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Heart Rate Variability as a Potential Noninvasive Tool to Complement Quality of Life Assessment and Monitor Recovery after Cardiac Surgery

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Research Article

Keywords: Cardiac surgery, heart rate variability, postoperative recovery, quality of life

Posted Date: September 17th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10417592/v1

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Additional Declarations: No competing interests reported.

Abstract

This study aimed to investigate changes in heart rate variability (HRV) in patients undergoing cardiac surgery and examined the association between HRV and patient-reported quality of life (QoL) during postoperative recovery. Twenty-one patients who underwent cardiac surgery were prospectively enrolled. Short-term HRV was measured at three timepoints: preoperatively (measurement 1), early postoperatively (measurement 2), and at 1 month postoperatively (measurement 3). The HRV indices included standard deviation of all normal-to-normal intervals (SDNN), low-frequency (LF) power, high-frequency (HF) power, low-frequency percentage (LF%), and the ratio of low-to-high frequency (LF/HF). Differences between measurements were examined using repeated-measures analysis of variance. QoL was assessed at measurement 3 using the Taiwanese version of the World Health Organization Quality-of-Life-Brief (WHOQOL-BREF) scale, and the associations between HRV indices and QoL domains were analyzed using Spearman's correlation. HRV parameters (SDNN, LF, HF, and LF%) declined significantly at measurement 2 and showed a partial recovery at measurement 3 but remained below the preoperative (measurement 1) levels. Among the four WHOQOL-BREF domains, psychological health displayed the lowest scores. HRV indices, particularly SDNN, LF, LF%, and LF/HF, were positively associated with the psychological domain ($P < .05$). Cardiac surgery was associated with reduced HRV indices, displaying only a partial postoperative recovery. HRV was positively associated with patient-reported QoL, particularly in the psychological domain. These findings suggest that HRV may serve as a practical and noninvasive tool for monitoring postoperative recovery, thereby complementing QoL assessments and identifying patients at risk of a delayed psychological recovery.

INTRODUCTION

Heart disease remains one of the leading causes of morbidity and mortality worldwide, and many patients require cardiac surgery as part of their treatment protocol. Although surgical techniques and perioperative care have advanced considerably, the early postoperative period can still involve substantial physiological stress and psychological burden, which may influence functional recovery and health-related Quality of Life (QoL) (Roth, 2020).

Patients undergoing cardiac surgery may experience a prolonged autonomic imbalance and require emotional and cognitive adaptation during recovery. Therefore, physiological and psychological recovery may not progress at the same pace during the postoperative period.

Heart rate variability (HRV) is a noninvasive indicator of autonomic nervous system regulation that reflects the balance between sympathetic activation and parasympathetic modulation (Task Force Electrophysiology, 1996). Lower HRV has been associated with reduced stress regulation capacity, difficulties in emotional adjustment, and poorer psychological well-being (Schaffer, 2017; Kemp, 2010). Accordingly, HRV may offer insights into both the physiological and psychological components of postoperative recovery without the use of invasive procedures or instruments.

Previous studies have described postoperative reductions and a gradual recovery of HRV (Matusik, 2024), while others have reported emotional distress and reduced psychological well-being during recovery (Correa-Rodriguez, 2020). However, these physiological and psychological domains of QoL have largely been examined separately. Studies that simultaneously evaluated HRV recovery trajectories and psychological well-being during the early postoperative recovery period remain limited (Laborde, 2017). A clearer understanding of this relationship is needed to help clinicians identify patients who would benefit from additional supportive care.

Therefore, this study aimed to investigate the changes in HRV from the preoperative condition of the patient to postoperative recovery and examined the association between HRV and QoL after cardiac surgery.

METHODS

STUDY PARTICIPANTS

Patients who underwent cardiac surgery involving cardiopulmonary bypass (CPB) equipment at Taoyuan Hospital, Ministry of Health and Welfare, Taiwan, between June 2019 and February 2020 were included in this study. Patients aged < 20 years, those who received extracorporeal support preoperatively, those with severe heart or lung failure, and those who experienced major postoperative complications and could not complete the study protocol were excluded from the study. Patients with poor ECG signal acquisition were also excluded from the study.

