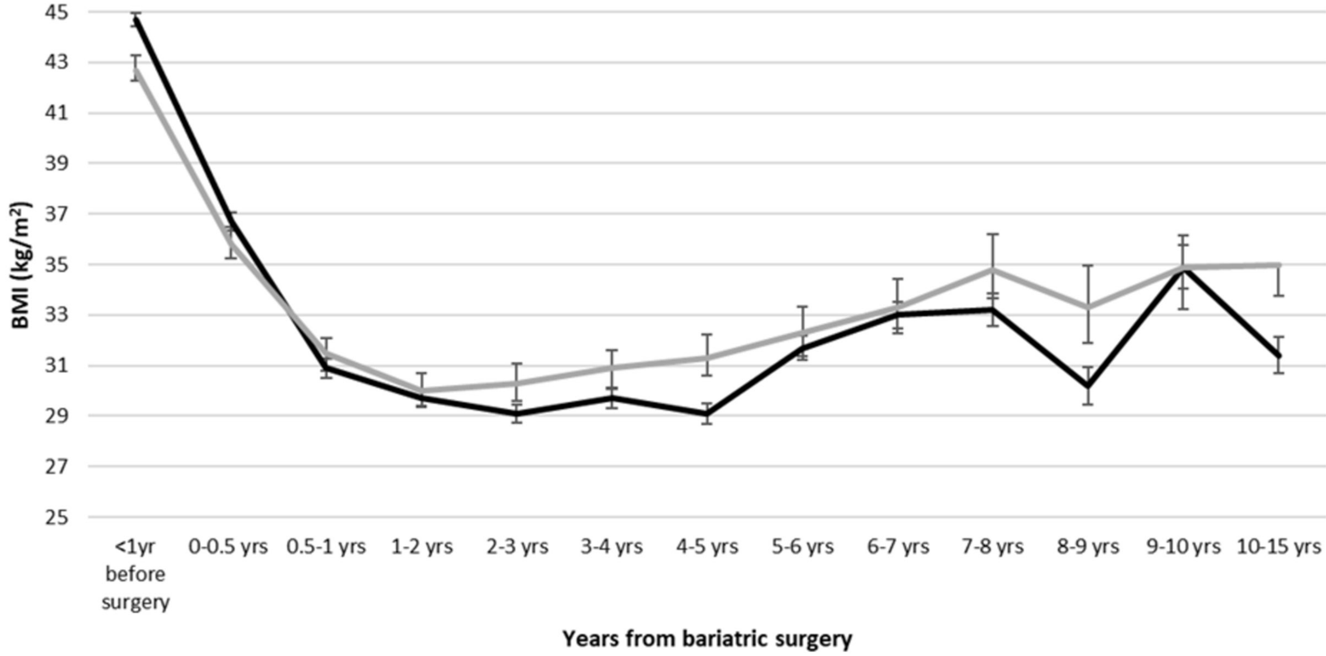

FIGURE 3 | Changes in BMI post bariatric surgery by sex. Gray line = females, black line = males. Number of participants included at each time point: Total (males/females): < 1 year before BS, $n = 977$ (292/685); 0–0.5 year post BS, $n = 469$ (145/324); 0.5–1 year post BS, $n = 355$ (97/258); 1–2 years post BS, $n = 500$ (135/365); 2–3 years post BS, $n = 365$ (95/270); 3–4 years post BS, $n = 327$ (74/253); 4–5 years post BS, $n = 305$ (88/217); 5–6 years post BS, $n = 207$ (52/155); 6–7 years post BS, $n = 166$ (42/124); 7–8 years post BS, $n = 115$ (33/82); 8–9 years post BS, $n = 82$ (20/62); 9–10 years post BS, $n = 59$ (16/43); 10–15 years post BS, $n = 96$ (29/67).

