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# Association of Sleeve Gastrectomy With Glycemic Control in Jordanian Adults With Type 2 Diabetes Mellitus and Dysglycemia

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## Abstract

# Purpose

To evaluate whether sleeve gastrectomy is associated with better glycemic and metabolic outcomes than non-surgical management in Jordanian adults with type 2 diabetes mellitus (T2DM) and dysglycemia.

# Methods

This retrospective cohort study included 239 adults treated at Prince Hamza Hospital in Amman, Jordan: 65 underwent sleeve gastrectomy and 174 received medical management. Baseline and follow-up data included BMI, HbA1c, insulin use, comorbidities, and microvascular complications. The primary outcome was glycemic control, defined as HbA1c < 6.5%. Group comparisons were performed using parametric and non-parametric tests. Modified Poisson regression with robust variance estimation was used to adjust for age, sex, baseline BMI, duration of T2DM and dysglycemia, baseline HbA1c, and insulin use.

# Results

Median follow-up HbA1c was 5.2% after sleeve gastrectomy and 7.5% with medical management ($p < 0.001$). Among patients with available follow-up HbA1c measurements, glycemic control was achieved in 57 of 59 surgical patients (96.6%) and 42 of 167 medically managed patients (25.1%). Mean BMI changed by − 10.9 kg/m² in the surgery group and + 1.3 kg/m² in the non-surgical group ($p < 0.001$). New microvascular complications occurred in 4.6% and 16.1% of patients, respectively. After adjustment, sleeve gastrectomy remained independently associated with glycemic control (adjusted risk ratio 4.92, 95% CI 2.37–10.24; $p < 0.001$).

# Conclusion

Sleeve gastrectomy was associated with better glycemic control and greater BMI reduction than non-surgical management in this Jordanian cohort. A lower frequency of newly documented microvascular complications was also observed in the surgical group, although this exploratory finding should be interpreted cautiously.

## INTRODUCTION

Type 2 diabetes mellitus (T2DM) and dysglycemia represent a major global health challenge associated with obesity and an increased risk of microvascular and macrovascular complications [1, 2]. Sleeve gastrectomy has emerged as an important therapeutic strategy for obesity, T2DM and dysglycemia. Although targeted to severe obesity, the considerable metabolic benefits of sleeve gastrectomy extend

beyond weight loss. Sleeve gastrectomy has been shown to improve glycemic control and reduce insulin resistance, which may lead to remission of T2DM [3, 4]. Despite a growing body of evidence that shows metabolic benefits from this procedure, most studies evaluating its effectiveness have been conducted on Western populations. Few studies have addressed these effects of sleeve gastrectomy in Jordan, or in other Middle Eastern populations. In addition, the prevalence of diabetes in Jordan has increased substantially over recent decades, emphasizing the need for effective metabolic interventions within the local population [5]. Differences in genetic background, environmental influences, health care systems and patient characteristics may influence both disease patterns and treatment success. Therefore, evaluating the effectiveness of sleeve gastrectomy in the Jordanian population is important to determine its role in regional diabetes management. The aim of the study was to determine the effectiveness of sleeve gastrectomy for improving glycemic control in men and women with T2DM and dysglycemia in Jordan. The primary objective of this study was to assess differences in hemoglobin A1c (HbA1c) levels and the achievement of glycemic control among people undergoing sleeve gastrectomy compared with existing therapy.

Extensive research has demonstrated that sleeve gastrectomy improves glycemic control and promotes remission of T2DM beyond the effects of weight loss alone. Reported remission rates range from 33% to 90% during the first postoperative year, compared with substantially lower rates following medical therapy. Long-term studies have also demonstrated improvements in glycemic control and diabetes-related complications after bariatric surgery [3, 6, 7, 8, 9].

Despite the growing body of evidence supporting the metabolic benefits of sleeve gastrectomy, several gaps in the literature remain. Reported remission rates differ widely across studies, largely due to variations in patient characteristics, definitions of diabetes remission, and lengths of follow-up [10, 11]. In addition, most available data are derived from Western populations, with relatively limited research conducted in Middle Eastern countries, including Jordan. Considering potential differences in demographic, genetic, and healthcare-related factors, further local studies are needed to better evaluate the effectiveness of sleeve gastrectomy in Jordanian patients with T2DM and dysglycemia.

This retrospective cohort study examined the relationship between sleeve gastrectomy and glycemic outcomes in Jordanian adults with T2DM and dysglycemia treated at a tertiary hospital. The study focused on changes in HbA1c levels, the achievement of glycemic control, variations in BMI, and the progression of microvascular complications, comparing patients who underwent surgery with those who received non-surgical medical treatment.

