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Postoperative effects of bariatric surgery on heart rate recovery and heart rate variability

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Background: Several studies have reported associations between obesity and autonomic dysfunction. However, little research has investigated the effect of bariatric surgery on heart rate recovery (HRR) in the treadmill test and heart rate variability (HRV) in 24-hour Holter monitoring. We investigated the effects of bariatric surgery on HRR and HRV, which are parameters related to autonomic dysfunction.
Methods: We retrospectively investigated patients who underwent bariatric surgery in 2019. The treadmill test, 24-hour Holter monitoring, and echocardiography were performed before and 6 months after surgery. We compared the changes in HRR in the treadmill test and HRV parameters such as the time domain and spectral domain in 24-hour Holter monitoring before and after surgery.
Results: Of the 40 patients who underwent bariatric surgery, 25 patients had the treadmill test or 24-hour Holter monitoring both before and after surgery. Body weight and body mass index significantly decreased after surgery (112.86±24.37 kg vs. 89.10±20.26 kg, $p<0.001$; 39.22±5.69 kg/m^2 vs. 31.00±5.09 kg/m^2, $p<0.001$, respectively). HRR significantly increased (n=23; 43.00±20.97 beats/min vs. 64.29±18.49 beats/min, $p=0.001$). The time domain of HRV parameters increased (n=21; standard deviation of the N-N interval 123.57±28.05 ms vs. 152.57±39.49 ms, $p=0.002$ and mean N-N interval 791.57±88.84 ms vs. 869.05±126.31 ms, $p=0.002$).
Conclusions: Our data showed that HRR after exercise and HRV during 24-hour Holter monitoring improved after weight reduction with bariatric surgery through improved cardiac autonomic function.

Keywords: Autonomic nervous system disorders; Bariatric surgery; Heart rate recovery; Heart rate variability

Introduction

Obesity is a state in which body weight is increased due to excessive accumulation of fat, defined by a body mass index (BMI) of over 30 kg/m^2. The World Health Organization estimated that 13% of the population worldwide was obese in 2016 [1]. An epidemiological study on obesity conducted in the United States reported that obesity prevalence has been gradually increasing over time [2]. Obesity is an important factor of metabolic syndrome and independent risk for cardiovascular diseases and mortality [1,3]. Of the physiologic changes occurring in obesity, autonomic dysfunction is no-

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table. Generally, the autonomic function in obese individuals is disturbed. The main mechanisms influencing various factors, such as insulin resistance, are reduced vagal tone and overactivated sympathetic nervous function [1,4,5]. Impaired autonomic function is associated with all-cause and cardiovascular mortality [6]. One study reported that cardiac autonomic dysfunction could be responsible for the 40 times higher rate of sudden cardiac death in obese people as compared to those with normal body weight [4]. Previous studies reported improvement of the autonomic function after weight loss in obese people [7-10].

Bariatric surgery is very effective intervention for weight loss that improves metabolic complications. Long-term follow-up data showed effective remission and prevention of type 2 diabetes mellitus (DM), dyslipidemia and hypertension after Roux-en-Y gastric bypass surgery [11]. After gastric bypass surgery, both disease-related mortality and risk of cardiovascular events are reduced significantly [12,13]. However, the effect on autonomic function after bariatric surgery is inconclusive.

The cardiac autonomic function can be assessed based on the heart rate recovery (HRR) in the exercise test and the heart rate variability (HRV) in 24-hour Holter monitoring. HRR is commonly defined heart rate decrease after cessation of exercise, as a predictor of coronary arterial disease and cardiovascular mortality [14]. HRV is regulated by the interaction between sympathetic and parasympathetic activities, and decreased HRV is associated with cardiovascular events [15,16].

We investigated the effects of bariatric surgery on the autonomic function and the factors influencing the improvement in autonomic function.

Methods

Ethical statements: This study was approved by the Ethics Committee of Kosin University Gospel Hospital (No. 2021-05-018). The need for written informed consent from the participants was waived because of the retrospective nature of this study.