This exploratory, single-center pilot study was designed to evaluate the feasibility of HRV as a potential indicator of postoperative recovery and QoL after cardiac surgery. This prospective study was reviewed and approved by the Institutional Review Board (IRB) of Taoyuan Hospital, Ministry of Health and Welfare, Taiwan (IRB No. TYH-IRB-108010). Written informed consent was obtained from all study participants before enrollment. All study procedures were conducted in accordance with the principles of the Declaration of Helsinki and the relevant national guidelines.

INSTRUMENTS

Wearable electrocardiogram (ECG)

This two-lead ECG patch continuously records an electrocardiogram, which can be wirelessly uploaded for analysis using a mobile phone connected via Bluetooth. The wearable ECG system used in this study is a prototype device currently under research and development, with the wireless transmission part certified by the National Communications Commission of Taiwan and the Federal Communications Commission.

The Taiwanese version of the QoL scale

A questionnaire was developed using the World Health Organization Quality of Lif Brief (WHOQOL-BREF) version (WHOQOL Group, 1998) that was further validated and adapted for use in the Taiwanese population (Yao, 2002). It consists of four main domains with 26 questions: seven on physical health, six on psychological health, four on social relationships, and nine on environmental health. In addition, two local-level questions, namely 'diet' and 'reputation,' were added, bringing the total to 28. The questionnaire was primarily designed to assess the perceptions of patients about health-related QoL over the past 2 weeks, and responses were scored on a 5-point Likert scale (range, 1–5). Higher scores indicate a better QoL. The distribution of patient scores in each domain was symmetrical, with complete coverage and good reliability and validity. The questionnaire was concise, and the test duration was short (approximately 15 minutes). The Health Promotion Administration of the Ministry of Health and Welfare in Taiwan included health-related QoL queries in the 2001 National Health Interview Survey and established norms for the Taiwanese population. The use of the questionnaire in the present study was approved.

Measurements

The study protocol is shown in Fig. 1. A 5-minute ECG was acquired from all patients by employing a wearable ECG device. The first measurement was acquired after the patient had been hospitalized but before surgery was carried out (measurement 1). The second measurement was acquired after the patient was transferred to the general ward postoperatively, with the inotropic agent discontinued (measurement 2). The third measurement was acquired at 1 month postoperatively in the outpatient department (measurement 3). The 1-month follow-up time point was selected because patients typically complete the acute postoperative inflammatory phase and initial wound stabilization at this stage, enabling an early assessment of autonomic recovery and psychological adjustment. All measurements were recorded in a quiet environment after the patients had rested and were emotionally and hemodynamically stable. The ECG waveform data were wirelessly uploaded to a server via Bluetooth and a mobile phone for HRV analyses. The patients also completed the Taiwanese version of the WHOQOL-BREF questionnaire at the time of acquiring measurement 3. The parameters of the HRV analysis included standard deviation of all normal-to-normal intervals (SDNN, ms), low-frequency (LF) power (ms^2), high-frequency (HF) power (ms^2), LF percentage (LF%), and LF/HF ratio (LF/HF ratio). LF and HF powers were natural logarithms and were transformed to improve normality prior to statistical analysis.

We assessed the standard time- and frequency-domain parameters in accordance with the established guidelines of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Task Force Electrophysiology, 1996) and the interpretive framework summarized by Shaffer and Ginsberg (Schaffer, 2017). In the time domain, SDNN was employed to quantify the overall magnitude of HRV. In the frequency domain, the following components were derived using fast Fourier transform:

- LF (0.04–0.15 Hz): reflects both sympathetic and parasympathetic modulation, with the sympathetic tone contributing to a greater extent under resting conditions.
- HF (0.15–0.40 Hz): corresponds to vagally mediated respiratory sinus arrhythmia and indicates parasympathetic activity.
- LF/HF: represents sympathovagal balance; elevated values indicate greater sympathetic influence.
- LF%: reflects sympathetic modulation of cardiac autonomic activity.