# MATERIALS AND METHODS

This retrospective cohort study was conducted at Prince Hamza Hospital, a tertiary referral center in Amman, Jordan. Electronic medical records were reviewed over an approximately two-year period to assess the impact of sleeve gastrectomy on glycemic control and metabolic outcomes in patients diagnosed with Type 2 Diabetes Mellitus (T2DM) and dysglycemia. The study compared patients who

underwent sleeve gastrectomy with patients who were managed with non-surgical medical therapy during the same period.

# Study Population

A total of 239 adult patients with confirmed T2DM and dysglycemia were included in the analysis. For the purposes of this study, dysglycemia was defined as impaired glucose regulation, including both prediabetes (HbA1c 5.7%–6.4%) and Type 2 Diabetes Mellitus (HbA1c ≥ 6.5% or a documented clinical diagnosis of T2DM in the medical record). Patients were categorized into two groups according to their management strategy: those who underwent sleeve gastrectomy (n = 65) and those who received non-surgical medical management (n = 174).

## Inclusion Criteria

Patients were eligible for inclusion if they met the following criteria:

1. Age between 25 and 73 years.
2. Documented diagnosis of dysglycemia (Type 2 Diabetes Mellitus or prediabetes) in the medical record.
3. Receipt of medical care at Prince Hamza Hospital during the study period.
4. Management with either sleeve gastrectomy or non-surgical medical treatment for diabetes.
5. Availability of baseline clinical data, including body mass index (BMI) and HbA1c at diagnosis.

## Exclusion Criteria

Patients were excluded if any of the following conditions were present:

1. Incomplete or missing medical records preventing extraction of key study variables.
2. Diagnosis of Type 1 Diabetes Mellitus.
3. Diagnosis of gestational diabetes mellitus.
4. Age younger than 25 years or older than 73 years.
5. History of bariatric surgery performed prior to the study period.
6. Insufficient follow-up duration after surgery or medical management to evaluate metabolic outcomes.
7. Lack of clear documentation regarding the treatment strategy (surgical versus non-surgical management).

All patients who satisfied the inclusion criteria and none of the exclusion criteria were included in the study. Patients who did not meet these criteria were excluded from the analysis.

Because all eligible patients during the study period were included, no formal sample size calculation was performed.

## Data Collection and Variables

Clinical and demographic data were extracted from the hospital's electronic medical record system. Data collection followed a standardized approach to reduce the risk of information bias.

Variables collected included demographic characteristics such as age, sex, marital status, smoking status, and family history of diabetes. Clinical variables included duration of T2DM and dysglycemia, BMI at diagnosis, and HbA1c at diagnosis.

Information on comorbid conditions was also obtained, including hypertension, dyslipidemia, and ischemic heart disease. Pharmacological treatment history was recorded, including the use of antidiabetic medications such as metformin (biguanides), second-generation sulfonylureas, DPP-4 inhibitors, SGLT2 inhibitors, and insulin therapy.

Lifestyle interventions documented in the medical records, including dietary modification and physical exercise, were also recorded when available.

## Outcome Measures

The primary outcome was glycemic control, assessed using the most recent HbA1c value recorded during follow-up in the electronic medical record within the study period. Follow-up duration was calculated from the date of sleeve gastrectomy or initiation of medical management to the date of the most recent HbA1c measurement. Median follow-up duration was 23.6 months (IQR 13.3–36.8) in the sleeve gastrectomy group and 26.9 months (IQR 17.5–36.3) in the non-surgical group. Achievement of the glycemic target was defined as HbA1c < 6.5%.

Secondary outcomes included change in body mass index (ΔBMI), change in HbA1c levels (ΔHbA1c), and progression of microvascular complications during follow-up.

Microvascular complications were identified from documented clinical diagnoses in the medical records and included diabetic nephropathy, diabetic retinopathy, and diabetic neuropathy. Progression was defined as the development of new complications during follow-up in patients who previously had no documented microvascular disease.

# Statistical Analysis

Continuous variables were summarized as mean ± standard deviation (SD) for normally distributed data or median with interquartile range (IQR) for non-normally distributed variables. The Kolmogorov–Smirnov test was used to assess normality.

Comparisons between the sleeve gastrectomy group and the non-surgical management group were performed using independent samples t-tests for normally distributed continuous variables and the Mann–Whitney U test for non-normally distributed variables. Categorical variables were compared using the chi-square test or Fisher's exact test when appropriate.

To account for baseline differences between treatment groups and reduce the potential impact of selection bias inherent to the retrospective study design, a multivariable modified Poisson regression model with robust variance estimation was performed. Achievement of glycemic control (HbA1c < 6.5%) was used as the dependent variable. Covariates entered into the model included treatment group (sleeve gastrectomy versus non-surgical management), age, sex, baseline BMI, duration of T2DM and dysglycemia, baseline HbA1c, and insulin use. Adjusted risk ratios (aRRs) with 95% confidence intervals were reported.