1. Study design and population

This was a retrospective, observational, single-cohort study. We reviewed the medical records of patients who underwent bariatric surgery in 2019 at Kosin University Gospel Hospital. We excluded patients who did not undergo baseline or follow-up treadmill test and 24-hour Holter monitoring. We compared the HRR 1 minute after the treadmill test and the HRR parameters such as time domain and spectral domain on 24-hour Holter monitoring at baseline and 6 months after surgery. We also compared the body weight, BMI, glycated hemoglobin (HbA1c), fasting insulin, C-peptide, lipid profile, and echocardiographic parameters. The patients were divided according to the type of surgical procedure which is one of the factors for autonomic function.

Hypertension was defined as systolic blood pressure (BP) >140 mmHg or diastolic BP >90 mmHg or previous diagnosis. DM was defined when the patient had fasting plasma glucose level >126 mg/dL, HbA1c level >6.5%, or was treated for DM. Dyslipidemia was considered if the patient was being treated with lipid-lowering drugs. Coronary arterial disease was defined as luminal stenosis of coronary artery over 50% on coronary angiography or computed tomographic coronary angiography or a history of previous coronary artery bypass graft or percutaneous coronary angioplasty. Chronic kidney disease was defined as estimated glomerular filtration rate <60 mL/min/1.73 m^2 in the baseline laboratory test. Obstructive sleep apnea was confirmed using nocturnal polysomnography.

2. Exercise test

The exercise test was a treadmill test that was performed according to the Bruce protocol using GE CASE version 6.51 (GE Healthcare, Boston, MA, USA) before and after surgery. Participants were encouraged to exercise up to 80% of their age-predicted maximal heart rate (HR) and at stage III of the Bruce protocol. The BP and HR were recorded during the last 30 seconds of each stage immediately after the exercise and at 1, 2, and 5 minutes of recovery. HRR was defined as the difference between the maximal HR during exercise and the HR at 1 minute of recovery. S-T segment abnormality is defined as an upsloping depression ≥1.5 mm or horizontal or down-sloping depression ≥1 mm [14].

3. 24-Hour Holter monitoring

The patients were subjected to 24-hour Holter monitoring before and after surgery. The three-channel 24-hour register was obtained from seven electrodes on the thoracic surface. The electrodes were connected to a Seer Light recorder (General Electric, Milwaukee, WI, USA). While the parasites were cleaned semi-manually during the analysis, the time domain parameters, such as standard deviation of the N-N interval (SDNN), standard deviation of sequential 5-minute N-N interval means (SDANN), mean number of normal sinus R (mean NN), percentage of successive normal sinus RR interval >50 ms (pNN50), and frequency domain parameters, such as very low frequency, low frequency, high frequency, and low to high frequency ratio, were recorded automatically.

4. Echocardiography

Standard two-dimensional echocardiography was performed for all subjects using a 3.5-MHz transducer. The examiners were blinded to the information of the subjects. The echocardiographic parameters measured included the left ventricle (LV) cavity diameter, LV end-diastolic volume, and LV end-systolic volume, according to the criteria of the American Society of Echocardiography. The LV ejection fraction was measured using the Simpson's method. The pulse-wave Doppler imaging of the trans-mitral LV inflow was performed in the apical four-chamber view, with the sample volume placed at the level of the mitral valve tips. Doppler variables were analyzed during three consecutive beats. The following measurements of the global LV diastolic function were also recorded: peak early (E) and late (A) diastolic mitral flow velocity, E/A ratio, and early (E') diastolic mitral annular velocity.

5. Statistical analysis

The data were analyzed using the Statistical Product and Service Solutions version 25.0 for Windows (IBM Corp., Armonk, NY, USA). All continuous values are reported as means±standard deviations. Normally distributed variables were compared using Student *t*-test. If the data were non-normally distributed, a Wilcoxon signed-rank test was used.

Results

Of the 40 subjects, 25 were enrolled in the final analysis. The mean age of the subjects was 37.4 years. The male was 14 (56%). Moreover, 14 subjects had DM (56%) and mean duration was 5.1 years (Table 1). Laparoscopic sleeve gastrectomy was performed in 14 patients (56%), laparoscopic Roux-en-Y gastric bypass surgery in 10 (40%), and gastric band ligation in one (4%) (Table 1).

