ARCHIVES OF THE TURKISH SOCIETY OF CARDIOLOGY

Official journal of the TURKISH SOCIETY OF CARDIOLOGY

Structural and Functional Cardiac Reverse Remodeling After Bariatric Surgery: A Prospective Comparison of Sleeve Gastrectomy and Roux-en-Y Gastric Bypass

Bariatrik Cerrahi Sonrası Yapısal ve Fonksiyonel Kardiyak Ters Yeniden Şekillenme: Sleeve Gastrektomi ve Roux-en-Y Gastrik Bypass'ın Prospektif Karşılaştırması

ABSTRACT

Objective: Obesity is associated with characteristic cardiac remodeling, including left ventricular (LV) hypertrophy, concentric geometry, and subclinical myocardial dysfunction. Bariatric surgery induces reverse cardiac remodeling; however, it remains unclear whether structural and functional recovery differ between sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB), and to what extent these changes are driven by weight loss versus metabolic and inflammatory mechanisms.

Method: In this prospective observational cohort study, 100 adults with severe obesity (body mass index [BMI] > 35 kg/m^2) undergoing primary bariatric surgery (SG, n = 50; RYGB, n = 50) were evaluated at baseline and six months postoperatively. Clinical, metabolic, inflammatory, and echocardiographic parameters—including left ventricular mass index (LVMI), epicardial adipose tissue (EAT) thickness, diastolic function, and global longitudinal strain (GLS)—were assessed using standardized transthoracic echocardiography with speckle-tracking analysis. Multivariable regression identified independent predictors of structural (ΔLVMI) and functional (ΔGLS) improvement.

Results: Baseline characteristics were comparable between groups (mean age 35.9 years; 67% female; BMI 47.1 kg/m^2). Both procedures resulted in significant improvements in anthropometric, metabolic, inflammatory, and cardiac parameters. RYGB was associated with greater reductions in BMI (−10.74 ± 2.42 vs. −9.32 ± 2.42 kg/m^2; P = 0.004), glycated hemoglobin (HbA1c) (median −1.40% vs. −0.90%; P = 0.007), and C-reactive protein (CRP) (P = 0.029). Structural reverse remodeling was more pronounced following RYGB, with greater reductions in LVMI (median −12.0 vs. −6.5 g/m$^{2.7}$; P < 0.001) and EAT thickness (−1.20 vs. −0.70 mm; P = 0.014). GLS improved in both groups (−2.33% vs. −1.40%; P = 0.031). However, multivariable analysis demonstrated that improvement in GLS was independently associated with baseline GLS, reduction in LV mass, and improvements in HbA1c and CRP, rather than the type of surgical procedure.

Conclusion: Bariatric surgery leads to significant reverse cardiac remodeling in patients with severe obesity. RYGB is associated with greater structural regression, whereas improvement in myocardial deformation appears to be primarily driven by metabolic improvement and inflammatory changes rather than surgical technique. These findings suggest that cardiac recovery reflects an integrated process involving structural, metabolic, and inflammatory restoration beyond weight loss alone.

Keywords: Bariatric surgery, epicardial adipose tissue, global longitudinal strain, left ventricular remodeling, obesity

ÖZET

Amaç: Obezitenin karakteristik bir kardiyak yeniden şekillenme süreciyle yakın ilişkisi vardır. Bu süreç, sıklıkla sol ventrikül (LV) hipertrofisini, konsantrik geometri değişimlerini ve alt düzeyde seyreden subklinik miyokardiyal disfonksiyonu kapsar. Bariatrik cerrahi girişimlerinin kardiyak yapıda tersine iyileşme sağladığı bilinmektedir. Ancak sleeve gastrektomi (SG) ile Roux-en-Y gastrik bypass (RYGB) uygulamaları arasında yapısal ya da fonksiyonel düzelme açısından belirgin bir fark olup olmadığı henüz tam olarak aydınlatılamamıştır. Ayrıca gözlenen bu olumlu değişimlerin doğrudan kilo kaybına mı, yoksa altta yatan metabolik ve inflamatuar mekanizmalara mı dayandığı sorusu literatürde güncelliğini korumaktadır.

ORIGINAL ARTICLE
ARAŞTIRMA MAKALESİ

Kareem Ali Maher[1]
Reda Nabil Dawoud[1]
Osama Abouelfetouh Elshaer[1]
Ramy Magdy Elgamal[1]
Mohamed Shokry Fahmy[1]
Ezz Eldin Ebrahim Gaber[1]
Dina Ahmed Muhammad Abdelmoneim[2]
Mohamed Elsayed Abdelfattah[1]
Reda Biomy[1]
Wael Anwar Hasib[1]

[1]*Department of Cardiovascular Medicine, Kafrelsheikh University Hospital, Kafrelsheikh, Egypt*
[2]*Mansoura Specialized Hospital, Mansoura, Egypt*

Corresponding author:
Osama Abouelfetouh Elshaer
✉ osamaelshaer568@gmail.com

Received: March 10, 2026
Accepted: April 08, 2026

Cite this article as: Maher KA, Dawoud RN, Elshaer OA, et al. Structural and Functional Cardiac Reverse Remodeling After Bariatric Surgery: A Prospective Comparison of Sleeve Gastrectomy and Roux-en-Y Gastric Bypass. *Turk Kardiyol Dern Ars.* 2026;54(6):471–479.

DOI: 10.5543/tkda.2026.23796

Copyright@Author(s)
Available online at archivestsc.com. Content of this journal is licensed under a Creative Commons Attribution – NonCommercial-NoDerivatives 4.0 International License.

Yöntem: Prospektif ve gözlemsel olarak tasarlanan bu kohort araştırmasına, primer bariatrik cerrahi geçirecek ve şiddetli obezite tanısı almış (VKİ>35 kg/m²) 100 yetişkin hasta dâhil edildi. Cerrahi yöntem olarak katılımcıların yarısına SG (n=50), diğer yarısına ise RYGB (n=50) uygulandı. Tüm olgular, ameliyat öncesi başlangıç döneminde ve postoperatif altıncı ayda ayrıntılı olarak incelendi. Hastaların klinik, metabolik ve inflamatuar bulguları ile birlikte çok sayıda ekokardiyografik parametresi ölçüldü. Bu kapsamda, standardize transtorasik ekokardiyografi ve speckle-tracking analizi kullanılarak sol ventrikül kitle indeksi (LVMİ), epikardiyal yağ dokusu (EAT) kalınlığı, diyastolik işlevler ve global longitudinal strain (GLS) değerleri kaydedildi. Yapısal (ΔLVMİ) ve fonksiyonel (ΔGLS) düzelmelerin bağımsız yordayıcılarını belirlemek amacıyla çok değişkenli regresyon analizleri yapıldı.