Paired categorical outcomes related to the progression of microvascular complications were analyzed separately within each group. For each group, the presence or absence of complications before and after the intervention was cross-tabulated, and changes were evaluated using McNemar's test for paired proportions.

A two-sided p-value < 0.05 was considered statistically significant. Follow-up HbA1c was unavailable for 13 patients (5.4%): seven in the nonsurgical group and six in the surgical group. Primary-outcome analyses were therefore conducted using 226 patients with available follow-up HbA1c data. No imputation was performed. Statistical analyses were conducted using R statistical software (version 4.3.1) and Jamovi (version 3.3.21).

## Sample Size and Statistical Power

Because this was a retrospective cohort study, all eligible patients meeting the inclusion criteria during the study period were included and no a priori sample size calculation was performed.

## Ethical Considerations

Ethical approval for the study was obtained from the Institutional Review Board of the Hashemite University (IRB No. 26/3/2024/2025). The study was conducted in accordance with the principles of the Declaration of Helsinki. Patient confidentiality was maintained throughout the study, and all data were anonymized prior to analysis. The requirement for informed consent was waived by the Institutional Review Board because of the retrospective nature of the study.

# RESULTS

# Baseline Characteristics of the Study Population

A total of 239 patients with Type 2 diabetes mellitus (T2DM) and dysglycemia were included in the study, comprising 65 patients in the bariatric surgery group and 174 in the non-surgery management group. The demographic and clinical profiles differed significantly between the two cohorts. Patients in the surgery group were younger (mean age 40.9 ± 9.1 vs. 62.8 ± 9.6 years, $p < 0.001$) and had a higher mean BMI at diagnosis (45.4 ± 5.9 vs. 32.3 ± 5.1 kg/m², $p < 0.001$) compared to the non-surgery group. The duration of T2DM and dysglycemia was significantly shorter in the surgery group (3.8 ± 2.1 years) than in the non-surgery group (8.4 ± 4.5 years, $p < 0.001$). To account for baseline differences between groups, a multivariable regression analysis was performed and the results are presented in Table 5. Baseline demographic and clinical characteristics of the study population are summarized in Table 1.

Table 1
Baseline Demographic and Clinical Characteristics

| Variable | No Surgery (n = 174) | Surgery (n = 65) | Total (n = 239) | P-value |
|---|---|---|---|---|
| Age (years) | 62.8 ± 9.6 | 40.9 ± 9.1 | 56.9 ± 13.6 | < 0.001 |
| Sex, n (%) | | | | < 0.001 |
| Female | 86 (49.4) | 51 (78.5) | 137 (57.3) | |
| Male | 88 (50.6) | 14 (21.5) | 102 (42.7) | |
| Marital Status, n (%) | | | | < 0.001 |
| Married | 164 (94.3) | 57 (87.7) | 221 (92.5) | |
| Single/Other | 10 (5.7) | 8 (12.3) | 18 (7.5) | |
| Duration of T2DM and dysglycemia (years) | 8.4 ± 4.5 | 3.8 ± 2.1 | 7.3 ± 4.5 | < 0.001 |
| HbA1c at Diagnosis (%) | 9.0 ± 2.1 | 6.3 ± 1.1 | 8.2 ± 2.2 | < 0.001 |
| BMI at Diagnosis (kg/m²) | 32.3 ± 5.1 | 45.4 ± 5.9 | 38.7 ± 8.6 | < 0.001 |
| Family History of DM, n (%) | 36 (20.7) | 43 (66.1) | 79 (33.1) | < 0.001 |
| Current Smoker, n (%) | 60 (34.5) | 28 (43.1) | 88 (36.8) | 0.282 |
| Comorbidities, n (%) | | | | |
| Hypertension | 72 (41.4) | 14 (21.5) | 86 (36.0) | 0.007 |
| Dyslipidemia | 23 (13.2) | 5 (7.7) | 28 (11.7) | 0.339 |
| IHD / CAD | 13 (7.5) | 0 (0.0) | 13 (5.4) | 0.052 |
| Any Comorbidity | 91 (52.3) | 31 (47.7) | 122 (51.0) | 0.625 |

Patients in the non-surgical group were more likely to be on antidiabetic medications across all major drug classes. Metformin use was higher in this group compared to those who underwent surgery (67.2% vs. 26.2%, $p < 0.001$). The same pattern was seen with other medications, including sulfonylureas (35.1% vs. 3.1%), DPP-4 inhibitors (48.9% vs. 4.6%), SGLT2 inhibitors (60.9% vs. 1.5%), and insulin (58.0% vs. 3.1%), all with $p < 0.001$.