Compared to the baseline, the postoperative body weight values reduced significantly (112.86±24.37 kg vs. 89.10±20.26 kg, p<0.001), and the BMI decreased according to the weight loss (39.22±5.69 kg/m^2 vs. 31.00±5.09 kg/m^2, p<0.001). The HbA1c, fasting blood sugar, fasting insulin, and C-peptide levels reduced significantly after surgery, as well as the Homeostatic Model Assessment for Insulin Resistance score that assesses insulin resistance. In the lipid profile, the triglyceride level and high-density lipoprotein cholesterol level were improved significantly (Table 2).

The echocardiographic variables are presented in Table 3. There were no significant differences in the LV end-diastolic diameter, LV end-systolic diameter, LV end-diastolic volume, LV end-systolic volume, end-diastolic interventricular septal thickness, and end-diastolic posterior LV wall thickness values after surgery. Moreover, no changes were noted in the Doppler parameters of E velocity, A velocity, E/A ratio, E', and E/E'.

1. Exercise test

Of the 25 patients, 23 underwent the exercise test before and after the surgery. No significant ST-T segment changes were observed. The total exercise time and metabolic equivalents improved significantly after surgery, whereas the baseline HR decreased and peak HR increased significantly. The HRR after 1 minute was significantly increased from the baseline (43.00±20.97 beats/min vs. 64.29±18.49 beats/min,

Table 1. Baseline characteristics

Characteristics	Value (n=25)
Age (yr)	37.40±10.49
Male sex	14 (56.0)
Hypertension	15 (60.0)
Diabetes mellitus[a]	14 (56.0)
Dyslipidemia	11 (44.0)
Chronic kidney disease	1 (4.0)
Congestive heart failure	0
Coronary arterial disease	3 (12.5)
Fatty liver	13 (52.0)
Stroke	1 (4.0)
Sleep apnea	12 (48.0)
Laparoscopic sleeve gastrectomy	15 (60.0)
Laparoscopic Roux-en-Y gastric bypass	10 (40.0)

Values are represented as mean±standard deviation or number (%).
[a]Mean duration, 5.1 years.

Table 2. Changes in metabolic parameters

Variable	Mean±SD		p-value
	Before surgery	After surgery (6 mo)	
Weight (kg)	112.86±24.37	89.10±20.26	<0.001
Body mass index (kg/m^2)	39.22±5.69	31.00±5.09	<0.001
HbA1c (%)	7.14±1.93	5.64±0.71	<0.001
Insulin, fasting (mIU/L)	32.13±33.57	7.41±4.06	<0.001
C-peptide, fasting (ng/mL)	2.64±1.32	1.90±1.86	<0.001
Fasting blood sugar (mg/dL)	127.50±56.83	89.16±14.16	<0.001
HOMA-IR	9.26±8.61	1.63±0.96	<0.001
Triglycerides (mg/dL)	190.41±134.68	110.76±63.09	0.002
Total cholesterol (mg/dL)	174.75±51.04	168.80±42.55	0.475
High-density lipoprotein (mg/dL)	45.31±12.74	49.52±11.99	0.025
Low-density lipoprotein (mg/dL)	111.08±48.01	104.96±36.87	0.357

SD, standard deviation; HbA1c, glycated hemoglobin; HOMA-IR, Homeostatic Model Assessment for Insulin Resistance.

Table 3. Changes in echocardiographic parameters

Variable	Mean±SD		p-value
	Before surgery	After surgery (6 mo)	
LVEF (%)	64.97±4.17	61.19±4.08	0.681
LVEDD (mm)	50.60±4.39	50.22±3.59	0.823
LVESD (mm)	32.33±3.02	31.20±5.50	0.601
LVEDV (mL)	106.70±37.24	99.12±32.48	0.455
LVESV (mL)	37.69±13.60	36.02±11.54	0.823
IVSTd (mm)	10.82±1.46	10.45±1.47	0.140
PWTd (mm)	10.40±1.40	10.80±5.33	0.179
E velocity (cm/sec)	0.73±0.19	0.72±0.14	0.779
A velocity (cm/sec)	0.63±0.18	0.62±0.15	0.841
E/A ratio	1.27±0.55	1.18±0.43	0.888
E' (cm/sec)	0.10±0.11	0.08±0.01	0.794
E/E'	9.47±2.50	8.42±1.70	0.159