Bulgular: Grupların başlangıçtaki klinik özellikleri birbiriyle oldukça benzerdi (ortalama yaş 35,9; katılımcıların %67'si kadın; ortalama VKİ 47,1 kg/m²). Uygulanan her iki cerrahi yöntem de hastaların antropometrik, metabolik, inflamatuar ve kardiyak profillerinde kayda değer düzelmeler sağladı. Ancak bazı parametrelerde RYGB uygulamasının daha üstün sonuçlar verdiği gözlendi. Özellikle VKİ'de (−10.74±2.42'ye karşı −9.32±2.42 kg/m²; P = 0.004), HbA1c'de (ortanca −%1.40'a karşı −%0.90; P = 0.007) ve CRP düzeylerinde (P = 0.029) görülen düşüş RYGB grubunda daha belirgindi. Yapısal ters yeniden şekillenme açısından da RYGB sonrası tablo daha dikkat çekiciydi; nitekim LVMİ gerilemesi (ortanca −12.0'a karşı −6.5 g/m²,⁷; P<0.001) ve EAT azalması (−1.20'ye karşı −0.70 mm; P = 0.014) daha fazlaydı. Beklenildiği üzere GLS değerleri her iki grupta da iyileşme eğilimi gösterdi (−%2.33'e karşı −%1.40; P = 0.031). Buna rağmen çok değişkenli analizler, miyokardiyal fonksiyondaki bu toparlanmanın cerrahi prosedürden ziyade hastanın başlangıç GLS değeri, sol ventrikül kitlesindeki azalma, HbA1c regülasyonu ve CRP düşüşü ile bağımsız olarak ilişkili olduğunu gösterdi.

Sonuç: Şiddetli obezite olgularında bariatrik cerrahinin, kardiyak yapıda güçlü bir tersine iyileşme sağladığı açıktır. RYGB, daha yüksek düzeyde yapısal gerilemeyle ilişkilidir. Öte yandan miyokardiyal deformasyondaki toparlanma süreci, seçilen anatomik cerrahiden çok metabolik iyileşme ve inflamasyonun baskılanmasıyla tetiklenmektedir. Tüm bu bulgular, kardiyak işlevlerin geri kazanılmasının yalnızca basit bir kilo kaybının sonucu olmadığını; aksine yapısal, metabolik ve inflamatuar mekanizmaların karmaşık ve eş güdümlü restorasyonu sayesinde gerçekleştiğini düşündürmektedir.

Anahtar Kelimeler: Bariatrik cerrahi, epikardiyal yağ dokusu, global longitudinal strain, sol ventrikül yeniden şekillenmesi, obezite

Obesity affects more than 650 million adults worldwide and has redefined the traditional spectrum of cardiovascular disease.[1,2] It is associated with a distinct pattern of cardiac disease characterized by left ventricular (LV) hypertrophy and concentric remodeling. Although standard assessments often demonstrate preserved ejection fraction, affected individuals frequently exhibit underlying diastolic dysfunction and subclinical systolic impairment. Because conventional echocardiography may fail to detect these early abnormalities, two-dimensional speckle-tracking-derived global longitudinal strain (GLS) has emerged as an optimal diagnostic tool.[3] This remodeling is driven by multiple interrelated mechanisms, including chronic hemodynamic stress resulting from increased blood volume and elevated cardiac output, compounded by metabolic disturbances such as lipotoxicity and insulin resistance.[4] Additionally, visceral and epicardial fat depots contribute to ongoing tissue injury through systemic and paracrine inflammatory mechanisms.[5]

Bariatric surgery is the most effective long-term treatment for severe obesity (body mass index [BMI] ≥ 35 kg/m²), offering substantial benefits for both body composition and metabolic function. Sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB) both result in significant weight loss; however, their distinct surgical approaches produce different physiological effects. RYGB alters gut hormone pathways—most notably increasing glucagon-like peptide-1 (GLP-1) and peptide YY (PYY)—leading to rapid improvements in blood sugar control, often preceding meaningful weight reduction. In contrast, SG primarily restricts stomach size and modulates ghrelin levels.[6] Following either procedure, the heart undergoes significant reverse remodeling, including reductions in LV mass, improved diastolic function, and enhanced GLS.[7] Systemic inflammation

ABBREVIATIONS

ASE	American Society of Echocardiography
CRP	C-reactive protein
EACVI	European Association of Cardiovascular Imaging
EAT	Epicardial adipose tissue
GLP-1	Glucagon-like peptide-1
GLS	Global longitudinal strain
HbA1c	Glycated hemoglobin
LDL-C	Low-density lipoprotein cholesterol
LV	Left ventricular
LVEF	Left ventricular ejection fraction
LVMI	Left ventricular mass index
LVMI	Left ventricular mass index
PYY	Peptide YY
RYGB	Roux-en-Y gastric bypass
SG	Sleeve gastrectomy
TNF-α	Tumor necrosis factor-alpha

also declines markedly after surgery, as evidenced by decreased levels of C-reactive protein (CRP), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-α).[8] However, most studies combine multiple procedures or rely on uncontrolled observational data, limiting the availability of true direct comparisons.[6] Any procedure-specific advantage may have important clinical implications.

A critical question emerges from these findings: does cardiac recovery simply reflect mechanical unloading from weight loss, or do the distinct metabolic effects of specific procedures drive differential remodeling? The emerging concept of an "enterocardiac" pathway supports the latter. Indeed, reductions in visceral fat and resolution of systemic inflammation may influence cardiac outcomes more profoundly than absolute reductions in BMI.[9] This potential procedure-specific advantage carries substantial clinical significance. If RYGB confers superior, weight-independent cardiac benefits, this could fundamentally reshape surgical decision-making for patients with obesity and underlying heart failure.

To address this gap in the literature, we prospectively compared SG and RYGB in patients with severe obesity. Our primary objective was to quantify six-month changes in LV mass index and GLS, enabling us to disentangle the contributions of mechanical unloading, metabolic adaptation, and inflammatory attenuation to cardiac reverse remodeling. Our hypothesis was specific. We expected RYGB to induce greater structural regression of LV mass. In contrast, we anticipated that improvements in GLS would be largely independent of anatomy, reflecting instead profound systemic metabolic and inflammatory changes.