On the other hand, lifestyle changes were reported more often in the surgery group. Dietary modification was noted in 73.8% of surgical patients compared to 18.4% in the non-surgical group, and physical

exercise in 12.3% vs. 1.1%. Overall, any form of lifestyle modification was much more common among patients who had surgery (81.5% vs. 21.8%, p < 0.001). Baseline pharmacological treatment and lifestyle characteristics are summarized in Table 2.

Table 2
Baseline Pharmacological and Lifestyle Profile

| Variable | No Surgery (n = 174) | Surgery (n = 65) | Total (n = 239) | P-value |
|---|---|---|---|---|
| Antidiabetic Medication Classes Used, n (%) | | | | |
| Biguanides (Metformin) | 117 (67.2) | 17 (26.2) | 134 (56.1) | < 0.001 |
| Sulfonylureas (2nd Gen) | 61 (35.1) | 2 (3.1) | 63 (26.4) | < 0.001 |
| DPP-4 Inhibitors | 85 (48.9) | 3 (4.6) | 88 (36.8) | < 0.001 |
| SGLT2 Inhibitors | 106 (60.9) | 1 (1.5) | 107 (44.8) | < 0.001 |
| Insulin Therapy | 101 (58) | 2 (3.1) | 103 (43.1) | < 0.001 |
| Lifestyle Interventions Attempted, n (%) | | | | |
| Dietary Modification | 32 (18.4) | 48 (73.8) | 80 (33.5) | < 0.001 |
| Physical Exercise | 2 (1.1) | 8 (12.3) | 10 (4.2) | 0.001 |
| Any Lifestyle Modification | 38 (21.8) | 53 (81.5) | 91 (38.1) | < 0.001 |

### Anthropometric Outcomes

Sleeve gastrectomy resulted in substantial weight reduction compared with non-surgical management. The surgery group achieved a mean reduction in BMI (ΔBMI) of − 10.9 (SD 3.8) kg/m², whereas the non-surgery group experienced a slight mean increase in BMI of + 1.3 (SD 5.1) kg/m² (p < 0.001). Despite this reduction, the final median BMI remained marginally higher in the surgery group than in the non-surgery group (34.6 vs. 32.6 kg/m², p = 0.054), reflecting the significantly higher baseline obesity in the surgical cohort.

# Microvascular Complications

The progression of microvascular complications differed significantly between the two management strategies. In the non-surgery group, 28 patients (16.1%) experienced worsening complications

(progression from no known complications to documented complications), with no patients showing improvement. McNemar's test confirmed this progression as statistically significant ($p < 0.001$).

In contrast, the bariatric surgery group demonstrated relative stability in microvascular status. Three patients in the surgical group developed newly documented microvascular complications. The within-group change was not statistically significant using McNemar's test ($p = 0.25$). The between-group difference in complication progression rates was statistically significant ($p < 0.001$), based on a chi-square/Fisher's exact test comparison. Anthropometric, glycemic, and microvascular outcomes are summarized in Table 3.

Table 3
Changes in Anthropometric, Metabolic and Microvascular Outcomes

| **Outcome Variable** | **No Surgery (n = 174)** | **Surgery (n = 65)** | **P-value** |
|---|---|---|---|
| BMI Outcomes | | | |
| Last Follow-up BMI (kg/m²) | 32.6 (IQR 5.4) | 34.6 (IQR 5.4) | 0.054† |
| Change in BMI (ΔBMI) | + 1.3 (SD 5.1) | -10.9 (SD 3.8) | < 0.001‡ |
| Glycemic Outcomes | | | |
| Last Follow-up HbA1c (%) | 7.5 (IQR 6.4–9.4) | 5.2 (IQR 5.0–5.4) | < 0.001† |
| Change in HbA1c (ΔHbA1c) | -1.0 (IQR − 2.3 to 0.2) | -0.8 (IQR − 1.1 to -0.5) | 0.956† |
| Microvascular Status Change | | | |
| Worsened (Developed New Complications) | 28 (16.1%) | 3 (4.6%) | < 0.001§ |
| Stable/Improved | 146 (83.9%) | 62 (95.4%) | |
| † P-value calculated using Mann-Whitney U test (data presented as Median [IQR]). ‡ P-value calculated using Independent Samples T-test (data presented as Mean [SD]). § P-value derived from comparison of complication progression rates ($\chi^2$/Fisher exact test context). (Within each treatment group, microvascular complication status before and after treatment was compared using McNemar's test for paired proportions. This analysis assessed changes over time within the same patients rather than differences between treatment groups.) | | | |

The distributions of ΔBMI and ΔHbA1c according to treatment group are illustrated in Fig. 1.