SD, standard deviation; LVEF, left ventricular ejection fraction; LVEDD, left ventricular end-diastolic diameter; LVESD, left ventricular end-systolic diameter; LVEDV, left ventricular end-diastolic volume; LVESV, left ventricular end-systolic volume; IVSTd, interventricular septal end diastole thickness; PWTd, posterior left ventricular wall thickness; E velocity, peak early diastolic mitral flow velocity; A velocity, late diastolic mitral flow velocity; E', early diastolic mitral annular velocity.

p=0.001) (Table 4).

2. 24-Hour Holter monitoring

Of the 25 patients, 21 patients were subjected to 24-hour Holter monitoring before and after surgery. Although maximal HR was not significantly different before and after surgery, the average HR and minimal HR showed a significant reduction after surgery. Of the time domain parameters, the mean NN, SDNN, and SDANN significantly increased after surgery. However, the frequency domain parameters like very low frequency, low frequency, high frequency, and low to high frequency ratio, did not differ statistically (Table 4).

3. Types of bariatric surgery

In laparoscopic sleeve gastrectomy cases, the HRR in the exercise test and all parameters of the time domain and frequency domain in the 24-hour Holter monitoring showed significant differences. Although SDNN, SDANN, and mean NN almost showed a statistical difference (p=0.008, p=0.006, and p=0.015, respectively), the HRR and other HRV parameters had no significant difference in laparoscopic Roux-en-Y gastric bypass surgery cases (Table 5).

Table 4. Changes of exercises test parameters and 24-hour Holter monitoring parameters

Variable		Mean±SD		*p*-value
		Before surgery	After surgery (6 mo)	
Exercise ECG test				
Time (sec)		397.52±91.14	495.48±104.18	0.001
Metabolic equivalents		8.14±1.53	9.60±1.84	0.002
Baseline	SBP (mmHg)	124.95±16.95	121.19±17.63	0.104
	DBP (mmHg)	71.90±15.80	69.62±12.55	0.475
	HR (beats/min)	78.90±18.31	68.81±15.90	0.039
Peak	SBP (mmHg)	186.19±24.81	175.48±30.75	0.080
	DBP (mmHg)	77.90±24.05	81.38±20.38	0.455
	HR (beats/min)	143.00±21.47	156.57±19.13	0.007
Recovery	SBP (mmHg)	171.19±36.67	159.67±25.66	0.104
	DBP (mmHg)	68.81±21.05	69.67±15.16	0.398
	HR (beats/min)	100.00±11.84	82.29±21.09	0.010
Change in	SBP (mmHg)	61.24±31.08	54.29±25.11	0.139
	DBP (mmHg)	6.00±19.27	11.76±20.29	0.204
Heart rate recovery (beats/min)		43.00±20.97	64.29±18.49	0.001
24-Hour Holter monitoring				
QRS interval (beats)		97,967±17,304	77,020±20,365	<0.001
HR	Minimum	51.86±6.82	47.23±7.75	0.003
	Average	76.86±8.89	71.09±9.88	0.005
	Maximum	126.38±15.88	127.59±20.07	0.835
Mean NN (ms)		791.57±88.84	869.05±126.31	0.002
SDNN (ms)		123.57±28.05	152.57±39.49	0.002
SDANN (ms)		106.19±26.44	134.76±36.82	0.001
pNN50 (%)		11.66±8.01	15.29±11.42	0.181
Frequency (ms)	Very low	31.41±11.56	33.64±12.39	0.058
	Low	19.98±11.96	20.81±8.40	0.076
	High	13.34±5.04	14.89±5.62	0.181
L/H ratio		1.48±0.40	1.72±1.69	0.263

SD, standard deviation; EGC, electrocardiogram; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; mean NN, mean number of normal sinus R; SDNN, standard deviation of the N-N interval; SDNN, standard deviation of the N-N interval; SDANN, standard deviation of sequential 5-minute N-N interval means; pNN50, percentage of successive normal sinus RR intervals >50 ms; L/H, low frequency/high frequency.