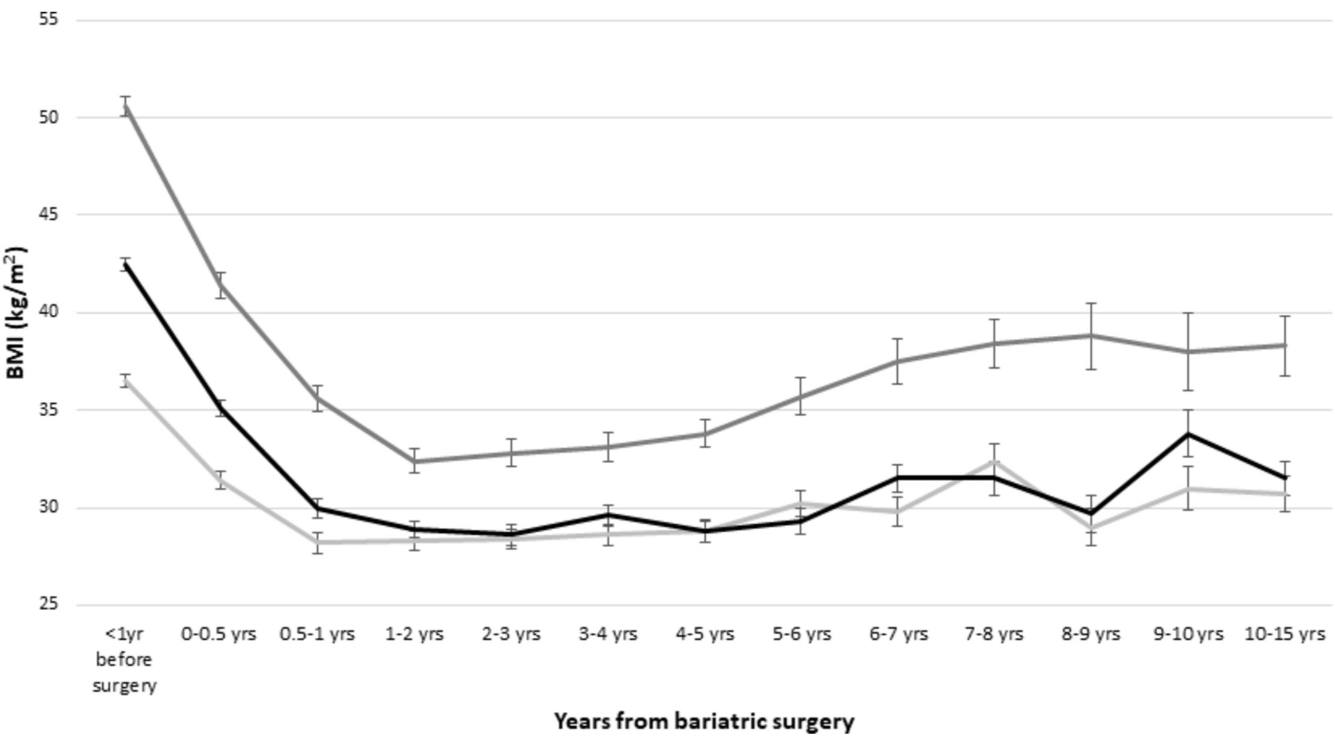

FIGURE 4 | Changes in BMI post bariatric surgery by baseline BMI tertile before surgery. Light gray line = BMI < 40.5 kg/m^2, black line = BMI 40.5–45.4 kg/m^2, dark gray line = BMI > 45.4 kg/m^2.

4.2 | Socioeconomic and Ethnic Considerations

Adolescents from lower SEP groups entered surgery with higher BMI and maintained higher BMI values throughout follow-up. However, postoperative BMI trajectories did not differ by SEP, indicating comparable relative effectiveness of BS once access to care is achieved. This finding aligns with prior reports [37]. This is particularly relevant given concerns

TABLE 3 | Changes in blood pressure and laboratory parameters analyzed by sex.