# Glycemic Control Outcomes

The primary outcome analysis showed superior glycemic control in the bariatric surgery group. The median last HbA1c was significantly lower in the surgery group (5.2% [IQR 5.0–5.4]) than in the non-surgery group (7.5% [IQR 6.4–9.4], $p < 0.001$). Achievement of the glycemic target, defined as HbA1c < 6.5%, was observed in 96.6% (n = 57) of patients in the surgery group compared with 25.1% (n = 42) in

the non-surgery group. This association was statistically significant ($\chi^2 = 90.4$, $p < 0.001$), indicating a significant association between surgical intervention and achievement of glycemic control. The absolute change in HbA1c (ΔHbA1c) did not differ significantly between groups ($p = 0.956$), which may reflect the lower baseline HbA1c in the surgery cohort. The distribution of patients achieving the glycemic target is shown in Table 4.

Table 4
Achievement of Glycemic Control Target

| Outcome | No Surgery (n = 167) | Surgery (n = 59) | Total (n = 226) | P-value |
|---|---|---|---|---|
| Achieved HbA1c < 6.5% | | | | < 0.001* |
| Yes | 42 (25.1%) | 57 (96.6%) | 99 (43.8%) | |
| No | 125 (74.9%) | 2 (3.4%) | 127 (56.2%) | |

**Note: 7 patients from the non-surgery group and 6 patients from the surgery group were excluded from this specific cross-tabulation due to missing post-baseline HbA1c follow-up records.*

Figure 2 illustrates the proportion of patients achieving HbA1c < 6.5% according to treatment group.

# Multivariable Regression Analysis

To account for baseline differences between treatment groups, including treatment group, age, sex, baseline BMI, baseline HbA1c, duration of T2DM/dysglycemia, and insulin use, a modified Poisson regression model with robust variance estimation was performed. Achievement of glycemic control (HbA1c < 6.5%) was used as the dependent variable.

After adjustment, sleeve gastrectomy remained a significant independent predictor of achieving glycemic control. Patients who underwent sleeve gastrectomy were 4.92 times more likely to achieve HbA1c < 6.5% compared with those managed medically (aRR 4.92, 95% CI 2.37–10.24, $p < 0.001$). Higher baseline HbA1c was associated with a lower likelihood of achieving glycemic control (aRR 0.77, 95% CI 0.62–0.97, $p = 0.025$). Age, duration of T2DM and dysglycemia, Baseline BMI (aRR 1.00, 95% CI 0.98–1.01, $p = 0.647$), female sex (aRR 0.83, 95% CI 0.64–1.07, $p = 0.154$), and insulin use (aRR 0.59, 95% CI 0.22–1.57, $p = 0.291$) were not independently associated with achievement of the glycemic target after adjustment.

Table 5
Adjusted Regression Analysis for Predictors of Achievement of Glycemic Control (HbA1c < 6.5%)

| Predictor Variable | Adjusted Risk Ratio (aRR) | 95% Confidence Interval | P-value |
|---|---|---|---|
| Sleeve Gastrectomy (vs. No Surgery) | 4.92 | 2.37–10.24 | < 0.001 |
| Age (per year increase) | 1.00 | 0.98–1.01 | 0.579 |
| Duration of T2DM and dysglycemia (per year increase) | 0.98 | 0.90–1.07 | 0.646 |
| Baseline HbA1c (per 1% increase) | 0.77 | 0.62–0.97 | 0.025 |
| Baseline BMI (per kg/m² increase) | 1.00 | 0.98–1.01 | 0.647 |
| Female Sex (vs Male) | 0.83 | 0.64–1.07 | 0.154 |
| Insulin Use (Yes vs No) | 0.59 | 0.22–1.57 | 0.291 |

# DISCUSSION

This retrospective cohort study looked at how sleeve gastrectomy affects glycemic control, body composition, and the progression of microvascular complications in Jordanian adults with Type 2 Diabetes Mellitus and dysglycemia. Overall, the results point in a clear direction; patients who underwent surgery showed better metabolic outcomes than those managed medically during the follow-up. The differences were not limited to blood sugar levels, but also extended to weight and complication patterns, with surgical intervention being associated with markedly improved glycemic control and a lower observed frequency of newly documented microvascular complications.

What stood out most was the gap in glycemic control between the two groups. Patients who underwent sleeve gastrectomy reached much lower HbA1c levels at follow-up, with a median of 5.2% compared with 7.5% in the medical group, and almost all of them met the target of HbA1c < 6.5%. In contrast, only a small proportion of medically treated patients achieved that goal. These findings are consistent with previous evidence showing that sleeve gastrectomy is associated with superior glycemic outcomes compared with medical therapy alone. Similar findings were reported by Canakis et al., who demonstrated substantially higher rates of T2DM remission following bariatric surgery compared with matched non-surgical controls, with benefits persisting up to 3 years after surgery, and by the STAMPEDE trial, which showed that surgical intervention was more effective than intensive medical therapy in achieving glycemic control. These observations are further supported by randomized trials, observational studies and meta-analyses [12, 13, 14, 15, 16].