DISCUSSION

The major results of this report were increased HRR and exercise capacity; increased HRV parameters of time domain including SDNN, SDANN, and mean NN; and reduced baseline HR on exercise test and mean HR on 24-hour Holter monitoring in patients after bariatric surgery. The metabolic parameters of DM and dyslipidemia also improved.

Previous studies have reported an association between autonomic function and weight reduction [7-9,17]. Brinkworth et al. [10] showed that the HRR improved after weight loss. Similarly, Wasmund et al. [18] reported improvement in the HRR 2 years after gastric bypass surgery, and Nault et al. [19] reported an increase in HRV on 24-hour Holter monitoring following weight loss after biliopancreatic diversion and duodenal switch surgery. Maser et al. [20] reported favorable effects on the cardiovascular autonomic function 12 months after surgery. However, some studies reported unfavorable results after bariatric surgery [21-23]. Zhang et al. [22] reported that approximately 4.2% of patients experienced orthostatic intolerance within 5 years of bariatric surgery, and 16.5% of them had severe symptoms that needed treatment with vasopressor agents. Our results showed improvement of the autonomic function, and no orthostatic intolerance was reported in the participants after bariatric surgery.

The mechanisms underlying the improvement of auto-

Table 5. Changes in parameters related to sleeve gastrectomy and bypass surgery

	Laparoscopic sleeve gastrectomy cases (n=15)			Laparoscopic Roux-en-Y gastric bypass surgery cases (n=10)		
	Before surgery	After surgery (6 mo)	*p*-value	Before surgery	After surgery (6 mo)	*p*-value
Weight (kg)	113.97±16.80	87.56±14.45	0.001	113.41±33.65	91.45±27.51	0.005
Body mass index (kg/m^2)	39.47±2.93	30.63±3.07	0.001	38.83±8.53	31.56±7.34	0.005
HRR (beats/min)	44.53±20.04	67.00±20.20	0.003	39.22±28.56	59.00±13.20	0.123
Mean NN (ms)	796.08±87.30	895.83±146.54	0.012	785.56±95.84	833.33±88.59	0.066
SDNN (ms)	117.08±30.58	152.17±38.88	0.008	132.22±23.12	153.11±42.65	0.086
SDANN (ms)	98.67±29.21	130.42±32.62	0.006	116.22±19.41	140.56±43.13	0.051
pNN50 (%)	9.58±6.10	18.42±12.90	0.015	14.43±9.71	11.12±7.92	0.374
Low frequency (ms)	18.48±4.98	22.22±10.10	0.060	21.98±17.78	18.94±5.38	0.594
High frequency (ms)	12.05±3.41	16.24±6.07	0.023	15.06±6.47	13.11±4.71	0.314
L/H ratio	1.57±0.38	1.33±0.39	0.008	1.35±0.42	2.23±2.53	0.173
HbA1c (%)	6.58±1.83	5.45±0.74	0.001	7.94±1.89	5.92±0.59	0.005
Insulin (mIU/L)	28.21±26.29	8.37±4.45	0.005	38.02±43.19	5.98±3.07	0.005
C-peptide (ng/mL)	2.60±1.49	1.66±0.65	0.004	2.70±1.11	2.28±2.88	0.139
HOMA-IR	8.19±9.80	1.78±1.03	0.004	10.87±6.62	1.41±0.84	0.005

Values are represented as mean±standard deviation.
HRR, heart rate recovery; mean NN, mean number of normal sinus R; SDNN, standard deviation of the N-N interval; SDANN, standard deviation of sequential 5-minute N-N interval means; pNN50, percentage of successive normal sinus RR intervals >50 ms; L/H, low frequency/high frequency; HbA1c, glycated hemoglobin; HOMA-IR, Homeostatic Model Assessment for Insulin Resistance.