STATISTICAL ANALYSIS

Differences across the three time points were examined using repeated-measures analysis of variance. Wilcoxon signed-rank tests were used for repeated non-parametric comparisons across time points. Numerical values were expressed as mean ± standard deviation and were compared using Student's *t* test. Spearman's rank correlation coefficients were employed to assess the associations between HRV parameters and the four questionnaire domains. Statistical significance was set at $P < .05$. All analyses were carried out by employing SPSS statistics software version 26.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Thirty-one patients were enrolled during the study period; however, seven patients with poor ECG signal acquisition, one patient with an abnormal response in the questionnaire (outside the observed range), and two patients with major comorbidities (one patient died, while another was dependent on a ventilator and could not complete the study protocol) were excluded. Finally, 21 patients were included in the analysis. The demographic characteristics are shown in Table 1. Of the 21 patients, 12 were men, and 9 were women. Regarding the educational level attained by the study participants, six patients had only completed elementary school, nine had completed junior high school, four had completed high school, one had a college and another a graduate degree. Most patients (17, 84%) were married; one was unmarried, one was divorced, and two were widowed. In terms of medical history, 14 patients had hypertension, six had diabetes, and five had chronic kidney disease (CKD). Five patients had no history of hypertension, diabetes, or CKD. Ten patients had one chronic comorbid disease (hypertension, diabetes, or CKD), three had two chronic diseases, and three had all three chronic diseases. The mean score value derived from the European System for Cardiac Operative Risk Evaluation (EuroSCORE) for our patient cohort was 2.35, and the mean ejection fraction value was 63.3%. Further, 10 (47.6%) patients had undergone heart valve surgery, and 9 (42.7%) had undergone coronary artery bypass. One patient had undergone aortic repair surgery, and another had undergone coronary artery bypass and valve surgery. The mean intensive care unit (ICU) stay was 5.1 days and the mean hospital stay was 14.1 days.

A comparison of the HRV parameters is shown in Table 2. Significant differences were observed in SDNN, LF, HF, and LF% values among the three measurements (all $P <.001$), whereas no significant difference was observed in the LF/HF ratio for any of the measurements. A significant reduction was noted in the SDNN, LF, and LF% parameters of HRV between measurements 1 and 2 ($P < .05$), whereas

no significant differences were noted in HF and LF/HF ratios. A significant increase in the SDNN parameter of HRV was observed when comparing measurements 2 and 3 ($P < .05$), whereas no significant differences were observed in the other parameters.

The mean scores of the four domains of the QOL questionnaire are shown in Table 3. The psychological domain score was the lowest of all. The Spearman coefficients of the correlation between the third measurement of HRV parameters and the QoL domains are shown in Table 4. SDNN, LF, LF%, and LF/HF parameters were significantly and positively correlated with the psychological domain, whereas no correlation was identified with HF. LF and LF% were significantly positively correlated with the environmental domain (all $P < .05$), whereas no correlations were observed for SDNN, HF, or LF/HF. None of the HRV parameters correlated with the physiological and social relationship domains of QoL.

DISCUSSION

Cardiac surgery involving CPB induces acute autonomic dysregulation through inflammatory activation, surgical stress, anesthetic effects, and hemodynamic changes. A postoperative decline in HRV has been reported consistently in studies of both coronary artery bypass and valvular procedures (Schmidt-Rio Valle, 2020; Pacaric, 2020; Moreira, 2019). However, most previous studies have focused on the long-term cardiovascular outcomes rather than on the early recovery trajectory and its potential association with psychological well-being. The present study addressed this gap by examining perioperative HRV dynamics and their relationship with QoL until the first outpatient visit following surgery.

In this study, the HRV parameters declined markedly immediately after surgery and demonstrated only a partial recovery within the first postoperative month, that is, the early recovery phase. This pattern is consistent with prior reports, suggesting that sympathetic re-activation occurs during the early recovery phase, whereas parasympathetic restoration may require a longer rehabilitation period (Matusik, 2024). The resulting sympathovagal imbalance may contribute to fatigue, sleep disturbances, and emotional vulnerability during the early postoperative phase. These findings highlight the clinical importance of monitoring autonomic function as part of the postoperative assessment rather than relying solely on hemodynamic or functional recovery indicators.