The reasons behind this improvement are likely layered rather than driven by a single mechanism. Weight loss clearly plays a major role, but it does not fully explain the changes seen after surgery. Metabolic procedures like sleeve gastrectomy trigger hormonal shifts that directly influence glucose handling,

particularly through increased GLP-1 secretion, which enhances insulin response. At the same time, changes in gut signaling, bile acids, and even the microbiome seem to contribute, helping explain why some benefits appear early, even before significant weight loss occurs [17, 18]. Previous studies have also demonstrated significant reductions in HbA1c following sleeve gastrectomy through both weight-dependent and independent mechanisms, supporting the metabolic effects observed in this study.

A similar pattern was seen in the anthropometric outcomes. Patients in the surgical group experienced a marked drop in BMI, while those in the non-surgical group showed a slight increase over time. Even though the final BMI remained somewhat higher in the surgical group, this reflects where they started rather than a weaker response to treatment. Patients selected for surgery usually begin with more severe obesity, so even after meaningful weight loss, they may still fall within a higher BMI range, which has been described in other bariatric cohorts as well [19, 20].

An interesting nuance in the results is that despite the clear superiority in final HbA1c levels among surgical patients, the absolute change in HbA1c did not significantly differ between groups, which can reasonably be attributed to baseline differences since the surgical group started with lower HbA1c values and therefore had less room for further reduction, a pattern often described as a floor effect and reported in similar observational studies where baseline disparities influence the magnitude of change over time [21].

A further important observation relates to microvascular complications, where patients managed medically showed a clear progression over time while most patients in the surgical group remained stable, with only a small proportion developing new complications, and although this difference within the surgical group did not reach statistical significance, the overall trend suggests a less frequent observation of such complications among sleeve gastrectomy sample, consistent with previous studies linking surgical intervention to reductions in both microvascular and macrovascular complications through improvements in glycemic control, body weight, and cardiovascular risk profiles [18, 19, 22].

At the same time, these findings should be interpreted in light of baseline differences between the groups, as patients selected for surgery were younger, had higher BMI, and a shorter duration of T2DM and dysglycemia, factors that are known to influence outcomes and may introduce selection bias, particularly given that shorter disease duration has been repeatedly identified as a key predictor of remission following sleeve gastrectomy due to better preservation of pancreatic β-cell function [15, 16, 23, 24]. In addition, differences in treatment intensity and baseline disease severity may have contributed to the observed outcomes.

To address these baseline imbalances, a multivariable modified Poisson regression analysis was performed adjusting for age, sex, baseline BMI, duration of T2DM and dysglycemia, baseline HbA1c, and insulin use. Importantly, sleeve gastrectomy remained an independent predictor of achieving glycemic control after adjustment (aRR 4.92, 95% CI 2.37–10.24, $p < 0.001$). This finding suggests that the observed association was not solely explained by differences in baseline patient characteristics and

supports the robustness of the primary outcome. Nevertheless, these findings should be interpreted as demonstrating an association rather than causation because of the observational study design.

The observation that final BMI remained higher in the surgical group despite significant weight loss further highlights the importance of considering baseline characteristics, since patients undergoing sleeve gastrectomy typically present with more severe obesity and may still remain within the obesity range even after substantial reductions, a pattern that has been consistently described in prior cohorts [19].

From a clinical perspective, these findings matter, especially in a setting like Jordan where the burden of T2DM and dysglycemia continues to grow. Managing diabetes effectively is not only about lowering glucose levels but also about preventing long-term complications. In this context, sleeve gastrectomy appears to offer an option for patients who do not achieve adequate glycemic control with medical therapy alone. The improvements seen in this study suggest that surgery could play a role in reducing the long-term impact of diabetes at both the individual and population levels [25].

There are, however, several limitations that should be considered. The retrospective study design is inherently susceptible to selection bias and unmeasured confounding. Patients in the surgical group were younger, had higher baseline BMI, and had a shorter duration of T2DM and dysglycemia than those managed medically. Although multivariable regression was performed to adjust for measured confounders, residual confounding from unmeasured variables cannot be excluded and may have influenced the estimated treatment effect. In addition, lifestyle modification was more common among patients undergoing sleeve gastrectomy and may have contributed to the observed outcomes; however, the intensity and adherence to these interventions could not be reliably quantified and were therefore not included in the adjusted model. Furthermore, the median follow-up duration of approximately 2 years may not fully reflect the long-term durability of glycemic control or diabetes remission. Finally, this was a single-center study, which may limit the generalizability of the findings to other populations.