nomic function are complex and undefined. A prospective study with type 1 DM patients showed that BMI is an independent predictor of autonomic dysfunction as well as poor glycemic control [15]. Another recent study reported that the metabolic benefits after bariatric surgery are related to weight loss itself in type 2 DM patients [24]. Some studies suggest that the improvement of autonomic function is associated with weight reduction after bariatric surgery [18,20,25]. A previous study reported that the HRV improved after bariatric surgery, and this was associated with adipose tissue and adipocyte secretors that are affected by weight loss [26]. On the other hand, Perugini et al. [27] showed that the HRV improved after laparoscopic Roux-en-Y gastric bypass surgery, which correlates with insulin resistance but not with the degree of obesity. In this study, we could not determine a correlation between the autonomic function parameters and the independent factors such as weight reduction or insulin resistance.

Autonomic function is also influenced by the surgical technique [25,28,29]. A recent meta-analysis showed gastric sleeve gastrectomy is more effective on the parasympathetic nervous function due to preserving the vagal trunk of the stomach's lesser curvature [30]. other prospective study reported that both sleeve gastrectomy and gastric bypass surgery are effective in weight reduction, remission of obesity-associated comorbidities, and improvement of quality of life but less nutritional deficiency in sleeve gastrectomy [28]. In our data, only sleeve gastrectomy group showed significant increase of HRV and HRR parameters. however, previous multiple studies reported improvement of autonomic function with gastric bypass surgery. this study is inconclusive because of small sample size and uncontrolled other factors such as diabetes (35.71% in sleeve gastrectomy vs. 90% in gastric bypass).

HRR and HRV are one of the noninvasive methods of autonomic function and reflect balance of sympathetic activities and parasympathetic activities. Previous studies reported that the risk of coronary arterial disease, death from myocardial infarction, cardiovascular mortality was increased as reduced HRR and increased resting HR [31,32]. The ARIC study showed decreased HRV parameters were important risk factor of coronary heart disease [33]. The reduction of HRV on 24-hour Holter monitoring indicates the risk of increased arrhythmia after myocardial infarction and long-term cardiac events [34,35]. So, reduction of HRR and HRV parameters are associated with cardiac autonomic dysfunction and risk of cardiovascular events. Postoperative increase of the HRR and HRV suggests improvement of autonomic function and a reduction in the cardiovascular mortality risk. It supports the findings of a prior long-term study on the mortality benefits after bariatric surgery, especially disease-related death including cardiovascular death [12].

The limitations of this study include the single-center design, small sample size, and relatively short follow-up duration. Other confounding factors, such as obstructive sleep apnea, were not well controlled. Adipocyte secretors and other neurohormones such as adiponectin and leptin were not considered in this study. Additional case-control studies with further long-term period data involving mortality and cardiovascular events are warranted.

In conclusion, our results showed that the HRR on exercise test and HRV on 24-hour Holter monitoring improved after bariatric surgery. This suggests that the improvement in the autonomic function with weight reduction after bariatric surgery could be one of the major factors in reduction of long-term cardiovascular mortality.

Article information

Conflicts of interest

Sung Il Im is an editorial board member of the journal but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflicts of interest relevant to this article were reported.

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Author contributions

Conceptualization: HSP, JHH. Data curation: HSP, JHH. Formal analysis: HSP. Investigation: HSP, JHH. Methodology: HSP, BKK, JHH. Project administration: HSP, BKK, JHH. Resources: HSP. Software: HSP. Supervision: KWS, HSK, SII, BJK, BKK, JHH. Validation: KWS, BKK, JHH. Visualization: HSP. Writing - original draft: HSP. Writing - review & editing: KWS, HSK, SII, BJK, BKK, JHH. Approval of final manuscript: all authors.