Materials and Methods

This prospective observational cohort study was conducted at the Departments of Cardiology and General Surgery of a large university hospital between May 2024 and June 2025. Participants were evaluated at baseline (preoperative) and at six months following surgery. The study protocol received The Scientific Research Ethics Committee of Kafrelsheikh University (Approval Number: KFSIRB200-225, Date: 29.04.2024), and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment. The study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies.

Eligible participants were adults (≥ 18 years) with obesity and a BMI > 35 kg/m^2 who had an indication for primary bariatric surgery, as determined by the treating surgical team. Patients were enrolled consecutively. To isolate obesity-related subclinical cardiac remodeling, individuals with established cardiac disease were excluded, including prior myocardial infarction or ischemic heart disease, greater-than-mild valvular disease, previous cardiac surgery, persistent atrial fibrillation, left bundle branch block, or prior bariatric procedures. Patients with inadequate acoustic windows for speckle-tracking analysis (defined as > 2 non-traceable myocardial segments on baseline echocardiography) were also excluded.[10]

During recruitment, 27 patients were excluded to achieve the target of 50 evaluable patients per group: five due to prior myocardial infarction, one due to previous cardiac surgery, two due to persistent atrial fibrillation, seven due to prior bariatric surgery, and 12 due to poor acoustic windows.

Sample size was calculated a priori based on the primary endpoint, defined as the absolute change in global longitudinal strain (ΔGLS). To detect a between-group difference of 1.5 percentage points (assuming a standard deviation of 2.2) with 90% statistical power and a two-sided α level of 0.05, at least 46 patients per group was required. To account for potential attrition during follow-up, 100 patients were initially enrolled.[4]

Participants were recruited consecutively according to their scheduled surgical procedure. Enrollment continued until 50 evaluable patients were obtained in each surgical group: sleeve gastrectomy and Roux-en-Y gastric bypass. The choice of surgical procedure was determined by the treating surgical team in accordance with routine clinical practice.

At both study visits, standardized clinical evaluation included medical history, medication use, smoking status, and physical measurements (resting blood pressure and heart rate). Fasting blood samples were analyzed in the hospital laboratory using validated assays to measure plasma glucose, glycated hemoglobin (HbA1c), total cholesterol, triglycerides, low-density lipoprotein cholesterol (LDL-C), C-reactive protein, and interleukin-6.

Transthoracic echocardiography was performed using a Philips EPIQ 7C system with electrocardiographic (ECG) gating, in accordance with recommendations from the European Association of Cardiovascular Imaging and the American Society of Echocardiography.[11] Three cardiac cycles per view were stored in DICOM (Digital Imaging and Communications in Medicine) format, and identical acquisition and analysis settings were applied at baseline and follow-up to minimize measurement variability.

Left ventricular dimensions and wall thickness were measured from parasternal long-axis views using 2D-guided M-mode recordings to ensure optimal alignment with the LV long axis, in accordance with current recommendations from the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI). Left ventricular mass was calculated using the Devereux-modified ASE formula and indexed to height$^{2.7}$ to derive the left ventricular mass index (LVMI), while left ventricular ejection fraction (LVEF) was calculated using the biplane Simpson method. Epicardial adipose tissue (EAT) thickness was measured at the end-systole over the right ventricular free wall in parasternal long- and short-axis views at the point of maximal thickness. The mean of three measurements was recorded.

Two-dimensional speckle-tracking echocardiography was acquired from apical two-, three-, and four-chamber views, with frame rates optimized between 50 and 80 frames/s. Offline analysis was performed using Philips QLAB software, with semi-automated endocardial border tracking and manual adjustment when required. Global longitudinal strain was calculated as the mean peak systolic strain across a 17-segment model.

All analyses were performed by a single primary reader blinded to patient identifiers, surgical procedure, and time point. Baseline and follow-up studies were analyzed in randomized order to

Table 1. Baseline characteristics of patients undergoing sleeve gastrectomy and RYGB

Variables	Sleeve gastrectomy (n = 50)	RYGB (n = 50)	*P*	Effect size
Demographic characteristics				
Age (years), mean ± SD	36.52 ± 8.52	35.28 ± 7.84	0.451	d = 0.15
Female sex, n (%)	32 (64%)	35 (70%)	0.523	Φ = 0.064
Comorbidities				
Hypertension, n (%)	28 (56%)	26 (52%)	0.688	Φ = 0.040
Diabetes mellitus, n (%)	15 (30%)	20 (40%)	0.295	Φ = 0.105
Hyperlipidemia, n (%)	27 (54%)	29 (58%)	0.687	Φ = 0.040
Smoking, n (%)	9 (18%)	7 (14%)	0.585	Φ = 0.055
Medications				
Antihypertensive therapy, n (%)	18 (36%)	18 (36%)	1.000	Φ = 0.000
Antidiabetic therapy, n (%)	13 (26%)	17 (34%)	0.383	Φ = 0.087
Statin therapy, n (%)	19 (38%)	21 (42%)	0.683	Φ = 0.041
Clinical parameters				
SBP (mmHg)	139.26 ± 17.60	135.96 ± 18.77	0.367	d = 0.18
DBP (mmHg)	92.10 ± 9.83	90.64 ± 7.29	0.401	d = 0.17
BMI (kg/m²)	46.49 ± 5.43	47.80 ± 6.87	0.291	d = −0.21
Waist circumference (cm)	127.08 ± 17.70	130.20 ± 18.48	0.391	d = −0.17
CRP (mg/L)	12.27 ± 8.80	12.34 ± 7.63	0.966	d = −0.01
Echocardiographic parameters				
LVMI (g/m$^{2.7}$)	51.39 ± 11.95	50.13 ± 10.60	0.579	d = 0.11
Ejection fraction (%)	57.46 ± 4.91	57.09 ± 5.63	0.730	d = 0.07
E/A ratio	1.16 ± 0.33	1.20 ± 0.30	0.579	d = −0.14
E/e′ ratio	9.28 ± 2.42	9.94 ± 2.34	0.166	d = -0.28
LAVI (mL/m²)	15.90 ± 2.84	15.75 ± 2.52	0.774	d = 0.06
GLS (%)	−17.97 ± 1.56	−17.61 ± 1.89	0.291	d = −0.21
Epicardial adipose tissue thickness (mm)	5.10 ± 0.78	5.24 ± 0.90	0.391	d = −0.17