Importantly, the HRV parameters quantified in this study were positively correlated with the psychological domain responses of the WHOQOL-BREF questionnaire. This finding aligns with previous reports indicating that individuals with higher HRV tend to report better health-related QoL, even in non-clinical populations, suggesting that autonomic regulation may reflect broader psychological and functional well-being (Lu, 2016). Previous research has shown that lower HRV is associated with heightened psychological stress and symptoms of depression (Kim, 2018; Lischke, 2018; Patron, 2012). Our current findings extend this evidence by demonstrating that autonomic recovery and psychological well-being progress asynchronously after cardiac surgery. This suggests that HRV may serve as a physiological marker and an objective indicator of psychological adaptation during recovery, particularly when subjective distress is under-recognized in clinical encounters.

HRV reflects the balance of autonomic regulation between sympathetic activation and parasympathetic recovery, both of which are highly sensitive to surgical stress, pain, sleep disturbance, and psychological adaptation (Task Force Electrophysiology, 1996; Schaffer, 2017; Matusik, 2024). Unlike laboratory biomarkers that require repeated blood sampling or invasive monitoring, HRV can be obtained continuously and conveniently from standard ECG recordings routinely used in cardiac surgery. This makes HRV particularly suitable for the longitudinal monitoring of postoperative recovery without any additional clinical workload.

In the present study, the observed association between HRV parameters and the psychological domain suggests that autonomic function may provide physiological insights into the emotional and adaptive responses of patients during the recovery period. Therefore, HRV may serve as a complementary indicator, along with physical and functional assessments, to help clinicians identify individuals who may benefit from early supportive or psychosocial rehabilitation interventions.

Beyond psychological recovery, another exploratory observation that has been reported showed that patients who developed postoperative stroke exhibited marked HRV suppression preceding clinical onset (Aftyka, 2023). As continuous ECG monitoring is routinely performed in the ICU, HRV analysis may provide a practical foundation for real-time trend monitoring and future predictive analytics, including artificial intelligence–assisted detection of neurological complications. Although preliminary, these findings warrant further evaluation in larger multi-center cohorts to determine whether HRV-guided monitoring can enhance postoperative neurological surveillance and improve patient outcomes.

Sternotomy is required in traditional cardiac surgery, and postoperative pain is strongest in the first 3 days, with most patients experiencing complete pain relief by the second to third month postoperatively. However, in this study, measurement 3 of HRV analysis was performed 1 month after cardiac surgery, along with the QOL questionnaire. Some patients may still experience pain or discomfort from the wound, and questionnaire responses may be affected by these factors. Future studies should use long-term tracking to determine changes in HRV and QoL after cardiac surgery over a longer time span. Our HRV analysis was based on small variations in the R-R interval between normal heartbeats under normal sinus rhythm. However, six enrolled patients with arrhythmia were excluded. Many patients who undergo cardiac surgery experience preoperative arrhythmia, which is unavoidable, resulting in a small sample size. A larger sample size in future studies could help increase statistical power.

In the present study, the observed associations between HRV indices (LF and LF%) and the environmental domain suggest that environmental conditions may also play a role in autonomic regulation during postoperative recovery. These findings highlight the importance of environmental and contextual factors in interpreting HRV.

Taken together, HRV may have value in cardiac rehabilitation settings as a simple, non-invasive tool for monitoring both physiological recovery and psychological adaptation. Incorporating HRV assessments into rehabilitation programs may help clinicians identify patients who require tailored interventions during the early recovery period.

CONCLUSIONS

Cardiac surgery was observed to be associated with a significant reduction in HRV, with only a partial recovery achieved at 1 month postoperatively. HRV parameters were positively correlated with the psychological domain of patient-reported quality of life in the postoperative phase, suggesting a link between autonomic recovery and emotional adjustment.

HRV may serve as a practical, noninvasive tool to complement postoperative QoL assessments and help identify patients requiring additional psychological care. Although further large-scale studies are warranted to validate our current findings, HRV monitoring offers valuable clinical insights for tailored interventions during postoperative recovery.