	<1 year before surgery	0–0.5 year	0.5–1 year	1–2 years	2–3 years	3–4 years	4–5 years	5–6 years	6–7 years	7–8 years	8–9 years	9–10 years	10–15 years	p_{time}	p_{sex}	$p_{time \times sex}$
Systolic BP (mmHg)																
Males (n=247)	125.5^{a} (1.2)	120.9^{b} (1.6)	119.3^{bc} (1.8)	118.9^{bc} (1.4)	119.7^{bc} (1.8)	119.5^{bc} (1.9)	115.5^{c} (1.6)	121.2^{b} (201)	120.5^{bc} (2.1)	118.9^{bc} (3.1)	118.0^{bc} (2.9)	125.3^{ab} (3.9)	123.8^{ab} (3.1)	<0.001	<0.001	0.545
Females (n=597)	121.2^{a} (0.8)	115.8^{b} (1.0)	114.0^{bc} (1.0)	111.0^{d} (0.8)	112.2^{cd} (0.9)	111.7^{cd} (0.9)	110.2^{d} (1.0)	112.6^{cd} (1.1)	110.9^{d} (1.3)	113.4^{bcd} (1.6)	113.3^{bcd} (1.8)	114.7^{bc} (2.0)	115.3^{bc} (1.6)	<0.001		
Diastolic BP (mmHg)																
Males (n=247)	72.8^{a} (1.0)	69.1^{b} (1.3)	70.1^{ab} (1.4)	68.9^{b} (1.1)	71.2^{ab} (1.4)	70.9^{ab} (1.5)	68.5^{b} (1.3)	71.7^{ab} (1.6)	71.8^{ab} (1.6)	71.9^{ab} (2.4)	70.6^{ab} (2.3)	74.1^{abc} (3.1)	79.2^{c} (2.5)	0.006	<0.001	0.036
Females (n=597)	74.0^{a} (0.6)	70.9^{b} (0.8)	69.8^{bc} (0.8)	68.2^{c} (0.7)	68.6^{bc} (0.7)	68.6^{bc} (0.7)	68.3^{bc} (0.8)	69.8^{bc} (0.9)	68.9^{bc} (1.0)	69.8^{bc} (1.2)	70.4^{bc} (1.4)	71.4^{ab} (1.5)	71.0^{b} (1.3)	<0.001		
FPG (mg/dL)																
Males (n=296)	90.4^{a} (1.1)	84.1^{b} (1.3)	83.0^{b} (1.4)	83.4^{b} (1.5)	86.3^{b} (1.8)	91.7^{a} (1.9)	86.2^{a} (2.0)	83.9^{b} (2.5)	88.8^{a} (2.5)	91.8^{a} (3.2)	83.7^{ab} (3.5)	92.3^{a} (4.2)	88.0^{ab} (3.3)	<0.001	<0.001	<0.001
Females (n=708)	91.3^{a} (0.6)	84.7^{bc} (0.7)	83.2^{cd} (0.8)	84.2^{cd} (0.8)	84.7^{bc} (0.8)	82.8^{cd} (0.9)	82.0^{d} (1.0)	82.4^{cd} (1.1)	81.7^{d} (1.3)	83.3^{cd} (1.6)	83.2^{cd} (1.7)	88.7^{ab} (2.0)	83.3^{cd} (1.6)	<0.001		
HbA1c (%)																
Males (n=206)	5.47^{a} (0.05)	5.19^{c} (0.07)	5.14^{c} (0.08)	5.13^{c} (0.08)	5.27^{abc} (0.11)	5.45^{ab} (0.11)	5.57^{a} (0.13)	5.06^{c} (0.14)	5.16^{bc} (0.15)	5.17^{bc} (0.14)	5.07^{bc} (0.17)	5.14^{abc} (0.19)	5.14^{abc} (0.19)	<0.001	0.204	0.332
Females (n=548)	5.39^{a} (0.03)	5.17^{c} (0.05)	5.15^{c} (0.05)	5.14^{c} (0.05)	5.32^{ab} (0.06)	5.25^{bc} (0.06)	5.22^{bc} (0.06)	5.14^{c} (0.07)	5.31^{abc} (0.08)	5.24^{abc} (0.09)	5.21^{abc} (0.10)	5.16^{bc} (0.11)	5.23^{abc} (1.0)	<0.001		
Triglycerides (mg/dL)																
Males (n=285)	135.8^{a} (3.3)	109.8^{b} (3.8)	83.9^{cd} (4.1)	80.3^{cd} (4.3)	75.0^{cd} (5.4)	82.6^{cd} (5.6)	78.8^{cd} (5.7)	86.9^{cd} (6.8)	74.6^{d} (6.8)	82.9^{c} (8.4)	88.7^{cd} (9.1)	101.9^{bc} (10.8)	68.5^{d} (9.9)	<0.001	0.888	<0.001
Females (n=695)	117.6^{a} (1.9)	106.5^{b} (2.2)	90.5^{c} (2.4)	82.0^{d} (2.4)	78.9^{d} (2.6)	77.1^{d} (2.7)	81.6^{d} (3.0)	80.4^{d} (3.3)	84.7^{cd} (3.7)	82.4^{cd} (4.6)	92.6^{c} (5.0)	96.0^{bc} (6.0)	91.5^{c} (4.9)	<0.001		
LDL cholesterol (mg/dL)																
Males (n=283)	99.7^{a} (1.8)	91.6^{b} (2.2)	89.1^{bc} (2.3)	84.4^{cd} (2.4)	78.1^{d} (3.1)	84.6^{cd} (3.1)	87.9^{bc} (3.1)	91.0^{bc} (3.9)	86.9^{cd} (3.9)	92.9^{ab} (4.7)	93.3^{ab} (5.4)	87.1^{bcd} (5.9)	84.4^{bcd} (5.6)	<0.001	<0.001	0.077
Females (n=694)	97.1^{a} (1.2)	93.8^{b} (1.4)	91.2^{b} (1.4)	87.0^{c} (1.5)	87.1^{c} (1.6)	86.4^{c} (1.6)	88.1^{c} (1.8)	89.6^{bc} (2.0)	92.7^{ab} (2.2)	93.9^{ab} (2.7)	96.8^{a} (3.0)	94.0^{ab} (3.4)	99.9^{a} (3.0)	<0.001		
HDL cholesterol (mg/dL)																