Despite these limitations, the study offers useful real-world insight into how sleeve gastrectomy performs in routine clinical practice within a Jordanian population. Looking at glycemic control, weight changes, and complications together provides a more complete picture of its impact rather than focusing on a single outcome. These findings may be most applicable to patients with obesity and a relatively shorter duration of T2DM and dysglycemia managed in tertiary care settings.

In summary, sleeve gastrectomy was linked to better glycemic control, meaningful weight loss, and a lower observed rate of newly documented microvascular complications compared with standard medical therapy over an approximately 2-year period. These findings support the role of sleeve gastrectomy as a practical and effective option for improving metabolic outcomes in patients with Type 2 Diabetes Mellitus and dysglycemia.

# CONCLUSION

In this retrospective Jordanian cohort, sleeve gastrectomy was independently associated with a greater likelihood of achieving HbA1c < 6.5% and substantial BMI reduction compared with non-surgical management. Patients who underwent surgery also had a lower observed frequency of newly documented microvascular complications; however, this finding should be interpreted cautiously because of the observational design and potential residual confounding. Prospective studies with longer follow-up are needed to confirm the durability and causal effects of these findings.

## Declarations

# Conflict of interest

The authors declare that they have no conflict of interest.

**Ethics Approval**

This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Review Board of the Hashemite University (IRB No. 26/3/2024/2025).

**Consent to Participate**

The requirement for informed consent was waived by the Institutional Review Board of the Hashemite University because of the retrospective nature of the study.

**Consent to Publish**

Not applicable as no identifiable data or images are present within the manuscript.

# Clinical trial number

Not applicable.

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# Author Contribution

R.T., M.A., M.K., and M.M.S. conceived and designed the study, developed the research proposal, collected and curated the data, performed the statistical analysis, interpreted the results, and drafted the manuscript. These authors also critically revised the manuscript and approved the final version.M.Z.S.,

A.A., and A.S. contributed to data collection, preparation of the Methods section, and completion of the Institutional Review Board (IRB) documentation.L.A. and R.A. contributed to data collection and preparation of the Introduction section. R.A., A.S., and M.Z.S. also contributed to preparation of the IRB documentation.M.I.S. designed the data collection form, contributed to data collection, and participated in drafting the Conclusion section.Z.E. and M.I.S. contributed to preparation of the Conclusion section and assisted with data collection.All authors contributed to interpretation of the findings, critically reviewed the manuscript for important intellectual content, and approved the final version of the manuscript.

# Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to privacy and ethical restrictions but are available from the corresponding author on reasonable request, subject to institutional approval and applicable ethical regulations.