Declarations

Conflict-of-Interest Statement

The authors declare that they have no conflicts of interest.

Data Availability Statements

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Funding Declarations

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

Clinical Trial Number

Not applicable

Human Ethics and Consent to Participate Declarations

This study was approved by the Institutional Review Board (IRB) of Taoyuan General Hospital, Ministry of Health and Welfare (Approval No. TYGH108010). Written informed consent was obtained from all individual participants prior to inclusion in the study.

Consent to Publish declaration

Not applicable

Acknowledgements

We would like to thank Editage (www.editage.com.tw) for English language editing.

Author Contribution

1. LC Lee participated in the study design, data collection, analysis, and interpretation, and drafted the initial manuscript.2. CC Hsieh was responsible for data analysis, critical revision of the manuscript and approved the version to be published.3. SL Chen was responsible for data analysis and participated in drafting the initial manuscript.4. TBJ Kuo was responsible for the study conception, equipment preparation, data collection, and revised the manuscript critically.5. ST Gan was responsible for data analysis and statistics, and revised the initial manuscript. All authors reviewed and approved the final manuscript.

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Tables

Table 1. Basic demographic and clinical characteristics of the study participants (N = 21)

	Mean	Standard deviation	Min	Max
Age (years)	61.1	11.8	40	78
BSA (m^2)	1.71	0.23	1.30	2.32
EuroSCORE	2.35	1.46	0.67	6.00
EF (%)	63.3	11.7	36	80
CPB time (min)	165	57	30	300
X-clamp time (min)	108	37.9	0	167
ICU stay (days)	5.1	2.2	3	12
Hospital stay (days)	14.1	7.9	8	37

[a] **Abbreviations:**

BSA, body surface area; CPB, cardiopulmonary bypass; EF, ejection fraction; EuroSCORE, European System for Cardiac Operative Risk Evaluation; ICU, intensive care unit; X-clamp, aortic cross-clamp time.

Table 2. Comparison of HRV parameters among measurement 1 (preoperative), measurement 2 (postoperative), and measurement 3 (one month post-operative) (N = 21)

Parameter	Measurement 1	Measurement 2	Measurement 3	F value	*P* value
SDNN (ms)	22.52 ± 10.34	10.22 ± 5.65	20.44 ± 15.50	92.7	<.001
LF (ms^2)	3.70 ± 1.59	2.21 ± 1.83	3.21 ± 1.80	132.7	<.001
HF (ms^2)	3.11 ± 1.51	2.43 ± 1.10	2.97 ± 1.15	211.5	<.001
LF%	55.24 ± 23.04	40.27 ± 28.77	50.91 ± 27.91	163.4	<.001
LF/HF	0.59 ± 1.22	−0.22 ± 1.69	0.24 ± 1.47	1.14	.300

[a] Data are shown as mean ± SD.

[b] **Abbreviations**:

HF, heart failure; HRV, heart rate variability; LF, low frequency; HF, high frequency; SD, standard deviation; SDNN, standard deviation of all normal-to-normal intervals.

Table 3. Mean and standard deviation values of scores for different domains of quality of life (N = 21)

	Mean	Standard deviation	Minimum	Maximum
Physical health	68.86	8.70	56	81
Psychological health	60.57	12.50	31	88
Social relationships	66.14	10.77	44	94
Environment	67.10	9.03	44	81

Table 4. Correlation between HRV and quality of life in patients after cardiac surgery (N = 21)

Domains		Physical health	Psychological health	Social relationships	Environment
Parameters					
SDNN	r	.029	.458	.218	.398
	p	.901	.037*	.343	.082
LF	r	.128	.535	.347	.528
	p	.579	.013*	.123	.014*
HF	r	.035	.112	-0.24	.273
	p	.881	.629	.918	.231
LF%	r	.137	.551	.293	.458
	p	.553	.010*	.198	.037*
LF/HF	r	.125	.521	.273	.406
	p	.588	.015*	.231	.068

*$P < .05$

[a] **Abbreviations:**

HF, heart failure; HRV, heart rate variability; LF, low frequency; HF, high frequency; SD, standard deviation; SDNN, standard deviation of all normal-to-normal interv