BMI, Body mass index; CRP, C-reactive protein; DBP, Diastolic blood pressure; E/A, Ratio of peak early to late diastolic filling velocity; EAT, Epicardial adipose tissue; GLS, Global longitudinal strain; LAVI, Left atrial volume index; LVMI, Left ventricular mass index; RYGB, Roux-en-Y gastric bypass; SBP, Systolic blood pressure; SD, Standard deviation; SG, Sleeve gastrectomy. Continuous variables are presented as mean ± standard deviation and compared using the independent samples t-test. Categorical variables are presented as number (percentage) and compared using Pearson's chi-square test. Effect sizes are reported as Cohen's d for continuous variables and the Phi coefficient for categorical variables. A P value < 0.05 was considered statistically significant.

minimize chronological bias. Interobserver reproducibility for GLS was assessed in 20 randomly selected studies, demonstrating excellent agreement (intraclass correlation coefficient 0.946, 95% confidence interval [CI]: 0.872–0.978; P < 0.001).

Statistical Analysis

Continuous variables are reported as mean ± standard deviation or median (interquartile range), as appropriate, and categorical variables as counts and percentages. Normality was assessed using the Shapiro–Wilk test and visual inspection of histograms. Between-group comparisons were performed using the independent samples t-test or the Mann–Whitney U test for continuous variables, and Pearson's chi-square test for categorical variables. Between-group differences are presented as mean differences with 95% confidence intervals for parametric variables and as Hodges–Lehmann median differences with 95% CI for nonparametric variables. Associations between continuous variables were evaluated using Spearman rank correlation. Effect sizes (Cohen's d, rank-biserial r, or Phi φ) were also calculated.

Multivariable linear regression (enter method) was used to identify independent predictors of cardiac improvement. Standardized (β) and unstandardized (B) coefficients with 95% CI are reported. The ΔLVMI model included baseline LV mass index, procedure type, ΔHbA1c, and excess weight loss (EWL%). The ΔGLS model included baseline GLS, ΔLV mass, ΔHbA1c, ΔCRP, ΔEAT, EWL%, and procedure type. Baseline values of the dependent variables were included to account for regression to the mean. Collinearity diagnostics confirmed no significant multicollinearity. Change in BMI was not entered separately into the multivariable models to preserve model parsimony and avoid conceptual redundancy. Instead, excess weight loss was retained as the primary anthropometric predictor, as it represents the standardized metric in bariatric literature and accounts for baseline variations in excess weight. Statistical analyses were performed using SPSS version 28.0 (IBM Corp., Armonk, NY, USA). All tests were two-sided, with P < 0.05 considered statistically significant.

Table 2. Six-month changes following sleeve gastrectomy and RYGB

Variables	Sleeve gastrectomy (n = 50)	RYGB (n = 50)	*p*	Effect size	Difference (95% CI)
Anthropometric and hemodynamic changes					
ΔBMI (kg/m²)	−9.32 ± 2.42	−10.74 ± 2.42	0.004	d = 0.59	1.42 (0.46 to 2.38)
EWL (%)	45.55 ± 14.73	50.22 ± 14.30	0.112	d = 0.32	4.66 (−1.10 to 10.43)
ΔSBP (mmHg)	−13.96 ± 6.66	−13.12 ± 6.22	0.516	d = -0.13	−0.84 (−3.40 to 1.72)
Metabolic improvements					
ΔHbA1c (%)	−0.90 (−1.40 to −0.30)	−1.40 (−2.10 to −0.70)	0.007	r = 0.27	0.30 (0.10 to 0.50)
ΔTC (mg/dL)	−29.38 ± 25.10	−42.42 ± 21.00	0.006	d = 0.56	13.04 (3.88 to 22.20)
ΔTG (mg/dL)	−48 (−90 to −15)	−65 (−120 to −30)	0.200	r = 0.13	11 (−6 to 29)
Inflammatory markers					
ΔCRP (mg/L)	−3.10 (−6.00 to −1.00)	−4.80 (−8.20 to −2.30)	0.029	r = 0.22	2.10 (0.20 to 3.90)
ΔIL-6 (pg/mL)	−1.20 (−2.10 to −0.40)	−2.10 (−3.50 to −1.10)	0.028	r = 0.22	0.73 (0.08 to 1.32)
Cardiac structural remodeling and functional improvement					
ΔLVMI (g/m²)	−6.50 (−11.00 to −2.00)	−12.00 (−18.00 to −6.00)	<0.001	r = 0.43	1.76 (1.04 to 2.39)
ΔRWT	−0.035 (−0.050 to −0.030)	−0.050 (−0.060 to −0.040)	<0.001	r = 0.36	0.01 (0.01 to 0.02)
ΔEAT (mm)	−0.70 (−1.20 to −0.30)	−1.20 (−1.80 to −0.60)	0.014	r = 0.26	0.50 (0.10 to 0.90)
ΔGLS (%)	−1.40 ± 2.22	−2.33 ± 2.01	0.031	d = 0.44	0.93 (0.10 to 1.76)
ΔE/A ratio	0.10 (−0.05 to 0.30)	0.18 (0.02 to 0.40)	<0.001	r = 0.41	−0.08 (−0.04 to −0.12)
ΔE/e′ ratio	−0.74 ± 1.04	−1.00 ± 1.68	0.353	d = 0.19	0.26 (−0.29 to 0.82)
ΔLAVI (mL/m²)	1.27 ± 1.37	1.15 ± 1.45	0.684	d = 0.08	0.12 (−0.45 to 0.68)
ΔEF (%)	2.10 ± 2.13	2.48 ± 2.48	0.411	d = 0.17	−0.38 (−1.29 to 0.53)

Δ, Absolute change from baseline; BMI, Body mass index; CI, Confidence interval; CRP, C-reactive protein; E/A, Ratio of peak early to late diastolic filling velocity; E/e′, Ratio of early diastolic mitral inflow velocity to early diastolic annular velocity; EAT, Epicardial adipose tissue; EF, Ejection fraction; EWL, Excess weight loss; GLS, Global longitudinal strain; HbA1c, Glycated hemoglobin; IL-6, Interleukin-6; LAVI, Left atrial volume index; LVMI, Left ventricular mass index; RWT, Relative wall thickness; RYGB, Roux-en-Y gastric bypass; SBP, Systolic blood pressure; SG, Sleeve gastrectomy; TC, Total cholesterol; TG, Triglycerides. Data are presented as mean ± standard deviation for normally distributed variables and as median (interquartile range) for non-normally distributed variables. Between-group comparisons were performed using the independent samples t-test for normally distributed variables and the Mann–Whitney U test for non-normally distributed variables. Effect sizes are reported as Cohen's d for parametric variables and rank-biserial correlation (r) for nonparametric variables. Between-group differences are presented as mean differences with 95% confidence intervals (CI) for parametric variables and as Hodges–Lehmann median differences with 95% CI for nonparametric variables. All tests were two-tailed, and a P value < 0.05 was considered statistically significant.