(Continues)

TABLE 3 | (Continued)

	<1 year before surgery	0–0.5 year	0.5–1 year	1–2 years	2–3 years	3–4 years	4–5 years	5–6 years	6–7 years	7–8 years	8–9 years	9–10 years	10–15 years	p_{time}	p_{sex}	$p_{time \times sex}$
Males ($n=284$)	39.4^{a} (0.6)	38.6^{a} (0.8)	43.0^{b} (0.8)	46.6^{c} (0.8)	49.5^{d} (1.1)	50.3^{d} (1.1)	50.7^{d} (1.1)	50.4^{d} (1.4)	49.6^{cd} (1.8)	49.2^{cd} (1.8)	49.6^{cd} (1.7)	51.2^{d} (2.1)	48.1^{cd} (2.0)	<0.001	<0.001	0.102
Females ($n=694$)	43.0^{a} (0.5)	43.5^{b} (0.6)	49.4^{c} (0.7)	54.2^{cd} (0.7)	54.9^{dc} (0.7)	57.0^{de} (0.8)	56.2^{de} (0.8)	56.8^{de} (0.9)	56.8^{de} (1.0)	57.1^{de} (1.3)	57.0^{de} (1.3)	58.2^{de} (1.6)	58.9^{e} (1.4)	<0.001		
GPT (U/L)																
Males ($n=292$)	45.5^{a} (2.3)	30.2^{b} (2.7)	21.5^{c} (2.8)	20.2^{c} (3.0)	22.1^{bc} (3.6)	23.3^{bc} (3.9)	18.3^{c} (4.0)	22.8^{bc} (4.9)	22.6^{bc} (4.7)	24.5^{bc} (6.2)	23.1^{bc} (7.2)	35.5^{abc} (8.8)	24.5^{bc} (6.7)	<0.001	<0.001	<0.001
Females ($n=706$)	27.2^{a} (0.7)	23.0^{b} (0.8)	17.9^{c} (0.8)	16.3^{cd} (0.8)	16.4^{cd} (0.9)	16.5^{cd} (0.9)	15.2^{d} (1.0)	15.5^{cd} (1.1)	15.3^{cd} (1.3)	18.0^{cd} (1.6)	19.4^{bc} (1.8)	16.0^{cd} (2.0)	15.3^{cd} (1.7)	<0.001		
GGT (U/L)																
Males ($n=238$)	39.9^{a} (2.2)	30.9^{b} (2.7)	21.5^{c} (2.9)	22.0^{c} (3.0)	19.5^{c} (3.9)	29.7^{bc} (3.9)	28.6^{bc} (4.0)	23.8^{bc} (4.7)	25.7^{bc} (4.6)	22.9^{bc} (5.3)	23.3^{bc} (6.3)	35.7^{ab} (6.7)	22.8^{bc} (6.3)	<0.001	<0.001	0.014
Females ($n=552$)	26.7^{a} (1.4)	20.1^{c} (1.7)	22.3^{bc} (1.8)	16.5^{cd} (1.7)	12.7^{d} (1.9)	13.9^{cd} (2.0)	12.6^{d} (2.2)	17.9^{cd} (2.5)	12.6^{d} (2.8)	20.4^{cd} (3.2)	21.7^{abc} (3.7)	16.5^{cd} (3.8)	12.5^{cd} (3.7)	<0.001		
Uric acid (mg/dL)																
Males ($n=263$)	7.1^{a} (0.1)	7.2^{a} (0.1)	6.4^{bc} (0.1)	6.0^{c} (0.1)	6.1^{bc} (0.2)	5.8^{c} (0.2)	5.8^{c} (0.2)	6.3^{bc} (0.3)	5.8^{c} (0.2)	6.2^{bc} (0.3)	5.7^{c} (0.3)	6.3^{bc} (0.4)	5.5^{c} (0.3)	<0.001	<0.001	0.103
Females ($n=662$)	5.5^{a} (0.1)	5.3^{b} (0.1)	4.6^{c} (0.1)	4.3^{d} (0.1)	4.2^{d} (0.1)	4.2^{d} (0.1)	4.3^{d} (0.1)	4.2^{d} (0.1)	4.3^{d} (0.1)	4.4^{cd} (0.1)	4.4^{cd} (0.1)	4.3^{d} (0.2)	4.2^{d} (0.1)	<0.001		