Figures

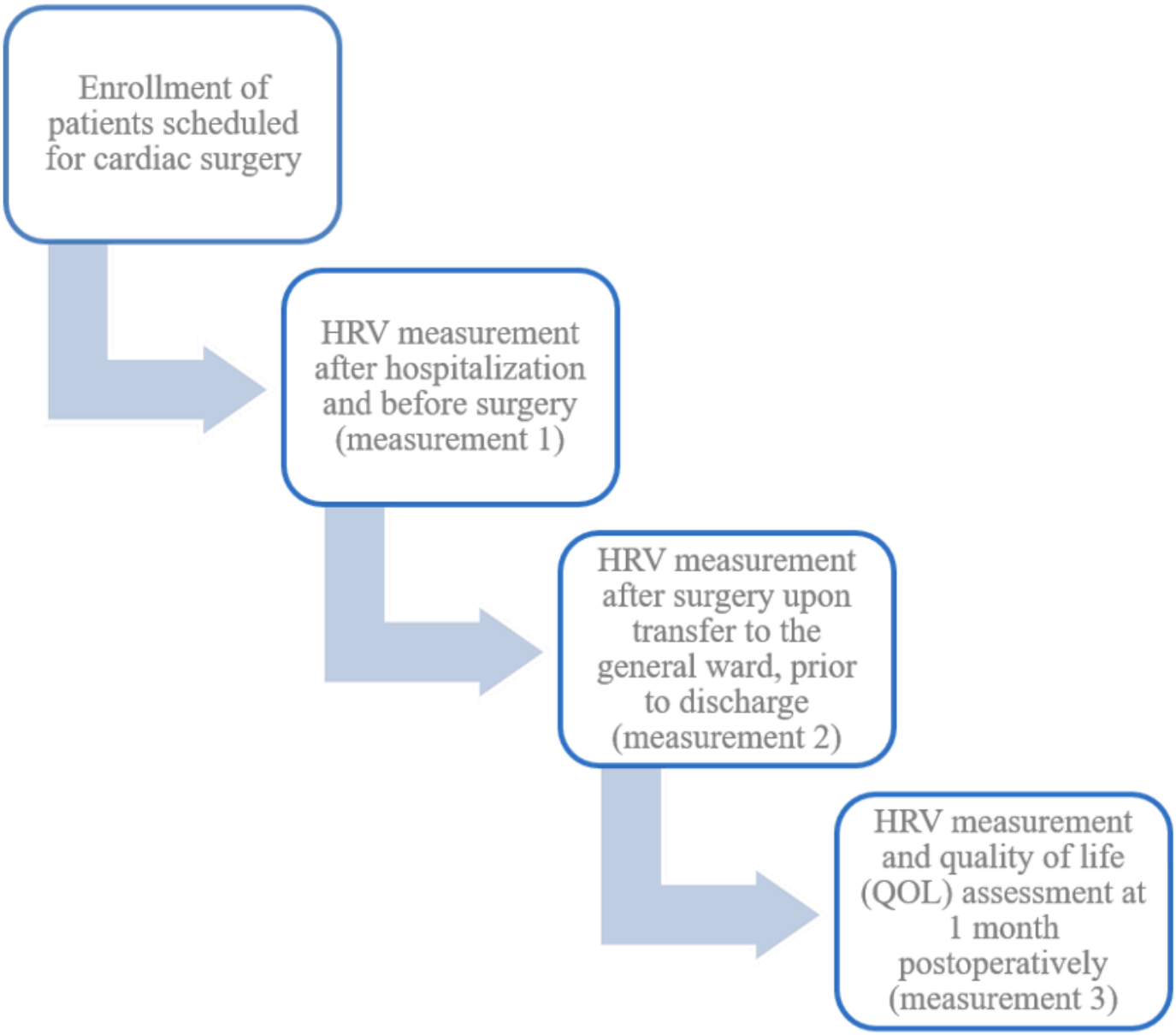


Figure 1

Flow chart of the study, timeline of heart rate variability (HRV) measurements, and quality of life assessment