Results

A total of 100 patients with severe obesity were prospectively enrolled, including 50 undergoing sleeve gastrectomy and 50 undergoing Roux-en-Y gastric bypass. Baseline demographic, clinical, metabolic, and echocardiographic characteristics were broadly comparable between the groups, with no statistically significant differences observed (Table 1). The cohort had a mean age of 35.9 years (SG: 36.52 ± 8.52 years; RYGB: 35.28 ± 7.84 years), and two-thirds of participants were female. The mean BMI was 47.1 kg/m². Comorbidities, including hypertension, diabetes mellitus, and hyperlipidemia, were similarly distributed between groups. Baseline echocardiographic parameters, including left ventricular mass index, global longitudinal strain, ejection fraction, E/A ratio, and epicardial adipose tissue thickness, were also comparable across groups.

At the six-month follow-up, both procedures produced substantial improvements in anthropometric, hemodynamic, metabolic, and inflammatory parameters (Table 2). RYGB was associated with a significantly greater reduction in BMI compared with SG (P = 0.004; Cohen's d = 0.59). However, excess weight loss and reductions in systolic blood pressure did not differ significantly between groups. Metabolic improvements were more pronounced following RYGB, including greater reductions in HbA1c (P = 0.007; rank-biserial r = 0.27) and total cholesterol (P = 0.006; Cohen's d = 0.56), while triglyceride reductions were comparable (P = 0.200). Inflammatory markers decreased significantly in both groups, with RYGB yielding larger reductions in C-reactive protein (P = 0.029; r = 0.22) and interleukin-6 (P = 0.028; r = 0.22).

Significant cardiac reverse remodeling was observed postoperatively in both groups, with greater reductions in LVMI (P < 0.001; r = 0.43), relative wall thickness (RWT; P < 0.001; r = 0.36), and EAT thickness (P = 0.014; r = 0.26) following RYGB. Myocardial function improved more markedly after RYGB, as evidenced by improvements in GLS (P = 0.031; Cohen's d = 0.44) and the E/A ratio (P < 0.001; r ≈ 0.41). Changes in left ventricular ejection fraction were modest and similar between groups (P = 0.411).

A moderate positive correlation was observed between ΔLVMI and ΔGLS (Spearman ρ = 0.465, P < 0.001), indicating that greater structural regression was associated with greater functional recovery (Figure 1). Multivariable linear regression analyses (Table 3) identified independent predictors of cardiac remodeling. For

Table 3. Multivariable linear regression analysis of predictors of left ventricular mass regression and global longitudinal strain improvement

Predictor	ΔLVMI (Structural remodeling)			ΔGLS (Functional Improvement)		
	B (95% CI)	β	*P*	B (95% CI)	β	*P*
Procedure type	−1.521 (−2.05 to −0.99)	−0.372	< 0.001	0.232 (−0.49 to 0.95)	0.055	0.529
Baseline LVMI	−0.122 (−0.15 to −0.09)	−0.670	< 0.001	—	—	—
Baseline GLS	—	—	—	−0.321 (−0.54 to −0.10)	−0.260	0.004
ΔHbA1c	0.463 (0.01 to 0.91)	0.133	0.045	0.674 (0.02 to 1.33)	0.185	0.043
EWL (%)	−0.004 (−0.02 to 0.01)	−0.030	0.627	−0.015 (−0.04 to 0.01)	−0.105	0.239
ΔLV Mass	—	—	—	0.261 (0.08 to 0.44)	0.250	0.006
ΔCRP	—	—	—	0.046 (0.00 to 0.09)	0.181	0.032
ΔEAT	—	—	—	0.360 (−0.01 to 0.73)	0.168	0.052

B, Unstandardized coefficient; β, Standardized beta coefficient; CI, Confidence interval; CRP, C-reactive protein; EAT, Epicardial adipose tissue; EWL, Excess weight loss; GLS, Global longitudinal strain; HbA1c, Glycated hemoglobin; LV, Left ventricular; LVMI, Left ventricular mass index.Multivariable linear regression analyses were performed using the enter method. Results are presented as standardized beta coefficients (β) and unstandardized coefficients (B) with 95% confidence intervals (CI). The ΔLVMI model included baseline left ventricular mass index (LVMI), procedure type (sleeve gastrectomy vs. Roux-en-Y gastric bypass), change in glycated hemoglobin (ΔHbA1c), and excess weight loss (EWL%). The ΔGLS model included baseline global longitudinal strain (GLS), change in LV mass index (ΔLVMI), ΔHbA1c, change in C-reactive protein (ΔCRP), change in epicardial adipose tissue thickness (ΔEAT), EWL%, and procedure type. Baseline values of the dependent variables were included to account for regression to the mean and interindividual variability. Collinearity diagnostics were assessed using variance inflation factors (VIF), with no evidence of significant multicollinearity. All tests were two-tailed, and a P value < 0.05 was considered statistically significant.

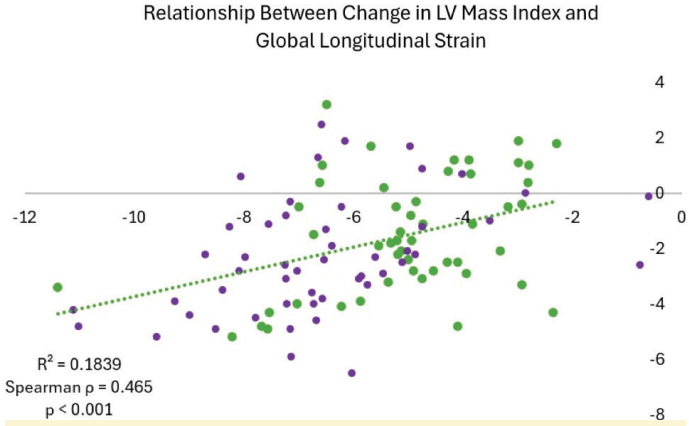

Figure 1. Association between changes in left ventricular mass index and global longitudinal strain following bariatric surgery. Scatter plot illustrating the relationship between change in left ventricular mass index (ΔLVMI) and change in global longitudinal strain (ΔGLS) at six months after bariatric surgery. Each point represents an individual patient. A moderate positive correlation was observed between LVMI regression and improvement in myocardial deformation (Spearman ρ = 0.465; P < 0.001), indicating that greater structural reverse remodeling was associated with greater functional recovery.