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References

1. Cercato C, Fonseca FA. Cardiovascular risk and obesity. Diabetol Metab Syndr 2019;11:74.
2. Inoue Y, Qin B, Poti J, Sokol R, Gordon-Larsen P. Epidemiology of obesity in adults: latest trends. Curr Obes Rep 2018;7:276–88.
3. GBD 2015 Obesity Collaborators, Afshin A, Forouzanfar MH, Reitsma MB, Sur P, Estep K, et al. Health effects of overweight and obesity in 195 countries over 25 years. N Engl J Med 2017;377:13–27.
4. Kannel WB, Plehn JF, Cupples LA. Cardiac failure and sudden death in the Framingham Study. Am Heart J 1988;115:869–75.
5. Kreier F, Fliers E, Voshol PJ, Van Eden CG, Havekes LM, Kalsbeek A, et al. Selective parasympathetic innervation of subcutaneous and intra-abdominal fat: functional implications. J Clin Invest 2002;110:1243–50.
6. Gerritsen J, Dekker JM, TenVoorde BJ, Kostense PJ, Heine RJ, Bouter LM, et al. Impaired autonomic function is associated with increased mortality, especially in subjects with diabetes, hypertension, or a history of cardiovascular disease: the Hoorn Study. Diabetes Care 2001;24:1793–8.
7. Balci GU, Kilicaslan B, Dursun H, Geroglu B, Ozdogan O, Ongel K. Evaluation of Holter results in patients with obesity: a cross section study. Biomed Res 2014;25:173–7.
8. Barbosa Lins TC, Valente LM, Sobral Filho DC, Barbosa e Silva O. Relation between heart rate recovery after exercise testing and body mass index. Rev Port Cardiol 2015;34:27–33.
9. Sjoberg N, Brinkworth GD, Wycherley TP, Noakes M, Saint DA. Moderate weight loss improves heart rate variability in overweight and obese adults with type 2 diabetes. J Appl Physiol (1985) 2011;110:1060–4.
10. Brinkworth GD, Noakes M, Buckley JD, Clifton PM. Weight loss improves heart rate recovery in overweight and obese men with features of the metabolic syndrome. Am Heart J 2006;152:693.e1–6.
11. Adams TD, Davidson LE, Litwin SE, Kim J, Kolotkin RL, Nanjee MN, et al. Weight and metabolic outcomes 12 years after gastric bypass. N Engl J Med 2017;377:1143–55.
12. Adams TD, Gress RE, Smith SC, Halverson RC, Simper SC, Rosamond WD, et al. Long-term mortality after gastric bypass surgery. N Engl J Med 2007;357:753–61.
13. O'Brien PE, Hindle A, Brennan L, Skinner S, Burton P, Smith A, et al. Long-term outcomes after bariatric surgery: a systematic

review and meta-analysis of weight loss at 10 or more years for all bariatric procedures and a single-centre review of 20-year outcomes after adjustable gastric banding. Obes Surg 2019;29:3–14.