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# Figures

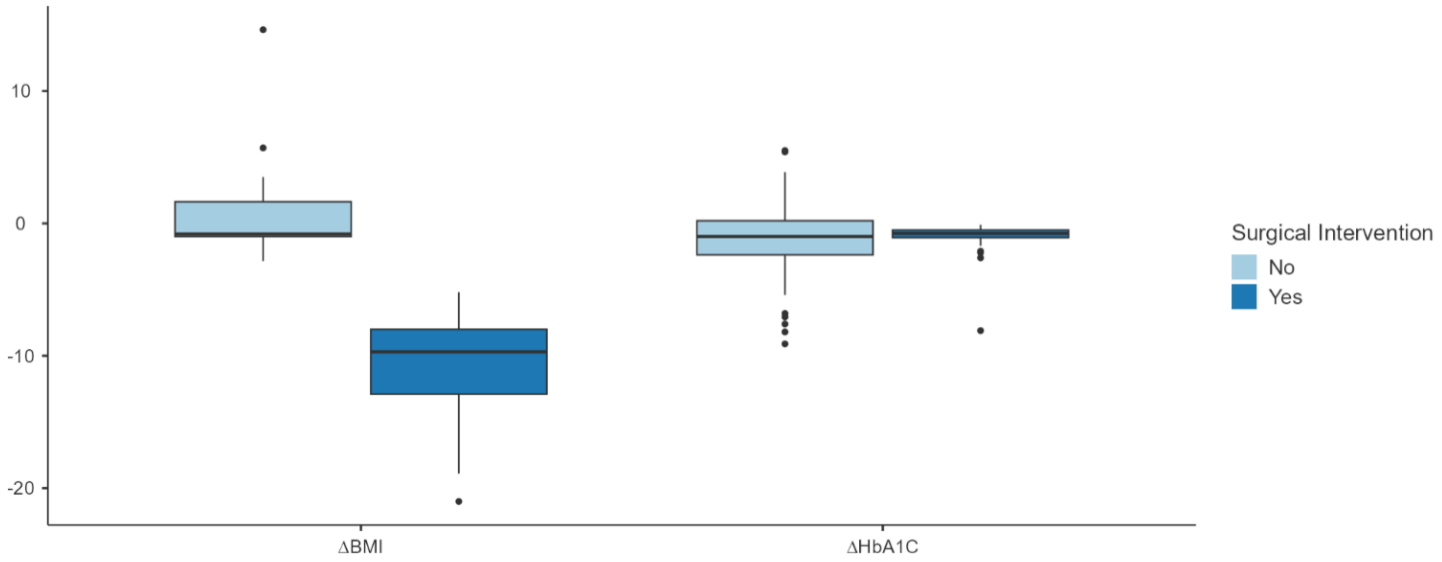



**Figure 1**

Distribution of ΔBMI and ΔHbA1c by treatment group

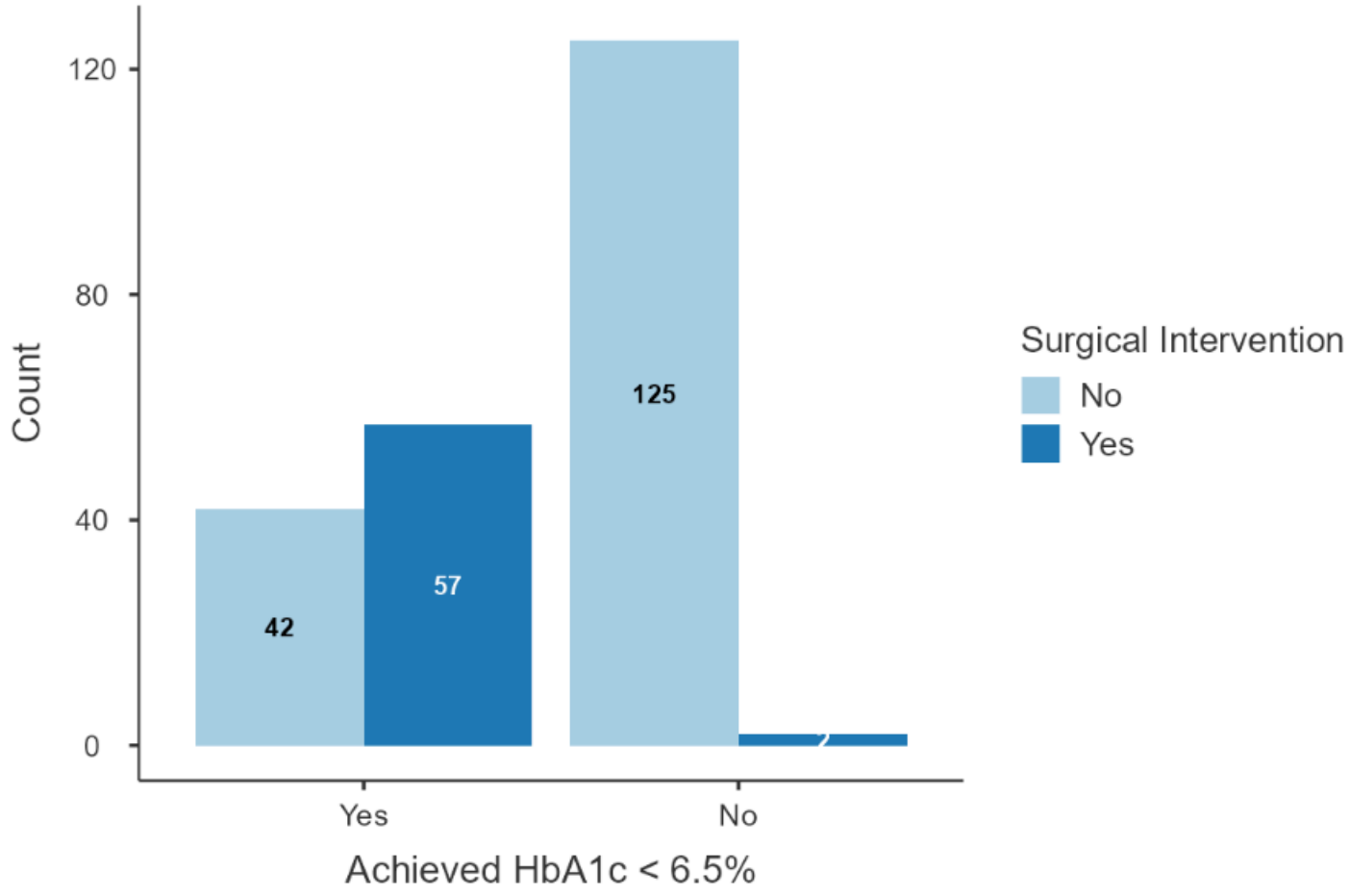



**Figure 2**

Achievement of HbA1c <6.5% by treatment group