ΔLVMI, significant predictors included procedure type (RYGB vs. SG; β = -0.372; P < 0.001), baseline LVMI (β = -0.670; P < 0.001), and ΔHbA1c (β = 0.133; P = 0.045), whereas EWL% was not significant. This model explained 64% of the variance (adjusted R^2 = 0.643). For ΔGLS, independent predictors were baseline GLS (β = -0.260; P = 0.004), ΔLVMI (β = 0.250; P = 0.006), ΔHbA1c (β = 0.185; P = 0.043), and ΔCRP (β = 0.181; P = 0.032), with ΔEAT showing borderline significance (β = 0.168; P = 0.052). Procedure type and EWL% were not independently associated. No multicollinearity was detected (variance inflation factors < 2.5), and the model explained 44% of the variance (adjusted R^2 = 0.441).

Discussion

In this prospective cohort of patients with severe obesity undergoing bariatric surgery, we observed a coordinated pattern of cardiac recovery characterized by partially distinct structural and functional responses. Structural reverse remodeling of the left ventricle was strongly influenced by surgical procedure, with Roux-en-Y gastric bypass producing greater regression of LV mass. In contrast, improvement in myocardial deformation appeared largely independent of surgical anatomy and was instead associated with metabolic improvement, attenuation of systemic inflammation, and the magnitude of LV mass regression. Collectively, these findings suggest that structural and functional myocardial recovery after bariatric surgery are driven by overlapping but distinct mechanisms: surgical anatomy primarily influences LV mass regression, whereas metabolic and inflammatory improvements predominantly drive recovery of myocardial deformation.

Both procedures resulted in significant regression of LVMI; however, the magnitude of change was substantially greater after Roux-en-Y gastric bypass, with nearly double the median reduction compared with sleeve gastrectomy (P < 0.001). Importantly, procedure type remained an independent predictor of LVMI regression after multivariable adjustment (β = −0.372, P < 0.001), supporting a procedure-specific effect beyond baseline metabolic differences.

The degree of LV mass regression observed in our cohort is consistent with prior pooled analyses. Aggarwal et al.[4] reported a 12.2% reduction in LV mass, a finding supported by the large meta-analysis of Sargsyan et al.[12] Similarly, Cuspidi et al.,[13] in a meta-analysis of 1,022 patients, demonstrated significant reductions in both LV mass and relative wall thickness following bariatric surgery. Our findings extend this evidence by directly comparing surgical modalities within a single prospective cohort.

Interestingly, excess weight loss did not independently predict LVMI regression in our cohort. This finding is consistent with the long-term study by Sorimachi et al.,[14] which demonstrated

that reductions in visceral adipose tissue, rather than overall BMI change, were more strongly associated with improvements in LV mass. This concept is further supported by prior work indicating that obesity-related cardiac remodeling is influenced not only by total body weight but also by visceral adiposity, inflammatory activation, and neurohormonal pathways that directly affect myocardial structure. Direct comparisons of cardiac outcomes between SG and RYGB are limited. Kokkinos et al.[15] reported broadly comparable effects on weight loss and cardiovascular parameters, with RYGB conferring modestly greater benefits on selected indices. More recently, Henry et al.[16] demonstrated that both RYGB and sleeve gastrectomy produced greater reverse remodeling (particularly in LV mass and concentric geometry) than adjustable gastric banding. These findings support our observation of procedure-related differences in structural regression, while also highlighting that both restrictive–malabsorptive and purely restrictive approaches outperform gastric banding.

The more pronounced reverse remodeling observed after Roux-en-Y gastric bypass may therefore reflect not only greater metabolic improvement but also procedure-specific physiological effects. The BRAVE mechanisms (Bile flow alteration, Reduction of gastric size, Anatomical gut rearrangement and altered nutrient flow, Vagal manipulation, and Enteric hormone modulation) described by Ashrafian et al.,[17] including alterations in gut hormone signaling such as GLP-1 and ghrelin, provide a plausible biological framework. These hormonal adaptations may exert direct myocardial effects via an enterocardiac axis, potentially contributing to the enhanced structural response observed in our cohort.

Both surgical groups demonstrated significant improvement in global longitudinal strain, with a greater mean change observed after Roux-en-Y gastric bypass (P = 0.031). The magnitude of GLS improvement is consistent with prior pooled evidence, including the large meta-analysis by Sargsyan et al.[12] and earlier observations by Ikonomidis et al.[18] However, after multivariable adjustment, procedure type was no longer independently associated with ΔGLS. Instead, functional recovery was independently associated with baseline GLS, reduction in LV mass, improvement in HbA1c, and reduction in CRP. The independent association between ΔCRP and ΔGLS provides imaging-based support for the concept that low-grade inflammation contributes meaningfully to obesity-related myocardial dysfunction, as proposed by Ashrafian et al.[17,19]

These findings align with growing evidence that adipose tissue distribution, rather than total body weight alone, plays a central role in obesity-related cardiac dysfunction. Sorimachi et al.[14] demonstrated stronger associations between reductions in visceral adipose tissue and improvements in myocardial strain parameters than with BMI reduction. Consistent with this observation, excess weight loss was not independently associated with ΔGLS in our cohort. Epicardial adipose tissue thickness declined significantly after surgery—more prominently following RYGB—with a borderline association between ΔEAT and ΔGLS after multivariable adjustment (P = 0.052). Although this did not reach conventional statistical significance, the direction and magnitude of the association suggest that epicardial adiposity may contribute to myocardial functional recovery.