Note: Mixed-model repeated-measures analysis. All models were adjusted for the following possible confounders: ethnicity; SEP, socioeconomic position; age at bariatric surgery; and baseline BMI. Values are presented as estimated means and standard errors (SE). Variables with different superscripts (a, b, c, d) significantly differ from each other at $p<0.05$ at post hoc least significant difference pairwise comparisons. Total number of females ($n=685$) and males ($n=292$) in the cohort.
Abbreviations: BP, blood pressure; FPG, fasting plasma glucose; GGT, gamma-glutamyl transferase; GPT, glutamic pyruvic transaminase; HDL cholesterol, high-density lipoprotein; LDL cholesterol, low-density lipoprotein.

TABLE 4 | Changes in obesity-related cardiometabolic outcomes and use of medications for obesity and obesity-related comorbidities following bariatric surgery.

	Pre BS	Post BS	p_1
Hypertension			
Males ($n = 92$)	35 (38%)	11 (12.0%)	< 0.001
Females ($n = 197$)	44 (22.3%)	10 (5.1%)	< 0.001
p_2	0.005	0.036	
IFG, prediabetes, and T2D			
Males ($n = 275$)	63 (22.9%)	22 (8.0%)	< 0.001
Females ($n = 676$)	136 (20.1%)	35 (5.2%)	< 0.001
p_2	0.337	0.096	
T2D			
Males ($n = 275$)	18 (6.5%)	4 (1.5%)	0.003
Females ($n = 676$)	19 (2.8%)	5 (0.7%)	< 0.001
p_2	0.007	0.291	
Dyslipidemia			
Males ($n = 257$)	180 (70.0%)	79 (30.7%)	< 0.001
Females ($n = 638$)	526 (82.4%)	228 (35.7%)	< 0.001
p_2	< 0.001	0.154	
Abnormal liver function			
Males ($n = 272$)	126 (46.3%)	47 (17.3%)	< 0.001
Females ($n = 674$)	113 (16.8%)	37 (5.5%)	< 0.001
p_2	< 0.001	< 0.001	
Hyperuricemia			
Males ($n = 216$)	106 (49.1%)	39 (18.1%)	< 0.001
Females ($n = 548$)	165 (30.1%)	33 (6.0%)	< 0.001
p_2	< 0.001	< 0.001	
Medications for glycemic control			
Males ($n = 292$)	37 (12.7%)	7 (2.4%)	< 0.001
Females ($n = 685$)	53 (7.7%)	11 (1.6%)	< 0.001
p_2	0.015	0.400	
Antihypertensive medications			
Males ($n = 292$)	18 (6.2%)	9 (3.1%)	0.049
Females ($n = 685$)	16 (2.3%)	10 (1.5%)	0.238
p_2	0.003	0.093	
Statins			
Males ($n = 292$)	7 (2.4%)	8 (2.7%)	0.999
Females ($n = 685$)	6 (0.9%)	7 (1.0%)	0.999
p_2	0.057	0.043	
Obesity medications			
Males ($n = 292$)	14 (4.8%)	24 (8.2%)	0.121
Females ($n = 685$)	37 (5.4%)	114 (16.6%)	< 0.001
p_2	0.696	< 0.001	