14. Cole CR, Blackstone EH, Pashkow FJ, Snader CE, Lauer MS. Heart-rate recovery immediately after exercise as a predictor of mortality. N Engl J Med 1999;341:1351–7.
15. Makimattila S, Schlenzka A, Mantysaari M, Bergholm R, Summanen P, Saar P, et al. Predictors of abnormal cardiovascular autonomic function measured by frequence domain analysis of heart rate variability and conventional tests in patients with type 1 diabetes. Diabetes Care 2000;23:1686–93.
16. Melillo P, Izzo R, Orrico A, Scala P, Attanasio M, Mirra M, et al. Automatic prediction of cardiovascular and cerebrovascular events using heart rate variability analysis. PLoS One 2015;10:e0118504.
17. Triggiani AI, Valenzano A, Trimigno V, Di Palma A, Moscatelli F, Cibelli G, et al. Heart rate variability reduction is related to a high amount of visceral adiposity in healthy young women. PLoS One 2019;14:e0223058.
18. Wasmund SL, Owan T, Yanowitz FG, Adams TD, Hunt SC, Hamdan MH, et al. Improved heart rate recovery after marked weight loss induced by gastric bypass surgery: two-year follow up in the Utah Obesity Study. Heart Rhythm 2011;8:84–90.
19. Nault I, Nadreau E, Paquet C, Brassard P, Marceau P, Marceau S, et al. Impact of bariatric surgery: induced weight loss on heart rate variability. Metabolism 2007;56:1425–30.
20. Maser RE, Lenhard MJ, Irgau I, Wynn GM. Impact of surgically induced weight loss on cardiovascular autonomic function: one-year follow-up. Obesity (Silver Spring) 2007;15:364–9.
21. Ponnusamy V, Owens AP, Purkayastha S, Iodice V, Mathias CJ. Orthostatic intolerance and autonomic dysfunction following bariatric surgery: a retrospective study and review of the literature. Auton Neurosci 2016;198:1–7.
22. Zhang JB, Tamboli RA, Albaugh VL, Williams DB, Kilkelly DM, Grijalva CG, et al. The incidence of orthostatic intolerance after bariatric surgery. Obes Sci Pract 2019;6:76–83.
23. Zadjali MAL, Alam F. New onset vasovagal syncope following bariatric surgery: a case report. MOJ Womens Health 2017;4:133–4.
24. Yoshino M, Kayser BD, Yoshino J, Stein RI, Reeds D, Eagon JC, et al. Effects of diet versus gastric bypass on metabolic function in diabetes. N Engl J Med 2020;383:721–32.
25. Boido A, Ceriani V, Cetta F, Lombardi F, Pontiroli AE. Bariatric surgery and prevention of cardiovascular events and mortality in morbid obesity: mechanisms of action and choice of surgery. Nutr Metab Cardiovasc Dis 2015;25:437–43.
26. Bobbioni-Harsch E, Sztajzel J, Barthassat V, Makoundou V, Gastaldi G, Sievert K, et al. Independent evolution of heart autonomic function and insulin sensitivity during weight loss. Obesity (Silver Spring) 2009;17:247–53.
27. Perugini RA, Li Y, Rosenthal L, Gallagher-Dorval K, Kelly JJ, Czerniach DR. Reduced heart rate variability correlates with insulin resistance but not with measures of obesity in population undergoing laparoscopic Roux-en-Y gastric bypass. Surg Obes Relat Dis 2010;6:237–41.
28. Khalaj A, Tasdighi E, Hosseinpanah F, Mahdavi M, Valizadeh M, Farahmand E, et al. Two-year outcomes of sleeve gastrectomy versus gastric bypass: first report based on Tehran obesity treatment study (TOTS). BMC Surg 2020;20:160.
29. Lee WJ, Chen CY, Chong K, Lee YC, Chen SC, Lee SD. Changes in postprandial gut hormones after metabolic surgery: a comparison of gastric bypass and sleeve gastrectomy. Surg Obes Relat Dis 2011;7:683–90.
30. Geronikolou SA, Albanopoulos K, Chrousos G, Cokkinos D. Evaluating the homeostasis assessment model insulin resistance and the cardiac autonomic system in bariatric surgery patients: a meta-analysis. Adv Exp Med Biol 2017;988:249–59.
31. Morshedi-Meibodi A, Larson MG, Levy D, O'Donnell CJ, Vasan RS. Heart rate recovery after treadmill exercise testing and risk of cardiovascular disease events (The Framingham Heart Study). Am J Cardiol 2002;90:848–52.
32. Jouven X, Empana JP, Schwartz PJ, Desnos M, Courbon D, Ducimetiere P. Heart-rate profile during exercise as a predictor of sudden death. N Engl J Med 2005;352:1951–8.
33. Liao D, Cai J, Rosamond WD, Barnes RW, Hutchinson RG, Whitsel EA, et al. Cardiac autonomic function and incident coronary heart disease: a population-based case-cohort study. The ARIC Study. Atherosclerosis Risk in Communities Study. Am J Epidemiol 1997;145:696–706.
34. Saito I, Hitsumoto S, Maruyama K, Nishida W, Eguchi E, Kato T, et al. Heart rate variability, insulin resistance, and insulin sensitivity in Japanese adults: the Toon Health Study. J Epidemiol 2015;25:583–91.
35. Benichou T, Pereira B, Mermillod M, Tauveron I, Pfabigan D, Maqdasy S, et al. Heart rate variability in type 2 diabetes mellitus: a systematic review and meta-analysis. PLoS One 2018;13:e0195166.