Experimental and imaging studies provide further mechanistic context. Epicardial fat is increasingly recognized as a metabolically active compartment capable of modulating myocardial function through local inflammatory signaling and mechanical ventricular interaction. Cardiac magnetic resonance imaging offers additional insight into this relationship. Gaborit et al.[20] reported a 27% reduction in epicardial fat volume six months after bariatric surgery—proportionally smaller than the 40% decrease in visceral abdominal fat—yet independent of BMI or visceral fat changes, with no alteration in myocardial triglyceride content. These observations suggest that epicardial adipose tissue represents a metabolically distinct compartment, with effects on myocardial function mediated primarily through paracrine inflammatory signaling and ventricular mechanical interaction rather than direct lipid infiltration.

The independent association between improvement in HbA1c and recovery of myocardial deformation in our cohort likely reflects restoration of myocardial metabolic efficiency following bariatric surgery. Using combined positron emission tomography (PET) and cardiac magnetic resonance imaging, Hannukainen et al.[21] demonstrated that morbid obesity is characterized by impaired myocardial substrate metabolism, including increased reliance on free fatty acid utilization and reduced glucose uptake—abnormalities that normalize after bariatric surgery in parallel with improvements in cardiac structure and function. Consistent with this concept, Iqbal et al.[22] reported that bariatric surgery leads to rapid improvements in insulin sensitivity and glycemic control, often preceding substantial weight loss, thereby highlighting a weight-independent metabolic contribution to cardiovascular recovery. Together, these findings provide a mechanistic framework linking glycemic improvement to recovery of myocardial deformation after bariatric surgery.

Beyond systolic deformation, our study also demonstrated improvement in diastolic function alongside regression of concentric geometry, reflected by a significant increase in the E/A ratio and a reduction in relative wall thickness. Additional indices of filling pressure and atrial remodeling improved following surgery in both groups. The E/e′ ratio declined after intervention; however, the magnitude of change did not differ significantly between procedures (ΔE/e′ −0.74 vs. −1.00; P = 0.353). Similarly, the left atrial volume index (LAVI), indexed to body surface area, showed modest changes without a significant between-group difference (ΔLAVI 1.27 vs. 1.15 mL/m²; P = 0.684). These findings suggest that early postoperative improvement in diastolic function occurs after both procedures and may primarily reflect enhanced ventricular relaxation and more favorable loading conditions, whereas structural atrial remodeling may require longer follow-up to become evident.[23]

This overall pattern of reverse remodeling is consistent with pooled imaging evidence across diverse bariatric cohorts. In the largest contemporary meta-analysis including over 1,000 patients, Cuspidi et al.,[13] reported significant reductions in LV mass and RWT, accompanied by improvements in diastolic indices without meaningful change in ejection fraction. Similarly, Aggarwal et al.,[4] in a systematic review of 40 imaging studies (n = 1,486), demonstrated a weighted mean increase in E/A ratio of 0.189, along with an 11.2% reduction in LV mass index and an

approximately 2-mm decrease in left atrial diameter. Sargsyan et al.[12] further confirmed a pooled increase in E/A ratio of 0.155 (95% confidence interval [CI]: 0.106–0.205), accompanied by reductions in left atrial diameter and LV diastolic dimension, reinforcing the consistency of diastolic improvement following bariatric surgery.

Taken together, these findings suggest that the determinants of cardiac recovery after bariatric surgery may differ between structural and functional domains. In our cohort, Roux-en-Y gastric bypass was associated with more pronounced structural unloading and greater reductions in inflammation, whereas improvement in myocardial deformation was more closely related to metabolic and inflammatory changes than to surgical anatomy itself. This distinction shifts the focus from identifying a universally superior surgical procedure toward understanding the mechanisms most relevant for individual patients, potentially supporting a more tailored approach to cardiovascular risk reduction in severe obesity.

This study has several strengths. It was prospectively designed, with well-balanced baseline characteristics and rigorous exclusion criteria aimed at isolating obesity-related cardiac remodeling. Speckle-tracking analysis was standardized using a single imaging platform, demonstrating excellent reproducibility (intraclass correlation coefficient [ICC] = 0.946), and multivariable modeling accounted for baseline values and potential regression to the mean.

Certain limitations warrant consideration. First, the single-center, nonrandomized design introduces a risk of residual confounding despite robust statistical adjustment. Although the multivariable models accounted for excess weight loss, RYGB was associated with a significantly greater absolute reduction in BMI (P = 0.004); therefore, we cannot fully exclude the possibility that differences in the magnitude of weight loss contributed, at least in part, to the observed procedure-specific differences in LV mass regression. Second, although the six-month follow-up captures the most dynamic phase of reverse remodeling, it limits extrapolation to longer-term cardiac adaptation. Third, pharmacotherapy represents a potential confounder. While medication use was documented, we did not systematically quantify dose reduction or discontinuation of antihypertensive and antidiabetic agents. As these changes were more frequent following RYGB, withdrawal of hemodynamically active medications may have contributed to the observed myocardial recovery independently of surgical anatomy. Future studies should incorporate detailed tracking of medication dose adjustments to better isolate true procedure-specific effects. Finally, the absence of routine measurement of cardiac biomarkers, such as N-terminal pro–B-type natriuretic peptide (NT-proBNP), limits our ability to firmly bridge echocardiographic observations with the corresponding serological data and objective biochemical markers of ventricular wall stress.

Conclusion

In this prospective observational cohort of patients with severe obesity undergoing bariatric surgery, significant reverse cardiac remodeling was observed at six months, including reductions in left ventricular mass index and epicardial adipose tissue thickness, along with improvements in myocardial deformation and diastolic function. Roux-en-Y gastric bypass was associated with greater structural regression, whereas recovery of myocardial deformation was primarily related to metabolic improvement and reduction in systemic inflammation rather than surgical anatomy itself. These findings suggest that cardiac recovery after bariatric surgery reflects coordinated structural, metabolic, and inflammatory restoration that extends beyond weight loss alone.

Ethics Committee Approval: Ethics committee approval was obtained from The Scientific Research Ethics Committee of Kafrelsheikh University (Approval Number: KFSIRB200-225, Date: 29.04.2024).

Informed Consent: Written informed consent was obtained from the patients.

Conflict of Interest: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study received no financial support.

Use of AI for Writing Assistance: Artificial intelligence-based tools were used to assist with language refinement and paraphrasing of the manuscript.