Note: Hypertension was defined as systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg. Dyslipidemia was defined as triglycerides ≥ 150 mg/dL or LDL-cholesterol ≥ 130 mg/dL or HDL-cholesterol < 40 mg/dL in males and < 50 mg/dL in females. IFG was defined as FPG > 100 mg/dL, prediabetes as 5.7% < HbA1c < 6.5%, and diabetes as FPG ≥ 126 mg/dL or HbA1c level ≥ 6.5%. Abnormal liver function was defined as GPT > 40 U/L or GGT > 40 U/L, and hyperuricemia as serum uric acid levels > 6.0 mg/dL in females and > 7.2 mg/dL in males. Data are presented as number (percentage). p_1 represents related-samples McNemar test to explore the difference between pre-BS and post-BS rates. p_2 represents Pearson's chi-square test or Fisher's exact test, appropriately, to explore the difference between males and females. Abbreviations: BS, bariatric surgery; IFG, impaired fasting glucose; T2D, type 2 diabetes.

that social disadvantage may compromise long-term adherence and outcomes, and suggests that structured multidisciplinary follow-up may mitigate socioeconomic disparities in surgical outcomes.

Similarly, BMI trajectories did not differ meaningfully between Jewish and Arab adolescents, despite known ethnic disparities in obesity prevalence. These results support the effectiveness of BS across ethnic groups within an equitable health care system.

4.3 | Cardiometabolic Outcomes

Consistent with previous studies [12, 17, 38–40], BS was associated with significant improvements in multiple cardiometabolic parameters. Although hypertension was more prevalent among males preoperatively, its prevalence declined significantly after BS in both sexes. SBP decreased early and remained below baseline throughout follow-up. In contrast, DBP showed sex-specific patterns. Females maintained values below baseline, whereas males exhibited a long-term rebound exceeding preoperative levels. This finding may reflect sex-related differences in vascular adaptation, lifestyle factors, or the reduction in antihypertensive medication use among males, underscoring the need for continued cardiovascular monitoring, particularly among male patients.

Glycemic control improved substantially in both sexes, with early reductions in FPG and HbA1c observed after BS. Consistent with most published human studies, short-term glycemic improvements were comparable between males and females. However, in our cohort, sex-specific differences emerged over time: females maintained glycemic levels below baseline values, whereas males showed partial attenuation of the initial improvement. This pattern parallels the observed sex differences in DBP and may suggest differential long-term metabolic resilience or adherence to dietary and behavioral recommendations. Hormonal factors may also contribute; for example, estrogen-mediated suppression of hepatic glucose production could partially account for lower fasting glucose levels in females. Nevertheless, the prevalence of impaired fasting glucose and T2D declined significantly in both sexes, accompanied by reduced use of glucose-lowering medications.

Lipid profiles improved markedly following BS. To date, many adolescent BS registries have not consistently provided sex-stratified lipid outcomes. In our cohort, triglyceride levels remained below baseline throughout follow-up, with more pronounced long-term reductions in males. HDL cholesterol increased early and remained elevated in both sexes, while LDL cholesterol showed an initial decline followed by partial rebound, with more sustained improvement in males.

These findings suggest potential sex-specific metabolic responses after BS, particularly with respect to hepatic processing and secretion of triglyceride-rich lipoproteins. Males generally exhibit higher triglyceride levels and lower HDL cholesterol compared with females, likely reflecting differences in hormonal milieu, genetic factors, and fat distribution. Consistent with this physiological pattern, males in our cohort had higher baseline triglyceride levels and lower HDL cholesterol. Accordingly, the greater absolute reduction in triglycerides among males may partially reflect higher preoperative values. In addition, sex hormones such as estrogen and androgens exert differential effects on lipoprotein metabolism, modulating triglyceride synthesis, clearance, and storage.

Importantly, dyslipidemia prevalence decreased significantly with no changes in statin utilization following BS.

Markers of liver function (GPT and GGT) declined significantly post BS and remained below baseline in both sexes, consistent with improvements in obesity-related liver disease. Uric acid levels also decreased durably, with a significant reduction in hyperuricemia prevalence in both sexes, indicating sustained metabolic benefit beyond weight loss.

Prior studies support the safety and efficacy of adjunctive pharmacotherapy following BS [41]. Interestingly, we found that postoperative use of GLP-1 receptor agonists increased, particularly among females. This may reflect smaller absolute weight reductions, persistent weight-related issues, or evolving treatment strategies aimed at optimizing postoperative outcomes.

4.4 | Strengths and Limitations

Key strengths of this study include its large, population-based design, extended duration of follow-up, and the use of comprehensive real-world data derived from Israel's largest health maintenance organization (HMO). Compared with prior reports [41–44], this study constitutes the largest cohort and the longest follow-up evaluation of adolescent BS conducted in Israel to date. These methodological attributes enhance the generalizability of the findings and allow for a robust assessment of long-term outcomes following BS.

Several limitations warrant consideration. The retrospective observational design limits causal inference and is subject to residual confounding. In addition, the database does not encompass all bariatric procedures performed nationwide, as surgeries conducted in centers outside the HMO were not captured.

Postoperative data on cardiometabolic outcome measurements (particularly blood pressure measurements) were incomplete for a subset of patients. To address missing data, mixed-effects models incorporating all available repeated measurements were applied. Although this approach assumes data are MAR, this assumption cannot be formally verified, and bias due to nonrandom missingness cannot be excluded. This represents an inherent limitation of observational longitudinal studies.

Furthermore, information on lifestyle behaviors, dietary adherence, micronutrient status, quality of life, and postoperative complications was unavailable.

Data regarding surgical procedure type were also incomplete, precluding detailed procedure-specific analyses. Nevertheless, according to the Israel National Bariatric Surgery Registry (IBSR), a mandatory and validated national registry for bariatric procedures [45], SG is the predominant bariatric surgical approach for adolescents in Israel. Although loss to follow-up may introduce selection bias, postoperative BMI data were available for the majority of patients in the cohort.

5 | Conclusion

In conclusion, when delivered within a multidisciplinary framework, BS in adolescents with severe obesity is associated with substantial and sustained improvements in BMI and cardiometabolic health extending into long-term follow-up. Despite some attenuation of benefits over time, outcomes remain markedly improved compared with baseline. The comparable effectiveness of BS across socioeconomic and ethnic groups highlights the importance of equitable access to comprehensive bariatric care, while observed sex-specific trajectories in blood pressure and metabolic parameters highlight the importance of individualized, postoperative, tailored long-term monitoring. These findings support the role of BS as an effective component of comprehensive obesity management in adolescents.

Author Contributions

S.S. was responsible for the conception and design of the study, the analysis and interpretation of data, and writing the article, approved the final version, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. M.P. was responsible for interpreting the results, revising the article critically for important intellectual content, and approved the final version. M.Y.-G. was responsible for the data analysis and interpretation of data, revising the article critically for important intellectual content, approved the final version, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The datasets generated and analyzed during the current study are not publicly available due to the privacy policy of Clalit Health Services but are available from the corresponding author on reasonable request, contingent upon approval from the legal department of Clalit Health Services for the transfer of the datasets and the signing of a suitable appropriate Non-Disclosure Agreement.

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