Author Contributions: Concept – K.A.M., O.A.E., M.E.A.; Design – K.A.M., R.N.D., O.A.E., M.S.F.; Supervision – R.M.E., M.S.F., E.E.E.G.; Resource – R.M.E., M.S.F., D.A.M.A.; Materials – K.A.M., R.N.D., O.A.E.; Data Collection and/or Processing – M.E.A., R.B., W.A.H.; Analysis and/or Interpretation – R.N.D., R.M.E., W.A.H.; Literature Review – E.E.E.G., D.A.M.A., R.B.; Writing – R.M.E., E.E.E.G., M.E.A., R.B.; Critical Review – M.S.F., D.A.M.A., W.A.H.

Peer-review: Externally peer-reviewed.

References

1. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in underweight and obesity from 1990 to 2022: a pooled analysis of 3663 population-representative studies with 222 million children, adolescents, and adults. *Lancet*. 2024;403(10431):1027-1050.
2. Haththotuwa RN, Wijeyaratne CN, Senarath U. Chapter 1 - Worldwide epidemic of obesity. In: Mahmood TA, Arulkumaran S, Chervenak FA, eds. Obesity and Obstetrics. *Elsevier*;2020:3-8. [CrossRef]
3. Gherbesi E, Gianstefani S, Angeli F, et al. Myocardial strain of the left ventricle by speckle tracking echocardiography: From physics to clinical practice. *Echocardiography*. 2024;41(1):e15753. [CrossRef]
4. Aggarwal R, Harling L, Efthimiou E, Darzi A, Athanasiou T, Ashrafian H. The Effects of Bariatric Surgery on Cardiac Structure and Function: a Systematic Review of Cardiac Imaging Outcomes. *Obes Surg*. 2016;26(5):1030-1040. [CrossRef]
5. Henry JA, Abdesselam I, Deal O, et al. Changes in epicardial and visceral adipose tissue depots following bariatric surgery and their effect on cardiac geometry. *Front Endocrinol (Lausanne)*. 2023;14:1092777. [CrossRef]
6. Nauck MA, Quast DR, Wefers J, Pfeiffer AFH. The evolving story of incretins (GIP and GLP-1) in metabolic and cardiovascular disease: A pathophysiological update. *Diabetes Obes Metab*. 2021;23(S3):5-29. [CrossRef]
7. Lascaris B, Pouwels S, Houthuizen P, et al. Cardiac structure and function before and after bariatric surgery: a clinical overview. *Clin Obes*. 2018;8(6):434-443. [CrossRef]
8. Askarpour M, Khani D, Sheikhi A, Ghaedi E, Alizadeh S. Effect of Bariatric Surgery on Serum Inflammatory Factors of Obese Patients: a Systematic Review and Meta-Analysis. *Obes Surg*. 2019;29(8):2631-2647. [CrossRef]
9. Vicardi M, Farzaneh-Far A, Fava C, Dalle Carbonare L, Romano S. Epicardial and Visceral Adipose Tissue and Global Longitudinal Strain: A Review of Cardiac Imaging Insights in Subclinical Myocardial Dysfunction. *Nutrients*. 2026;18(6):1009. [CrossRef]

10. Voigt JU, Pedrizzetti G, Lysyansky P, et al. Definitions for a common standard for 2D speckle tracking echocardiography: consensus document of the EACVI/ASE/Industry Task Force to standardize deformation imaging. *Eur Heart J Cardiovasc Imaging*. 2015;16(1):1-11. [CrossRef]
11. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr*. 2015;28(1):1-39.e14. [CrossRef]
12. Sargsyan N, Chen JY, Aggarwal R, Fadel MG, Fehervari M, Ashrafian H. The effects of bariatric surgery on cardiac function: a systematic review and meta-analysis. *Int J Obes (Lond)*. 2024;48(2):166-176. [CrossRef]
13. Cuspidi C, Rescaldani M, Tadic M, Sala C, Grassi G. Effects of bariatric surgery on cardiac structure and function: a systematic review and meta-analysis. *Am J Hypertens*. 2014;27(2):146-156. [CrossRef]
14. Sorimachi H, Obokata M, Omote K, et al. Long-Term Changes in Cardiac Structure and Function Following Bariatric Surgery. *J Am Coll Cardiol*. 2022;80(16):1501-1512. [CrossRef]
15. Kokkinos A, Alexiadou K, Liaskos C, et al. Improvement in cardiovascular indices after Roux-en-Y gastric bypass or sleeve gastrectomy for morbid obesity. *Obes Surg*. 2013;23(1):31-38. [CrossRef]
16. Henry JA, Abdesselam I, Deal O, et al. The effect of bariatric surgery type on cardiac reverse remodelling. *Int J Obes (Lond)*. 2024;48(6):808-814. [CrossRef]
17. Ashrafian H, le Roux CW, Darzi A, Athanasiou T. Effects of Bariatric Surgery on Cardiovascular Function. *Circulation*. 2008;118(20):2091-2102. [CrossRef]
18. Ikonomidis I, Mazarakis A, Papadopoulos C, et al. Weight loss after bariatric surgery improves aortic elastic properties and left ventricular function in individuals with morbid obesity: a 3-year follow-up study. *J Hypertens*. 2007;25(2):439-447. [CrossRef]
19. Erbay İ, Aladağ P. The Hemoglobin, Albumin, Lymphocyte, and Platelet Score as a Simple Blood-Based Predictor of Residual Coronary Disease Burden in Diabetic Patients with Non-ST-Elevation Myocardial Infarction. *Turk Kardiyol Dern Ars*. 2025;53(7):483-491. [CrossRef]
20. Gaborit B, Jacquier A, Kober F, et al. Effects of bariatric surgery on cardiac ectopic fat: lesser decrease in epicardial fat compared to visceral fat loss and no change in myocardial triglyceride content. *J Am Coll Cardiol*. 2012;60(15):1381-1389. [CrossRef]
21. Hannukainen JC, Lautamäki R, Pärkkä J, et al. Reversibility of myocardial metabolism and remodelling in morbidly obese patients 6 months after bariatric surgery. *Diabetes Obes Metab*. 2018;20(4):963-973. [CrossRef]
22. Iqbal Z, Adam S, Ho JH, et al. Metabolic and cardiovascular outcomes of bariatric surgery. *Curr Opin Lipidol*. 2020;31(4):246-256. [CrossRef]
23. Karagöz U, Kahya Eren N, Özdemir E, Emren SV, Gürsoy MO, Tokaç M. Left Ventricular Hypertrophy Findings on Electrocardiogram Predict Impaired Left Atrial Functions. *Turk Kardiyol Dern Ars*. 2024;52(5):322-329. [CrossRef]

